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(54) **COMBUSTION CONTROL DEVICE FOR INTERNAL COMBUSTION ENGINE**

(57) The invention provides a combustion control device applied to an internal combustion engine having a glow plug 23, the glow plug 23 heating a gas in a cylinder, the combustion control device comprising: a compression end temperature estimating means for estimating a compression end temperature T_t which is a temperature of the gas in a cylinder when a position of a piston moving in the cylinder in a reciprocating manner is at the compression top dead center; and a compression end temperature changing means for causing the internal combustion engine to perform a compression end temperature increasing operation in the case where the compression end temperature T_t estimated by the compression end temperature estimating means is lower than a predetermined compression end reference temperature T_{tref} during the operation of the glow plug, the compression end temperature increasing operation changing the compression end temperature T_t to be equal to or higher than the predetermined compression end reference temperature T_{tref} .

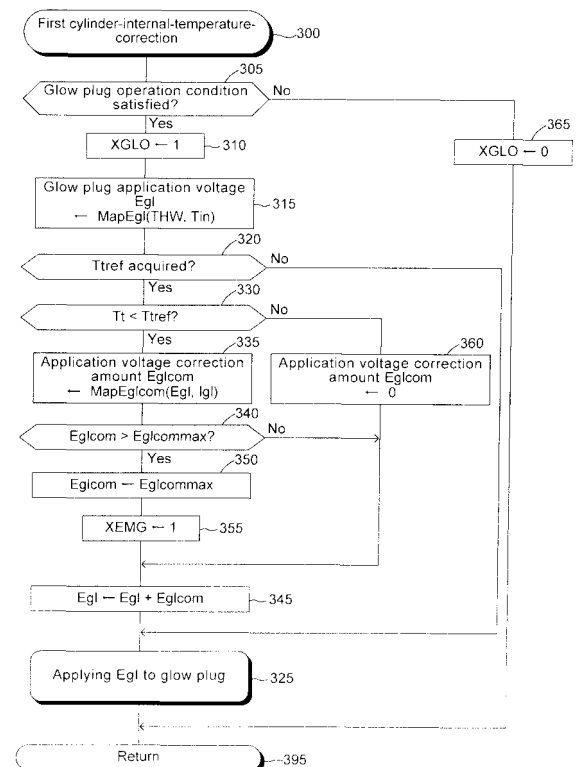


FIG. 3

Description**TECHNICAL FIELD**

5 **[0001]** The present invention relates to a combustion control device which is applied to an internal combustion engine (diesel engine) with a glow plug which heats a gas in a cylinder.

BACKGROUND ART

10 **[0002]** Hitherto, there has been suggested an internal combustion engine with a glow plug having a resistance heating portion that generates heat by the application of a voltage for the purpose of promoting the ignition of fuel in a cylinder of the internal combustion engine during a cold-starting operation in which the internal combustion engine is started in a state where the temperature of the internal combustion engine is low. More specifically, the glow plug is generally provided in the internal combustion engine so that the resistance heating portion protrudes into the cylinder of the internal combustion engine. Then, for example, during the cold-starting operation, a voltage is applied to the glow plug so that the resistance heating portion generates heat, and thereby the temperature of the gas in a cylinder is increased by the heat generated from the resistance heating portion. Thus, the ignition of the fuel in the cylinder of the internal combustion engine is promoted during the cold-starting operation.

15 **[0003]** On the other hand, during the operation of the internal combustion engine, the temperature and the pressure in the cylinder are high, and the resistance heating portion of the glow plug protrudes into the cylinder. Accordingly, when the glow plug is continuously used for a long period of time, a drawback such as a burning out of the resistance heating portion may arise (hereinafter, the occurrence of such drawback will be referred to as that the "glow plug is degraded"). When the glow plug is degraded, for example, since the current applicable cross-sectional area of the resistance heating portion decreases, the resistance value increases. Accordingly, in this case, even when a predetermined voltage is applied to the resistance heating portion, the magnitude of the current passing through the resistance heating portion decreases, so that the amount of heat generated in the resistance heating portion decreases. For this reason, the amount of heat given from the glow plug to the gas in a cylinder per unit time decreases, so that the temperature of the gas in a cylinder does not sufficiently increase. As a result, when the glow plug is degraded, there is a possibility that the fuel does not sufficiently ignite compared to the case where the glow plug is in a normal condition.

20 **[0004]** Therefore, one of the conventional combustion control devices (hereinafter, referred to as a "conventional device") applied to the internal combustion engine (especially, the diesel engine) is configured to change a timing of injecting fuel into a cylinder (hereinafter, referred to as a "fuel injection timing") so that the fuel injection timing is earlier than that of the case where the glow plug is in a normal condition (that is, the fuel injection timing is advanced) when the glow plug is degraded. Here, the fuel which is injected into the cylinder is heated by the gas in a cylinder to be vaporized, and undergoes a pre-self-ignition reaction including a decomposition, a low-temperature oxidization reaction, and the like while being mixed with the gas in a cylinder. Due to the pre-self-ignition reaction, the fuel further increases the temperature of the fuel itself. Then, when the temperature of the fuel reaches the self-ignitable temperature, the fuel ignites. That is, the ignition of the fuel is affected by the "temperature of the gas in a cylinder" and the "time length in which the pre-self-ignition reaction of the fuel may be performed".

25 **[0005]** The conventional device advances the fuel injection timing when the glow plug is degraded, so as to increase the "time length in which the pre-self-ignition reaction of the fuel may be performed". Thus, even when the glow plug is degraded and the temperature of the gas in a cylinder does not sufficiently increase, it is possible to sufficiently ensure the period in which the temperature of the fuel increases due to the pre-self-ignition reaction of the fuel itself. Accordingly, the conventional device may promote the ignition of the fuel during the cold-starting operation or the like even when the glow plug is degraded (for example, see JP2009-62835A).

SUMMARY OF INVENTION**1. Technical Problem**

30 **[0006]** Incidentally, as described above, the conventional device improves the ignition performance of the fuel in the cylinder by advancing the fuel injection timing when the glow plug is degraded. Certainly, the degradation in the glow plug affects the temperature of the gas in a cylinder, but the other factors such as the intake air temperature, the cylinder temperature, and the compression ratio of the gas in a cylinder also affect the temperature of the gas in a cylinder. That is, the degradation in the glow plug is merely one of the factors affecting the ignition of the fuel in the cylinder. Accordingly, in order to ensure the ignition of the fuel in the cylinder when the glow plug is degraded, the "temperature of the gas in a cylinder" needs to be considered.

35 **[0007]** However, in the conventional device, the fuel injection timing is advanced without considering the temperature

of the gas in a cylinder. Accordingly, in the conventional device, even when the fuel injection timing may be advanced when the glow plug is degraded, the fuel injection timing is not always the timing optimal for ensuring the ignition of the fuel in the cylinder. As a result, in the conventional device, there is a problem that the ignition of the fuel in the cylinder cannot be ensured.

2. Solution to Problem

[0008] The present invention is made in view of the above-described circumstances, and it is an object of the present invention to provide a combustion control device which is applied to an internal combustion engine with a glow plug heating a gas in a cylinder, which ensures the ignition of the fuel in the cylinder.

[0009] The combustion control device for the internal combustion engine according to the present invention for solving the above-described problem is applied to an internal combustion engine having a glow plug which heats a gas in a cylinder.

[0010] The configuration of the glow plug is not particularly limited. For example, the glow plug may include a resistance heating portion which generates heat by the application of the voltage. In addition, the glow plug may be disposed in the same engine so that at least a part of the resistance heating portion protrudes into the cylinder (combustion chamber) of the engine.

[0011] The combustion control device of the present invention which is applied to the engine includes a compression end temperature estimating means and a compression end temperature changing means.

[0012] More specifically, the compression end temperature estimating means is configured to estimate a "compression end temperature" which is a temperature of the gas in a cylinder when a position of a piston moving in the cylinder in a reciprocating manner is at the compression top dead center.

[0013] In addition, the compression end temperature changing means is configured to cause the internal combustion engine to perform a "compression end temperature increasing operation" in the case where "the compression end temperature estimated by the compression end temperature estimating means is lower than a predetermined compression end reference temperature" during the operation of the glow plug. The compression end temperature increasing operation is to change the compression end temperature to be equal to or higher than the predetermined compression end reference temperature.

[0014] In the internal combustion engine (diesel engine), generally the fuel is injected into the cylinder when the position of the piston is near the compression top dead center including the compression top dead center. Accordingly, the compression end temperature substantially corresponds to the "temperature of the gas in a cylinder". In the combustion control device of the present invention, the "compression end temperature" is estimated, and the "compression end temperature increasing operation" is performed when the compression end temperature is lower than the predetermined "compression end reference temperature".

[0015] The compression end reference temperature may be an appropriate value in which the fuel does not sufficiently ignite when the compression end temperature is lower than the compression end reference temperature.

[0016] In this way, the combustion control device of the present invention estimates the "compression end temperature" affecting the combustion of the fuel when the glow plug is operated, and performs the compression end temperature increasing operation of increasing the compression end temperature if necessary. Thus, since the combustion control device of the present invention may control the compression end temperature, even when the glow plug is degraded, the ignition of the fuel may be ensured.

[0017] As an aspect of the combustion control device of the present invention, the combustion control device may be configured to include:

a cylinder internal gas amount acquiring means for acquiring a "cylinder internal gas amount" which is an amount of the gas in a cylinder;

a compression end cylinder internal pressure acquiring means for acquiring a "compression end cylinder internal pressure" which is a pressure of the gas in a cylinder when the position of the piston is at the compression top dead center; and

a compression end cylinder internal gas volume acquiring means for acquiring a "compression end cylinder internal gas volume" which is a volume of the gas in a cylinder when the position of the piston is at the compression top dead center.

[0018] In the combustion control device of the above aspect, the compression end temperature estimating means may be configured to estimate the compression end temperature by applying the "cylinder internal gas amount" acquired by the cylinder internal gas amount estimating means, the "compression end cylinder internal pressure" acquired by the compression end cylinder internal pressure acquiring means, the "compression end cylinder internal gas volume" acquired by the compression end cylinder internal gas volume acquiring means, and a "gas constant" of the gas in a

cylinder to a gas state equation.

[0019] The temperature of the gas in a cylinder of the internal combustion engine (the diesel engine) severely changes due to the compression of the gas using the piston and the combustion of the fuel injected into the cylinder, etc. That is, the temperature of the gas in a cylinder changes rapidly and varies in a quite wide range. For this reason, even when a sensor or the like measuring the temperature of the gas in a cylinder is used, it is difficult to easily measure only the "compression end temperature".

[0020] Therefore, the combustion control device of the aspect estimates the compression end temperature by applying the "amount of the gas in a cylinder" the "compression end cylinder internal pressure", the "compression end cylinder internal gas volume", and the "gas constant of the gas in a cylinder" to the state equation of the gas. The "amount of the gas in a cylinder" may be easily acquired based on, for example, the amount of air or the like suctioned into the engine. In addition, the "compression end cylinder internal pressure" may be easily acquired by using, for example, a pressure measuring device or the like provided in the cylinder. Also, as the "compression end cylinder internal gas volume", for example, the volume in the cylinder when the position of the piston is at the compression top dead center, which is acquired in advance. Also, as the "gas constant of the gas in a cylinder", for example, a known gas constant of the ideal gas or the like may be employed. Accordingly, the combustion control device of the aspect may easily estimate only the "compression end temperature".

[0021] In this aspect, from the viewpoint of easily estimating the compression end temperature, it is desirable to employ the "state equation of the ideal gas" as the gas state equation. However, the gas state equation is not limited to the state equation of the ideal gas. As the gas state equation, the following gas state equations may be employed, such as the state equation of Peng-Robinson, the state equation of Van der Waals, and Virial equation, which is the known state equation corresponding to the actual gas.

[0022] Further, in this aspect, from the viewpoint of easily estimating the compression end temperature, as the gas constant of the gas in a cylinder, it is desirable to employ the "gas constant of the ideal gas". However, the gas constant of the gas in a cylinder is not limited to the gas constant of the ideal gas. As the gas constant of the gas in a cylinder, an appropriate value obtained in consideration of the gas (for example, air, an exhaust gas, an uncombusted material, and the like) actually existing in the cylinder may be employed.

[0023] In addition, as another aspect of the combustion control device of the present invention, the internal combustion engine may be configured to have a plurality of the cylinders.

[0024] In the combustion control device of this aspect, the compression end temperature changing means may be configured to employ, as the predetermined compression end reference temperature, any one of the followings:

- (1) a temperature lower than an average value of the compression end temperatures of the respective cylinders by a predetermined temperature;
- (2) a temperature lower than an average value of the compression end temperatures of the cylinders other than the subject cylinder for estimating the compression end temperature with the compression end temperature estimating means by a predetermined temperature;
- (3) a temperature lower than the compression end temperature of one cylinder among the cylinders other than the subject cylinder for estimating the compression end temperature with the compression end temperature estimating means by a predetermined temperature;
- (4) the average value of the compression end temperatures of the respective cylinders;
- (5) the average value of the compression end temperatures of the cylinders other than the subject cylinder for estimating the compression end temperature with the compression end temperature estimating means; and
- (6) the compression end temperature of one cylinder among the cylinders other than the subject cylinder for estimating the compression end temperature with the compression end temperature estimating means.

[0025] In this way, the combustion control device of this aspect determines the compression end reference temperature in consideration of the compression end temperatures of the "cylinders other than the cylinder (that is, the cylinder for verifying whether the glow plug is degraded) as the subject for estimating the compression end temperature". By performing the compression end temperature increasing operation based on the compression end reference temperature, a variation in the combustion between the respective cylinders is suppressed even when the glow plug is degraded. As a result, a variation in the torque generated in the respective cylinders may be prevented, and degradation in the emission of the cylinder with the degraded glow plug may be prevented. Accordingly, the combustion control device of this aspect may satisfactorily maintain the drivability and the emission of the engine even when the glow plug is degraded in one or two or more cylinders among plural cylinders.

[0026] In addition, the combustion control device of this aspect may prevent a variation in the compression end temperatures of the respective cylinders, for example, even when the glow plug provided in one cylinder among plural cylinders has a variation in manufacture (a difference in the dimension, the performance, and the like between the same type of members during the manufacture).

[0027] Also, as still another aspect of the combustion control device of the present invention, the combustion control device may be configured to include a pre-compression temperature acquiring means for acquiring a "pre-compression temperature" which is a temperature of the gas in a cylinder at a time point before the gas is compressed by the piston.

[0028] In the combustion control device of this aspect, the compression end temperature changing means may be configured to estimate the followings:

a "compression-induced temperature change amount" which is a change amount in the temperature of the gas caused by a compression, based on one or plural operation parameters of the internal combustion engine involved with the compression of the gas in a cylinder by the piston;

a "heating-induced temperature change amount" Which is a change amount in the temperature of the gas caused by heating, based on one or plural operation parameters of the internal combustion engine involved with the heating of the gas in a cylinder by the glow plug; and

a "thermal-loss-induced temperature change amount" which is a change amount in the temperature of the gas caused by a thermal loss, based on one or plural operation parameters of the internal combustion engine involved with the thermal loss of the gas in a cylinder,

and

the compression end temperature changing means may be configured to employ, as the "predetermined compression end reference temperature", one of the followings:

(7) a temperature lower by a predetermined temperature than a sum of the pre-compression temperature, the compression-induced temperature change amount, the heating-induced temperature change amount, and the thermal-loss-induced temperature change amount; and

(8) the sum of the pre-compression temperature, the compression-induced temperature change amount, the heating-induced temperature change amount, and the thermal-loss-induced temperature change amount.

[0029] In this aspect, as different from the "aspect in which the compression end reference temperature is determined in consideration of the compression end temperatures of the other cylinders different from the cylinder as the subject for estimating the compression end temperature (the aspect in which the temperature illustrated in (1) to (6) is employed as the compression end reference temperature)", the compression end reference temperature is determined in consideration of the heat balance until the gas inside one predetermined cylinder is compressed.

[0030] Specifically, when the position of the piston changes from the air intake bottom dead center toward the compression top dead center, the gas in a cylinder is compressed by the piston. Therefore, in this aspect, the compression end temperature changing means assumes that the compression is an adiabatic compression and estimates the temperature change amount (the compression-induced temperature change amount) caused when the gas in a cylinder is compressed. As the operation parameter involved with the compression, for example, the volume of the gas in a cylinder at the time point before the compression, the volume of the gas in a cylinder when the position of the piston is at the compression top dead center, the specific heat ratio of the gas in a cylinder, and the like may be exemplified. Further, the compression-induced temperature change amount is generally a positive value.

[0031] In addition, the gas in a cylinder is heated by the glow plug while being compressed as described above. Therefore, in this aspect, the compression end temperature changing means estimates the temperature change amount (the heating-induced temperature change amount) caused when the gas in a cylinder is heated by the glow plug. As the operation parameter involved with the heating, for example, the magnitude of the voltage applied to the glow plug, the engine rotation speed, the intake valve closing timing of the engine, the amount of the gas in a cylinder, the specific heat of the gas in a cylinder, and the like may be exemplified. Further, the heating-induced temperature change amount is generally a positive value.

[0032] Also, during a period in which the gas in a cylinder is compressed as described above, a part of the amount of heat of the gas in a cylinder is discharged to the outside of the gas through the inner wall surface of the cylinder, the upper surface of the piston, and the like. That is, a thermal loss occurs. Therefore, in this aspect, the compression end temperature changing means estimates the temperature change amount (the thermal-loss-induced temperature change amount) caused by the thermal loss. As the operation parameters involved with the thermal loss, for example, the temperature of the cooling water of the engine, the engine rotation speed, the intake valve closing timing of the engine, the amount of the gas in a cylinder, the specific heat of the gas in a cylinder, and the like may be exemplified. Further, the thermal-loss-induced temperature change amount is generally a negative value.

[0033] Then, the compression end temperature changing means determines the compression end reference temperature based on the temperature of the gas in a cylinder (the pre-compression temperature) before the compression, the "compression-induced temperature change amount", the "heating-induced temperature change amount" and the "thermal-loss-induced temperature change amount".

[0034] The compression end reference temperature is a uniform temperature (that is, the compression end temperature

obtained when the glow plug is not degraded) based on the heat balance of one cylinder. By performing the compression end temperature increasing operation based on the compression end reference temperature, the compression end temperature is maintained at the temperature as that of the case where the glow plug is not degraded even when the glow plug is degraded. Accordingly, even when the glow plug is degraded, the ignition of the fuel may be ensured.

[0035] In the combustion control device of the above-described respective aspects, the compression end temperature changing means may be configured to perform, as the compression end temperature increasing operation, at least one of the following operations:

a glow plug application voltage increasing operation in which a voltage applied to the glow plug is increased by a predetermined correction voltage value when the glow plug generates heat by the application of the voltage;
 an intake valve closing timing correcting operation in which a valve closing timing of an intake valve is changed to be close to an air intake bottom dead center by a predetermined first correction amount;
 an exhaust valve closing timing correcting operation in which a valve closing timing of an exhaust valve is changed to be away from an exhaust top dead center by a predetermined second correction amount;
 an intake valve opening timing advancing operation in which a valve opening timing of the intake valve is advanced relative to the exhaust top dead center by a predetermined third correction amount;
 a pilot injection amount increasing operation, when a main injection of injecting main fuel from a fuel injecting valve into a cylinder and a pilot injection of injecting preliminary fuel from the fuel injecting valve into the cylinder prior to the main injection are performed, in which an amount of fuel injected in the pilot injection is increased by a predetermined first correction fuel amount; and
 a main injection amount increasing operation, when a main injection of injecting main fuel from a fuel injecting valve into a cylinder and a pilot injection of injecting preliminary fuel from the fuel injecting valve into the cylinder prior to the main injection is performed, in which an amount of fuel injected in the main injection is increased by a predetermined second correction fuel amount.

[0036] When performing the "a glow plug application voltage increasing operation in which a voltage applied to the glow plug is increased by a predetermined correction voltage value when the glow plug generates heat by the application of the voltage", the voltage applied to the glow plug increases, so that the amount of heat emitted from the glow plug increases. Thus, the compression end temperature may be increased. The correction voltage value at this time may be determined in response to, for example, the value of the voltage applied to the glow plug and the passage current value when the voltage value is applied to the glow plug.

[0037] In addition, when performing the "an intake valve closing timing correcting operation in which a valve closing timing of an intake valve is changed to be close to an air intake bottom dead center by a predetermined first correction amount", the amount of the air suctioned into the cylinder increases, so that the compression ratio increases. Thus, the compression end temperature may be increased. The first correction amount at this time may be determined in response to, for example, a difference between the compression end temperature and the compression end reference temperature, the valve closing timing of the intake valve, and the like.

[0038] Also, when performing the "an exhaust valve closing timing correcting operation in which a valve closing timing of an exhaust valve is changed to be away from an exhaust top dead center by a predetermined second correction amount", the amount (that is, the inner EGR amount) of the retaining in the cylinder among the combusted hot gas (the exhaust gas) increases. Thus, the compression end temperature may be increased. As described above, the second correction amount at this time may be determined in response to, for example, a difference between the compression end temperature and the compression end reference temperature, the valve closing timing of the intake valve, and the like.

[0039] In addition, when performing the "an intake valve opening timing advancing operation in which a valve opening timing of the intake valve is advanced relative to the exhaust top dead center by a predetermined third correction amount", as described above, the amount of the gas remaining in the cylinder among the combusted hot gas (the exhaust gas) increases. Thus, the compression end temperature may be increased. As described above, the third correction amount at this time may be determined in response to, for example, a difference between the compression end temperature and the compression end reference temperature, the valve closing timing of the intake valve, and the like.

[0040] In addition, when the "a pilot injection amount increasing operation, when a 'main injection' of injecting main fuel from a fuel injecting valve into a cylinder and a 'pilot injection' of injecting preliminary fuel from the fuel injecting valve into the cylinder prior to the main injection are performed, in which an amount of fuel injected in the pilot injection is increased by a predetermined first correction fuel amount", the amount of heat generated by the pre-self-ignition reaction of the pilot-injected fuel increases. Thus, the compression end temperature may be increased. The first correction fuel amount at this time may be determined in response to, for example, a difference between the compression end temperature and the compression end reference temperature.

[0041] In addition, when the "a main injection amount increasing operation, when a 'main injection' of injecting main fuel from a fuel injecting valve into a cylinder and a 'pilot injection' of injecting preliminary fuel from the fuel injecting

valve into the cylinders prior to the main injection is performed, in which an amount of fuel injected in the main injection is increased by a predetermined second correction fuel amount", the amount of heat generated by the combustion of the main-injected fuel increases. For this reason, the temperature of the wall surface foaming the cylinder increases. Thus, the compression end temperature T_t increases. As described above, the second correction fuel amount at this

[0042] The compression end temperature changing means performs at least one operation of the above-described plural operations as the compression end temperature increasing operation. At least one operation selected from the above-described plural operations may be determined in response to the performance and the like required in the combustion control device of the present invention,

[0043] Also, as still another aspect of the combustion control device of the present invention, the combustion control device may be configured to perform the exhaust valve closing timing correcting operation or the intake valve opening timing advancing operation when performing the main injection amount increasing operation.

[0044] In this aspect, when the exhaust valve closing timing correcting operation is performed during the main injection amount increasing operation, the amount of heat generated by the combustion of the main-injected fuel increases, so that the temperature of the exhaust gas increases, and the amount (that is, the inner EGR amount) of the gas remaining in the cylinder among the combusted hot gas (the exhaust gas) increases. That is, the more exhaust gas of which the temperature further increases remains in the cylinder. Thus, the compression end temperature may be more surely increased.

[0045] Further, in this aspect, when the intake valve opening timing advancing operation is performed during the main injection amount increasing operation, the amount of heat generated by the combustion of the main-injected fuel increases, the temperature of the exhaust gas increases, and as described above, the amount of the gas remaining in the cylinder among the combusted hot gas (the exhaust gas) increases. That is, the more exhaust gas of which the temperature is further increased remains in the cylinder. Thus, the compression end temperature may be more surely increased.

[0046] In addition, in the combustion control device of the above-described respective aspects, the combustion control device may be configured to include an abnormality display means for displaying that the glow plug is in an abnormal condition when at least one of the following conditions is satisfied:

- the correction voltage value is larger than a predetermined correction voltage threshold value during the glow plug application voltage increasing operation;
- the first correction amount is larger than a predetermined first correction threshold amount during the intake valve closing timing correcting operation;
- the second correction amount is larger than a predetermined second correction threshold amount during the exhaust valve closing timing correcting operation;
- the third correction amount is larger than a predetermined third correction threshold amount during the intake valve opening timing advancing operation;
- the first correction fuel amount is larger than a predetermined first correction fuel threshold amount during the pilot injection amount increasing operation; and
- the second correction fuel amount is larger than a predetermined second correction fuel threshold amount during the main injection amount increasing operation.

[0047] By performing at least one operation among the above-described plural compression end temperature increasing operations, the compression end temperature may be increased. Incidentally, when the correction amounts (the correction voltage threshold value, the first correction threshold amount, the second correction threshold amount, the third correction threshold amount, the first correction fuel threshold amount, and the second correction fuel threshold amount) of the respective compression end temperature increasing operations are excessively large, there is a possibility that the drivability and the emission of the engine may be degraded. Therefore, when each of the above-described correction amounts is larger than the predetermined threshold value, a predetermined display means displays that the glow plug is in an abnormal condition, which prevents excessive degradation in the drivability and the emission of the engine. The threshold value of each correction amount at this time may be an appropriate value which has a possibility that the drivability and the emission of the engine may be degraded, for example, when each correction amount becomes larger than the threshold value.

[0048] Thus, since the operator or the like of the engine may be informed that the glow plug needs to be repaired or replaced at the time point before the excessive degradation in the glow plug, the drivability and the emission of the engine may be satisfactorily maintained,

BRIEF DESCRIPTION OF DRAWINGS**[0049]**

FIG. 1 is a schematic diagram of an internal combustion engine which employs a combustion control device according to a first embodiment of the present invention.

FIG. 2 is a schematic cross-sectional view of one cylinder of the internal combustion engine which employs the combustion control device according to the first embodiment of the present invention.

FIG. 3 is a flowchart illustrating a routine which is performed by a CPU of the combustion control device according to the first embodiment of the present invention.

FIG. 4 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the first embodiment of the present invention.

FIG. 5 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the first embodiment of the present invention.

FIG. 6 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the first embodiment of the present invention.

FIG. 7 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the first embodiment of the present invention.

FIG. 8 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the first embodiment of the present invention.

FIG. 9 is a flowchart illustrating a routine which is performed by a CPU of a combustion control device according to a second embodiment of the present invention.

FIG. 10 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the second embodiment of the present invention.

FIG. 11 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the second embodiment of the present invention.

FIG. 12 is a flowchart illustrating a routine which is performed by a CPU of a combustion control device according to a third embodiment of the present invention.

FIG. 13 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the third embodiment of the present invention.

FIG. 14 is a flowchart illustrating a routine which is performed by a CPU of a combustion control device according to a fourth embodiment of the present invention.

FIG. 15 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the fourth embodiment of the present invention.

FIG. 16 is a flowchart illustrating a routine which is performed by a CPU of a combustion control device according to a fifth embodiment of the present invention.

FIG. 17 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the fifth embodiment of the present invention.

FIG. 18 is a flowchart illustrating a routine which is performed by a CPU of a combustion control device according to a sixth embodiment of the present invention.

FIG. 19 is a flowchart illustrating a routine which is performed by the CPU of the combustion control device according to the sixth embodiment of the present invention.

FIG. 20 is a flowchart illustrating a routine which is performed by a CPU of a combustion control device according to a seventh embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

[0050] Hereinafter, respective embodiments of a combustion control device for an internal combustion engine according to the present invention will be described with reference to the drawings.

(First embodiment)

<Outline of device>

[0051] FIG. 1 illustrates a schematic configuration of a system which applies a combustion control device (hereinafter, also referred to as a "first device") according to a first embodiment of the present invention to an internal combustion engine 10. The engine 10 is a four-cylinder diesel engine which includes four cylinders of a first cylinder to a fourth cylinder. In addition, FIG. 2 is a cross-sectional view illustrating a schematic configuration of one cylinder of the engine

10 which employs the first device. Further, the other cylinders different from the one cylinder illustrated in FIG. 2 also have the same configuration as that of the one cylinder.

[0052] As illustrated in FIG. 1, the engine 10 includes an engine body 20 which includes a fuel supply system, an intake system 30 which introduces air into the engine body 20, an exhaust system 40 which discharges an exhaust gas from the engine body 20 to the outside, an EGR device 50 which re-circulates the exhaust gas to the intake system 30, and a supercharging device 60 which is driven by the energy of the exhaust gas and compresses the air introduced into the engine body 20.

[0053] The engine body 20 includes a cylinder head 21 which is connected to the intake system 30 and the exhaust system 40. The cylinder head 21 includes plural fuel injecting devices 22 which are respectively provided in the upper portions of the respective cylinders so as to correspond to the respective cylinders. The respective fuel injecting devices 22 are connected to a fuel tank (not illustrated), and are configured to inject fuel into the combustion chambers of the respective cylinders in response to a command signal from an electric control device 80.

[0054] In addition, the cylinder head 21 includes glow plugs 23 which are provided in the upper portions of the respective cylinders so as to be adjacent to the respective fuel injecting devices 22. The respective glow plugs 23 are configured to be heated by the application of the voltage in response to a command signal from the electric control device 80 and to heat the gas in the combustion chambers of the respective cylinders.

[0055] Also, as illustrated in FIG. 2, the cylinder head 21 includes an intake port which communicates with a combustion chamber 24, an intake valve 26 which opens and closes the intake port 25, a known variable intake timing control device 26a which is connected to the intake valve 26, an exhaust port 27 which communicates with the combustion chamber 24, an exhaust valve 28 which opens and closes the exhaust port 27, and a known variable exhaust timing control device 28a which is connected to the exhaust valve 28. Air In which is suctioned into the engine body 20 passes through the intake port 25 so as to be introduced into the combustion chamber 24, and an exhaust gas Ex passes through the exhaust port 27 so as to be discharged to the outside of the engine body 20.

[0056] In addition, a piston 29 is provided in the cylinder so as to be movable in a reciprocating manner between a predetermined compression top dead center and a predetermined intake bottom dead center. Also, the inside of the wall portion forming the cylinder is provided with a cooling water passageway 29a through which cooling water flows.

[0057] The variable intake timing control device (the variable valve timing mechanism) 26a is configured to advance or retard the valve opening timing and the valve closing timing of the intake valve 26 by a predetermined size in response to a command signal from the electric control device 80 (for example, see JP2007-303423A, JP2004-150397A, and the like). In addition, the variable exhaust timing control device (the variable valve timing mechanism) 28a is configured to advance or retard the valve opening timing and the valve closing timing of the exhaust valve 28 by a predetermined size in response to a command signal from the electric control device 80 as in the variable intake timing control device 26a.

[0058] Referring to FIG. 1 again, the intake system 30 includes an intake manifold 31 which communicates with the respective cylinders through the intake port 25 of the cylinder head 21, an intake pipe 32 which is connected to the upstream side assembly of the intake manifold 31, a throttle valve (intake diaphragm valve) 33 which changes the opening cross-sectional area of the intake passage in the intake pipe 32, a throttle valve actuator 33a which rotationally drives the throttle valve 33 in response to a command signal from the electric control device 80, an intercooler 34 which is interposed in the intake pipe 32 on the upstream of the throttle valve 33, and an air cleaner 35 which is disposed in the end portion of the intake pipe 32 on the upstream side of the supercharging device 60 provided in the upstream of the intercooler 34. The intake manifold 31 and the intake pipe 32 constitute the intake passage.

[0059] The exhaust system 40 includes an exhaust gas manifold 41 which communicates with the respective cylinders through the exhaust port 27 of the cylinder head 21, an exhaust pipe 42 which is connected to the downstream side assembly of the exhaust gas manifold 41, and a known exhaust gas purifying catalyst (DPNR) 43 which is interposed in the exhaust pipe 42 on the downstream side of the supercharging device 60 provided in the exhaust pipe 42. The exhaust gas manifold 41 and the exhaust pipe 42 constitute the exhaust passage.

[0060] The EGR device 50 includes an exhaust re-circulating pipe 51 which constitutes the passageway (EGR passageway) for re-circulating the exhaust gas from the exhaust gas manifold 41 to the intake manifold 31, an EGR gas cooling device (EGR cooler) 52 which is interposed in the exhaust re-circulating pipe 51, and an EGR control valve 53 which is interposed in the exhaust re-circulating pipe 51. The EGR control valve 53 is configured to change the amount of the exhaust gas which is re-circulated from the exhaust gas manifold 41 to the intake manifold 31 in response to the command signal from the electric control device 80.

[0061] The supercharging device 60 includes a compressor 61 and a turbine 62. The compressor 61 is disposed in the intake passage (intake pipe 32) and the turbine 62 is disposed in the exhaust passage (exhaust pipe 42). The compressor 61 and the turbine 62 are connected to each other by a rotor shaft (not illustrated) so as to be rotatable about the shaft. Thus, when the turbine 62 is rotatable by the exhaust gas, the compressor 61 rotates and the air supplied into the compressor 61 is compressed (supercharging is performed).

[0062] As illustrated in FIG. 1, the first device includes a hot-wire air flow meter 71, an intake air temperature sensor 72, an intake air pressure sensor 73, a crank position sensor 74, and an accelerator opening degree sensor 75. In

addition, as illustrated in FIG. 2, the first device includes a cylinder internal pressure sensor 76 and a cooling water temperature sensor 77.

[0063] Referring to FIG. 1, the hot-wire air flow meter 71 is disposed in the intake passage (intake pipe 32). The hot-wire air flow meter 71 is configured to output a signal in response to the mass flow (the mass of the air suctioned into the engine 10 per unit time) of the suctioned air flowing through the intake pipe 32.

[0064] The intake air temperature sensor 72 is disposed in the intake passage (intake pipe 32). The intake air temperature sensor 72 is configured to output a signal in response to the temperature (intake air temperature) of the suctioned air flowing through the intake pipe 32.

[0065] The intake air pressure sensor 73 is disposed on the downstream side of the throttle valve 33 of the intake pipe 32. The intake air pressure sensor 74 is configured to output a signal representing the pressure of the air in the exhaust pipe 42 of the portion where the sensor is disposed, that is, the pressure (the supercharging pressure caused by the supercharging device 60) of the air supplied to the combustion chamber of the engine 10.

[0066] The crank position sensor 74 is disposed near a crank shaft (not illustrated). The crank position sensor 74 is configured to output a signal having a pulse of a narrow width whenever the crank shaft rotates by 10° and a pulse of a wide width whenever the crank shaft rotates by 360° . Based on this signal, the number of rotations (the engine rotation speed) per unit time of the crank shaft is calculated.

[0067] The accelerator opening degree sensor 75 is disposed in an accelerator pedal AP which is operated by the operator of the engine 10. The accelerator opening degree sensor 75 is configured to output a signal in response to the opening degree of the accelerator AP.

[0068] Referring to FIG. 2, the cylinder internal pressure sensor 76 is disposed in the upper portion of the cylinder so as to be adjacent to the fuel injecting device 22. The cylinder internal pressure sensor 76 is configured to output a signal representing the pressure of the gas in the cylinder.

[0069] The cooling water temperature sensor 77 is disposed in a cooling water passageway 29a of the engine 10. The cooling water temperature sensor 77 is configured to output a signal representing a temperature (cooling water temperature) of the cooling water flowing through the cooling water passageway 29a.

[0070] Referring to FIG. 1 again, the electric control device 80 is a microcomputer which includes a CPU 81 which is connected via a bus, a ROM 82 which stores a program performed by the CPU 81, a table (map), a constant, and the like in advance, a RAM 83 which is used to temporarily store data by the CPU 81, if necessary, a back-up RAM 84 which stores data in a power input state and maintains the stored data even in a power off state, an interface 85 which includes an AD converter, and the like.

[0071] The interface 85 is configured to supply a signal from the respective sensors and the like to the CPU 81 by being connected to the respective sensors and the like. In addition, the interface 85 is configured to output a drive signal (command signal) to the fuel injecting device 22, the glow plug 23, the variable intake timing control device 26a, the variable exhaust timing control device 28a, and the throttle valve actuator 33a, and the like in response to the command of the CPU 81.

<Outline of operation of device>

[0072] Subsequently, the outline of the operation of the first device configured as described above will be described. The first device acquires the injection amount (the pilot injection amount Q_p and the main injection amount Q_m) of the fuel injected into the combustion chambers 24 of the respective cylinders, the injection timing (a pilot injection timing $finjp$ and a main injection timing $finjm$) of the fuel, the opening and closing timings (a target valve opening timing $Vino$ and a target valve closing timing $Vinc$) of the intake valve 26, and the opening and closing timings (a target valve opening timing $Vexo$ and a target valve closing timing $Vexc$) of the exhaust valve 28 based on the operation state of the engine 10. Then, the first device opens and closes the intake valve 26 at the acquired opening and closing timings so as to suction air from the intake passage into the combustion chamber 24. Subsequently, the first device injects the fuel of the acquired amount at the acquired injection timing from the fuel injecting device 22 into the combustion chamber 24. Subsequently, the first device opens and closes the exhaust valve 28 at the acquired opening and closing timings so as to discharge the combusted gas (the exhaust gas) from the inside of the combustion chamber 24 to the exhaust passage.

[0073] In addition, the first device applies a voltage of an application voltage value E_{gl} determined based on the operation state of the engine 10 to the glow plug 23 when a predetermined glow plug operation condition is satisfied. Thus, the glow plug 23 is operated, so that the ignition of the fuel is promoted. The first device estimates a compression end temperature T_t as the temperature of the gas in the cylinder when the piston 29 is at the compression top dead center in the respective cylinders (the first cylinder, the second cylinder, the third cylinder, and the fourth cylinder) when the glow plug 23 is operated. Also, the first device calculates the average value of the estimated compression end temperatures (T_{t1} , T_{t2} , T_{t3} , and T_{t4}) at the respective cylinders, and acquires a temperature lower than the average value by a predetermined temperature ΔT_{th1} as a compression end reference temperature T_{tref} .

[0074] Also, when the compression end temperature T_t of the cylinder (hereinafter, referred to as a "verification subject cylinder") as a subject for verifying the degradation degree of the glow plug 23 is equal to or higher than the compression end reference temperature T_{ref} , the first device verifies that the "glow plug 23 of the verification subject cylinder is not degraded or is degraded to a degree that the ignition of the fuel is not affected". Hereinafter, the meaning that the "glow plug is not degraded or is degraded to a degree that the ignition of the fuel is not affected" is referred to as that the "degradation degree of the glow plug is a first stage" for convenience of description.

[0075] On the other hand, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{ref} , the first device verifies that the "glow plug 23 of the verification subject cylinder is degraded to a degree that the fuel does not appropriately ignite". Hereinafter, the meaning that the "glow plug is degraded to a degree that the fuel is not appropriately degraded" is referred to as that the "degradation degree of the glow plug is a second stage" for convenience of description.

[0076] The first device applies the voltage of the determined application voltage value E_{gl} to the glow plug 23 when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage". On the other hand, the first device applies a voltage ($E_{gl} + E_{glcom}$) obtained by adding an "application voltage correction amount E_{glcom} determined in response to the degradation degree of the glow plug 23" to the determined application voltage value E_{gl} to the glow plug 23 when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage". That is, the application voltage value E_{gl} increases by the application voltage correction amount E_{glcom} .

[0077] Here, the first device verifies that the "glow plug 23 of the verification subject cylinder is degraded to a degree that a repair or a replacement is needed" when the application voltage correction amount E_{glcom} is larger than a predetermined application voltage upper limit correction amount $E_{glcommax}$. Hereinafter, the meaning that the "glow plug is degraded to a degree that a repair or a replacement is needed" is referred to as that the "degradation degree of the glow plug is a third stage".

[0078] The first device applies a voltage ($E_{gl} + E_{glcommax}$) obtained by adding an application voltage upper limit correction amount $E_{glcommax}$ to the determined application voltage value E_{gl} to the glow plug 23 when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage". That is, the application voltage value E_{gl} increases by the application voltage upper limit correction amount $E_{glcommax}$. In addition, at this time, the first device displays that the "glow plug is in an abnormal condition" on a display device (not illustrated) or the like. The description above is the outline of the operation of the first device.

<Combustion control method>

[0079] Subsequently, the combustion control method which is employed in the first device will be described before the description of the specific operation of the first device.

[0080] As described above, the amount of heat given from the glow plug 23 to the gas in the cylinder per unit time decreases when the glow plug 23 is degraded, the compression end temperature T_t decreases. Therefore, the first device increases the application voltage value E_{gl} applied to the glow plug 23 by the application voltage correction amount E_{glcom} when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage". The application voltage correction amount E_{glcom} is determined in response to the degradation degree of the glow plug 23.

[0081] When the application voltage value E_{gl} applied to the glow plug 23 increases, a passage current value I_{gl} passing through the glow plug 23 also increases. For this reason, the electric power consumed in the glow plug 23 increases, so that the amount of heat of the glow plug 23 increases. Accordingly, the amount of heat given from the glow plug 23 to the gas in the cylinder per unit time increases. In addition, since the application voltage correction amount E_{glcom} is determined in response to the degradation degree of the glow plug 23, the application voltage value E_{gl} increases by the sufficient amount necessary for compensating a decrease in the compression end temperature T_t caused by the degradation in the glow plug 23. As a result, the compression end temperature T_t of the verification subject cylinder may be increased to a temperature (that is, a temperature that is the same as the temperature set when the degradation degree of the glow plug 23 is the "first stage", or a temperature higher than the compression end reference temperature T_{ref}) for appropriately igniting the fuel by the right amount.

[0082] In addition, the first device changes the application voltage correction amount E_{glcom} to the application voltage upper limit correction amount $E_{glcommax}$ when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage". That is, at this time, the application voltage value E_{gl} is controlled so as not to be larger than the application voltage upper limit correction amount $E_{glcommax}$. Thus, since an excessive voltage is prevented from being applied to the glow plug 23, the breakage or the like of the glow plug 23 may be prevented. The description above is the combustion control method which is employed in the first device.

[0083] Hereinafter, as described above, the operation of increasing the compression end temperature T_t of the verification subject cylinder is also referred to as the "compression end temperature increasing operation" for convenience

of description.

<Actual operation>

[0084] Hereinafter, the actual operation of the first device will be described.

In the first device, the CPU 81 is configured to perform the respective routines indicated by the flowcharts of FIGS. 3 to 8 at a predetermined timing. The CPU 81 uses a glow plug operation flag XGLO and an abnormality occurrence flag XEMG in these routines.

[0085] The glow plug operation flag XGLO indicates that the glow plug 23 is not operated (a voltage is not applied to the glow plug 23) when its value is "0". On the other hand, the glow plug operation flag XGLO indicates that the glow plug 23 is operated (a voltage is applied to the glow plug 23) when its value is "1".

[0086] The abnormality occurrence flag XEMG indicates that the degradation degree of the glow plug 23 is the "first stage" or the "second stage" when its value is "0". On the other hand, the abnormality occurrence flag XEMG indicates that the degradation degree of the glow plug 23 is the "third stage" when its value is "1".

[0087] The values of the glow plug operation flag XGLO and the abnormality occurrence flag XEMG are stored in the back-up RAM 84. In addition, the value of the glow plug operation flag XGLO is set to "0" in the initial routine which is performed when an ignition key switch (not illustrated) is changed from the off state to the on state. Also, the value of the abnormality occurrence flag XEMG is set to "0" when a predetermined operation is performed on the electric control device 80 when it is verified that no abnormality occurs in the glow plug 23 in a case where a vehicle equipped with the engine 10 is shipped from a factory and a service inspection or the like is performed.

[0088] Hereinafter, the respective routines which are performed by the CPU 81 will be specifically described.

The CPU 81 is configured to repeatedly perform the "first cylinder-internal-temperature-correcting routine" which is indicated by the flowchart of FIG. 3 whenever a predetermined time elapses in each cylinder (each of the first cylinder to the fourth cylinder) when the engine 10 is started. By the routine, the CPU 81 verifies the degradation degree of the glow plug 23 and controls the "application voltage Egl to the glow plug 23" in response to the degradation degree. Specifically, by the routine, the CPU 81 determines whether or not to operate the glow plug 23 in response to the operation state of the engine 10. In addition, the CPU 81 increases the "application voltage value Egl to the glow plug 23" in response to the degradation degree of the glow plug 23 when the glow plug 23 is operated.

[0089] More specifically, the CPU 81 starts a process from step 300 of FIG. 3 at a predetermined timing and proceeds to step 305 so as to determine whether the "condition of operating the glow plug 23 (the glow plug operation condition)" is satisfied in each cylinder. More specifically, in step 305, the CPU 81 determines that the glow plug operation condition is satisfied when both Condition 1 and Condition 2 below are satisfied. In other words, the CPU 81 determines that the glow plug operation condition is not satisfied when at least one of Condition 1 and Condition 2 is not satisfied.

[0090]

(Condition 1) A cooling water temperature THW is lower than a predetermined threshold water temperature THWth.

(Condition 2) An intake air temperature T_{in} is lower than a predetermined threshold intake air temperature T_{in}th.

[0091] As described above, the ignition of the fuel is affected by the "temperature of the gas in the cylinder" and the "time length during which the pre-self-ignition reaction of the fuel may be performed". The cooling water temperature THW mentioned in Condition 1 and the intake air temperature T_{in} mentioned in Condition 2 affect the "temperature of the gas in the cylinder". Therefore, the CPU 81 determines that the temperature of the gas in the cylinder (compression end temperature T_t) is low to a degree that the fuel does not appropriately ignite when both Condition 1 and Condition 2 are satisfied, and operates the glow plug 23.

[0092] Hereinafter, the "case where the glow plug operation condition is satisfied" and the "case where the glow plug operation condition is not satisfied" will be separately described in more detail.

(Case 1-1) Case of satisfying glow plug operation condition

[0093] In this case, the CPU 81 determines that the determination result is "Yes" in step 305 so as to proceed to step 310, and stores "1" as the value of the glow plug operation flag XGLO. Further, for example, when the engine 10 is cold-started, there is a high possibility that the glow plug operation condition is satisfied.

[0094] Subsequently, the CPU 81 proceeds to step 315, and determines and acquires the application voltage value Egl by applying the cooling water temperature THW and the intake air temperature T_{in} at the current time point to a glow plug application voltage table MapEgl (THW, T_{in}) in which the "relation between the cooling water temperature THW, the intake air temperature T_{in}, and the application voltage value Egl to the glow plug 23" is determined in advance. In the glow plug application voltage table MapEgl (THW, T_{in}), the application voltage value Egl is designed to increase as the cooling water temperature THW decreases and to increase as the intake air temperature T_{in} decreases.

[0095] Subsequently, the CPU 81 proceeds to step 320, and determines whether the compression end reference temperature T_{tref} is acquired at the current time point. When the compression end reference temperature T_{tref} is not acquired at the current time point, the CPU 81 determines that the determination result is "No" in step 320, and proceeds to step 325. Further, since the current time point is immediately after the engine 10 is started, there is a high possibility

that the compression end reference temperature T_{tref} is not acquired.

[0096] The CPU 81 applies the voltage of the application voltage value E_{gl} to the glow plug 23 in step 325. Subsequently, the CPU 81 proceeds to step 395 so as to end the present routine once.

[0097] In this way, if the compression end reference temperature T_{tref} is not acquired when the glow plug operation condition is satisfied, the voltage of the application voltage value E_{gl} which is determined in response to the operation state of the engine 10 is applied to the glow plug 23. Thus, the glow plug 23 produces heat, so that the gas in the cylinder is heated. As a result, the compression end temperature T_t increases.

[0098] In addition, the CPU 81 is configured to repeatedly perform the "valve timing control routine" indicated by the flowchart of FIG. 4 whenever a predetermined time elapses in each cylinder. By the routine, the CPU 81 determines the target valve opening timing V_{ino} and the target valve closing timing V_{inc} of the intake valve 26 in response to the operation state of the engine 10 and controls the variable intake timing control device 26a so that the actual valve opening timing of the intake valve 26 is equal to the target valve opening timing V_{ino} and the actual valve closing timing of the intake valve 26 is equal to the target valve closing timing V_{inc} . Also, by the routine, the CPU 81 determines the target valve opening timing V_{exo} and the target valve closing timing V_{exc} of the exhaust valve 28 in response to the operation state of the engine 10, and controls the variable exhaust timing control device 28a so that the actual valve opening timing of the exhaust valve 28 is equal to the target valve opening timing V_{exo} and the actual valve closing timing of the exhaust valve 28 is equal to the target valve closing timing V_{exc} .

[0099] Specifically, the CPU 81 starts a process from step 400 of FIG. 4 at a predetermined timing and proceeds to step 410 so as to acquire an engine rotation speed NE based on the output value of the crank position sensor 74 and to acquire an accelerator pedal opening degree $Accp$ based on the output value of the accelerator pedal opening degree sensor 75. Then, the CPU 81 determines and acquires the intake valve target valve opening timing V_{ino} and the intake valve target valve closing timing V_{inc} by applying the acquired parameters to an intake valve target opening and closing timing table $MapVin$ (NE , $Accp$) in which the "relation between the engine rotation speed NE , the accelerator pedal opening degree $Accp$, and the target opening and closing timings V_{ino} and V_{inc} of the intake valve 26" is determined in advance. In the intake valve target opening and closing timing table $MapVin$ (NE , $Accp$), the intake valve target valve opening timing V_{ino} and the intake valve target valve closing timing V_{inc} are designed to become appropriate timings in consideration of the emission, the output, and the like of the engine 10.

[0100] Subsequently, the CPU 81 proceeds to step 420, and determines and acquires the exhaust valve target valve opening timing V_{exo} and the exhaust valve target valve closing timing V_{exc} by applying the engine rotation speed NE and the accelerator pedal opening degree $Accp$ acquired in step 410 to an exhaust valve target opening and closing timing table $MapVex$ (NE , $Accp$) in which the "relation between the engine rotation speed NE , the accelerator pedal opening degree $Accp$, and the target opening and closing timings V_{exo} and V_{exc} of the exhaust valve 28" is determined in advance. In the exhaust valve target opening and closing timing table $MapVex$ (NE , $Accp$), the exhaust valve target valve opening timing V_{exo} and the exhaust valve target valve closing timing V_{exc} are designed to become appropriate timings in consideration of the emission, the output, and the like of the engine 10.

[0101] Subsequently, the CPU 81 proceeds to step 430, and controls the variable intake timing control device 26a so that the actual valve opening timing of the intake valve 26 is equal to the target valve opening timing V_{ino} and the actual valve closing timing of the intake valve 26 is equal to the target valve closing timing V_{inc} .

[0102] Subsequently, the CPU 81 proceeds to step 440, and controls the variable exhaust timing control device 28a so that the actual valve opening timing of the exhaust valve 28 is equal to the target valve opening timing V_{exo} and the actual valve closing timing of the exhaust valve 28 is equal to the target valve closing timing V_{exc} . Subsequently, the CPU 81 proceeds to step 495 so as to end the present routine once.

[0103] In this way, the CPU 81 changes the opening and closing timings of the intake valve 26 and the exhaust valve 28 in response to the operation state (the engine rotation speed NE and the accelerator pedal opening degree $Accp$) of the engine 10 in each cylinder.

[0104] In addition, the CPU 81 is configured to repeatedly perform the "compression end temperature estimating routine" indicated by the flowchart of FIG. 5 whenever a predetermined time elapses in each cylinder. By the routine, the CPU 81 estimates the compression end temperature T_t (that is, the temperature of the gas in the cylinder when the position of the piston 29 is at the compression top dead center) when the glow plug 23 is operated.

[0105] More specifically, the CPU 81 starts a process from step 500 of FIG. 5 at a predetermined timing and proceeds to step 510 so as to determine whether the value of the glow plug operation flag $XGLO$ is "1". Since the value of the glow plug operation flag $XGLO$ at the current time point is "1", the CPU 81 determines that the determination result is "Yes" in step 510, and proceeds to step 520.

[0106] The CPU 81 determines whether a crank angle CA at the current time point matches the target valve closing

timing Vinc of the intake valve 26 in one cylinder in step 520. When the crank angle CA at the current time point does not match the target valve closing timing Vinc of the intake valve 26, the CPU 81 determines that the determination result is "No" in step 520, and directly proceeds to step 595 so as to end the present routine once. Here, when the crank angle CA at the current time point matches the target valve closing timing Vinc of the intake valve 26, the CPU 81 determines that the determination result is "Yes" in step 520, and proceeds to step 530. Hereinafter, the description will be continued on the assumption that the crank angle CA at the current time point "matches" the target valve closing timing Vinc of the intake valve 26.

[0107] According to the above-described assumption, the CPU 81 proceeds to step 530, acquires the intake air temperature Tin based on the output value of the intake air temperature sensor 72, and stores the intake air temperature Tin as the intake valve closing timing cylinder gas temperature Tc in the RAM 83. In addition, in step 530, the CPU 81 acquires the intake pressure Pin based on the output value of the intake air pressure sensor 73, and stores the intake pressure Pin as the intake valve closing timing cylinder gas pressure Pc in the RAM 83.

[0108] Subsequently, the CPU 81 proceeds to step 540, and acquires a cylinder gas amount n (mole number) by applying the intake valve closing timing cylinder gas temperature Tc and the intake valve closing timing cylinder gas pressure Pc acquired in step 530, a gas constant R of the ideal gas stored in advance in the ROM 82, and an intake valve closing timing cylinder volume Vc obtained by applying the target valve closing timing Vinc of the intake valve 26 to the "relation between the crank angle CA and the cylinder volume V" stored in advance in the ROM 82 to the following equation (1).

[0109]

$$n = (Pc \cdot Vc) / (R \cdot Tc) \dots (1)$$

[0110] Further, the above-described equation (1) is derived from the "state equation of the ideal gas illustrating the relation between the gas pressure P, the gas occupying volume V, the gas material amount n (mole number), the gas constant R, and the gas temperature T" illustrated in the following equation (2).

[0111]

$$PV = nRT \dots (2)$$

[0112] Subsequently, the CPU 81 proceeds to step 550, and determines whether the crank angle CA at the current time point matches the compression top dead center (hereinafter, referred to as "ATDC") at the same cylinder. When the crank angle CA at the current time point does not match ATDC, the CPU 81 determines that the determination result is "No" in step 550, and directly proceeds to step 595 so as to end the present routine once. Here, when the crank angle CA at the current time point matches ATDC, the CPU 81 determines that the determination result is "Yes" in step 550, and proceeds to step 560. Hereinafter, the description will be continued on the assumption that the crank angle CA at the current time point matches ATDC.

[0113] According to the above-described assumption, the CPU 81 proceeds to step 560, acquires a cylinder internal pressure P_{cyl} based on the output value of the cylinder internal pressure sensor 76, and stores the cylinder internal pressure P_{cyl} as the cylinder gas pressure Pt at the compression top dead center in the RAM 83.

[0114] Subsequently, the CPU 81 proceeds to step 570, and acquires the compression end temperature Tt by applying the cylinder gas amount n acquired in step 540, the cylinder gas pressure Pt at the compression top dead center acquired in step 560, the gas constant R stored in advance in the ROM 82, and a cylinder volume Vt at the compression top dead center which may be obtained by applying ATDC to the "relation between the crank angle CA and the cylinder volume" stored in advance in the ROM 82 to the following equation (3).

[0115]

$$Tt = (Pt \cdot Vt) / (n \cdot R) \dots (3)$$

[0116] The compression end temperature Tt which is acquired in this way includes the "increase amount of the temperature of the gas in the cylinder caused by the heating of the glow plug 23". Specifically, the "increase amount of the temperature of the gas in the cylinder caused by the glow plug 23" is reflected in the cylinder gas pressure Pt at the compression top dead center. As widely known, this is because a movement speed of a molecule constituting a gas

depends on the gas temperature when the gas is present in a predetermined area and the gas pressure is generated by the momentum given to the boundary surface of the area when the molecule collides with the boundary surface. That is, since the movement speed of the molecule constituting the gas in the cylinder increases as the "increase amount of the temperature of the gas in the cylinder caused by the glow plug 23" increases, the cylinder gas pressure P_t at the compression top dead center increases.

[0117] Further, the above-described equation (3) is derived from the known state equation of the ideal gas indicated by the above-described equation (2) as in the above-described equation (1). The CPU 81 acquires the compression end temperature T_t in step 570, and proceeds to step 595 so as to end the present routine once.

[0118] In this way, when the glow plug operation condition is satisfied, the cylinder gas amount n in one cylinder is calculated based on the operation parameters (the intake valve closing timing cylinder volume V_c , the intake valve closing timing cylinder gas pressure P_c , and the intake valve closing timing cylinder gas temperature T_c) which are acquired when the crank angle CA is at the target valve closing timing V_{inc} of the intake valve 26 (that is, the time point at which the intake valve 26 is closed). In addition, the compression end temperature T_t in the same cylinder is estimated based on the calculated cylinder gas amount n and the operation parameters (the cylinder volume V_t at the compression top dead center and the cylinder gas pressure P_t at the compression top dead center) which are obtained when the crank angle CA is at ATDC (the compression top dead center).

[0119] The CPU 81 performs the routine illustrated in FIG. 5 in each cylinder (each of the first cylinder to the fourth cylinder). Hereinafter, the compression end temperature which is estimated in this way in the first cylinder is referred to as a "first cylinder compression end temperature T_{t1} ", the compression end temperature in the second cylinder is referred to as a "second cylinder compression end temperature T_{t2} ", the compression end temperature in the third cylinder is referred to as a "third cylinder compression end temperature T_{t3} ", and the compression end temperature in the fourth cylinder is referred to as a "fourth cylinder compression end temperature T_{t4} ".

[0120] In addition, the CPU 81 is configured to repeatedly perform the "first compression-end-reference-temperature acquiring routine" indicated by the flowchart of FIG. 6 whenever a predetermined time elapses. By the routine, the CPU 81 acquires the compression end reference temperature T_{tref} which is an index for verifying the degradation degree of the glow plug 23.

[0121] Specifically, when the CPU 81 starts a process from step 600 of FIG. 6 at a predetermined timing, the CPU proceeds to step 610 and determines whether the value of the glow plug operation flag $XGLO$ is "1". Since the value of the glow plug operation flag $XGLO$ at the current time point is "1", the CPU 81 determines that the determination result is "Yes" in step 610, and proceeds to step 620.

[0122] The CPU 81 acquires the compression end reference temperature T_{tref} by applying the first cylinder compression end temperature T_{t1} , the second cylinder compression end temperature T_{t2} , the third cylinder compression end temperature T_{t3} , and the fourth cylinder compression end temperature T_{t4} to the following equation (4) in step 620. In the following equation (4), ΔT_{tth1} indicates a predetermined threshold value. The threshold value ΔT_{tth1} may be an appropriate value obtained in consideration of the degradation degree of the glow plug 23 and the like which may be allowed in the engine 10.

[0123]

$$T_{tref} = (T_{t1} + T_{t2} + T_{t3} + T_{t4})/4 - \Delta T_{tth1} \dots (4)$$

[0124] As illustrated in the above-described equation (4), the first device employs the "temperature lower than the average value of the compression end temperatures (T_{t1} , T_{t2} , T_{t3} , and T_{t4}) by the predetermined temperature (the threshold value ΔT_{tth1}) in the respective cylinders" as the compression end reference temperature T_{tref} . The CPU 81 acquires the compression end reference temperature T_{tref} in step 620, and proceeds to step 695 so as to end the present routine once.

[0125] In this way, when the glow plug operation condition is satisfied, the CPU 81 acquires the compression end reference temperature T_{tref} based on the compression end temperatures (T_{t1} , T_{t2} , T_{t3} , and T_{t4}) in the first cylinder to the fourth cylinder.

[0126] In addition, the CPU 81 is configured to repeatedly perform the "fuel injection control routine" indicated by the flowchart of FIG. 7 whenever the crank angle of the arbitrary cylinder becomes equal to a predetermined crank angle before the compression top dead center (for example, the crank angle of 90° before the compression top dead center) θ_f . By the routine, the CPU 81 performs the command of the calculation of the fuel injection amount (the pilot injection amount Q_p and the main injection amount Q_m) and the injection of the fuel. The routine is performed regardless of whether the glow plug operation condition is satisfied. Hereinafter, for convenience of description, the cylinder which is in the compression stroke in which the crank angle becomes equal to the predetermined crank angle θ_f before the compression top dead center is referred to as the "fuel injection cylinder".

[0127] Specifically, when the crank angle of the fuel injection cylinder becomes equal to the crank angle θ_f , the CPU 81 starts a process from step 700 of FIG. 7 so as to proceed to step 710, acquires the engine rotation speed NE based on the output value of the crank position sensor 74, and acquires the accelerator pedal opening degree Accp based on the output value of the accelerator pedal opening degree sensor 75. Then, the CPU 81 determines and acquires the pilot injection amount Qp and the main injection amount Qm by applying the acquired parameters to a fuel injection amount table MapQ (NE, Accp) in which the "relation between the engine rotation speed NE, the accelerator pedal opening degree Accp, and the fuel injection amount Q (the pilot injection amount Qp and the main injection amount Qm)" is determined in advance. In the fuel injection amount table MapQ (NE, Accp), the pilot injection amount Qp and the main injection amount Qm are designed to become appropriate amounts in consideration of the emission, the output, and the like of the engine 10.

[0128] Subsequently, the CPU 81 proceeds to step 720, and determines and acquires the pilot injection timing finjp and the main injection timing finjm by applying the engine rotation speed NE and the accelerator pedal opening degree Accp acquired in step 710 to a fuel injection timing table Mapfinj (NE, Accp) in which the "relation between the accelerator pedal opening degree Accp, the engine rotation speed NE, and the fuel injection timing finj (the pilot injection timing finjp and the main injection timing finjm)" is determined in advance. In the fuel injection timing table Mapfinj (NE, Accp), the pilot injection timing finjp and the main injection timing finjm are designed to become appropriate timings in consideration of the emission, the output, and the like of the engine 10.

[0129] Further, in the fuel injection timing table Mapfinj (NE, Accp), the pilot injection timing finjp in the predetermined engine rotation speed NE and the accelerator pedal opening degree Accp is determined so as to be earlier (faster) than the main injection timing finjm in the predetermined engine rotation speed NE and the accelerator pedal opening degree Accp.

[0130] Subsequently, the CPU 81 proceeds to step 730, and determines whether the crank angle CA at the current time point matches the above-described pilot injection timing finjp. Here, on the assumption that the current time point is a "time point before the crank angle CA reaches the pilot injection timing finjp", the CPU 81 determines that the determination result is "No" in step 730, and proceeds to step 740. In addition, according to the assumption, the CPU 81 also determines that the determination result is "No" in step 740, and proceeds to step 795 so as to end the present routine once.

[0131] Accordingly, both the pilot injection and the main injection are not performed at the "time point before the crank angle CA reaches the pilot injection timing finjp". The CPU 81 repeatedly performs the processes of step 710, step 720, step 730, step 740, and step 795 until the crank angle CA reaches the pilot injection timing finjp. Then, when the crank angle CA reaches the "pilot injection timing finjp", the CPU 81 determines that the determination result is "Yes" in step 730, and proceeds to step 750.

[0132] The CPU 81 gives a command to the injector 22 so that the fuel of the pilot injection amount Qp is injected from the injector 22 provided in the fuel injection cylinder in step 750. That is, at this time, the fuel of the pilot injection amount Qp is supplied (injected) to the fuel injection cylinder. Subsequently, the CPU 81 proceeds to step 795 so as to end the present routine once.

[0133] Subsequently, the CPU 81 repeatedly performs the processes of step 710, step 720, step 730, step 740, and step 795 until the crank angle CA exceeds the pilot injection timing finjp and reaches the main injection timing finjm. Then, when the crank angle CA reaches the "main injection timing finjm", the CPU 81 determines that the determination result is "Yes" in step 740, and proceeds to step 760.

[0134] The CPU 81 gives a command to the injector 22 so that the fuel of the main injection amount Qm is injected from the injector 22 provided in the fuel injection cylinder in step 760. That is, at this time, the fuel of the main injection amount Qm is supplied (injected) to the fuel injection cylinder. Subsequently, the CPU 81 proceeds to step 795 so as to end the present routine once.

[0135] In this way, the CPU 81 injects the fuel of the fuel injection amount (the pilot injection amount Qp and the main injection amount Qm) determined in response to the operation state of the engine 10 regardless of whether the glow plug operation condition is satisfied from the injector 22 provided in the fuel injection cylinder at the fuel injection timing (the pilot injection timing finjp and the main injection timing finjm).

[0136] In addition, the CPU 81 is configured to repeatedly perform the "abnormality notifying routine" indicated by the flowchart of FIG. 8 whenever a predetermined time elapses. By the routine, the CPU 81 displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated) by turning on an alarm lamp or the like when the degradation degree of the glow plug 23 is larger than a predetermined degree.

[0137] Specifically, the CPU 81 starts a process from step 800 of FIG. 8 at a predetermined timing and proceeds to step 810 so as to determine whether the value of the abnormality occurrence flag XEMG is "0". Since the value of the abnormality occurrence flag XEMG at the current time point is "0" which is set in the initial routine, the CPU 81 determines that the determination result is "Yes" in step 810, and proceeds to step 895 so as to end the present routine once.

[0138] In this way, in a case where the "compression end reference temperature Ttref is not acquired" when the glow plug operation condition is satisfied, the compression end temperatures (Tt1, Tt2, Tt3, and Tt4) of the respective cylinders

are estimated at the same time when the glow plugs 23 of the respective cylinders are operated. In addition, the compression end reference temperature T_{ref} is acquired based on the estimated compression end temperatures in the respective cylinders. On the other hand, the fuel of the fuel injection amount (Q_p and Q_m) determined in response to the operation state of the engine 10 regardless of whether the glow plug operation condition is satisfied is injected to the fuel injection cylinder at the fuel injection timing (fin_p and fin_m).

[0139] Here, in a case where the "compression end reference temperature T_{ref} is acquired" when the glow plug operation condition is satisfied, the CPU 81 verifies the degradation degree of the glow plug 23 by comparing the compression end temperature T_t of the verification subject cylinder with the compression end reference temperature T_{ref} (hereinafter, the verification of the degradation degree is also simply referred to as a "degradation verification"). When it is verified that the "degradation degree of the glow plug 23 is the second stage" in the degradation verification, the CPU 81 performs the "compression end temperature increasing operation" as an operation for allowing the application voltage value E_{gl} applied to the glow plug 23 to be increased in response to the degradation degree of the glow plug 23. Thus, since the amount of heat of the glow plug 23 increases, even when the glow plug 23 is degraded, the compression end temperature T_t may be increased to a temperature at which the fuel appropriately ignites.

[0140] Specifically, in this case, when the CPU 81 starts a process from step 300 of FIG. 3 at a predetermined timing, the CPU proceeds to step 320 through step 305, step 310, and step 315. Since the compression end reference temperature T_{ref} is acquired at the current time point, the CPU 81 determines that the determination result is "Yes" in step 320, and proceeds to step 330.

[0141] The CPU 81 determines whether the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{ref} in step 330. Then, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{ref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage" and increases the application voltage value E_{gl} applied to the glow plug 23. In addition, when the increase amount of the application voltage value E_{gl} exceeds a predetermined threshold value, the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage" and displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated). On the other hand, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{ref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" and does not increase the application voltage value E_{gl} applied to the glow plug 23.

[0142] Hereinafter, the case will be separately described in more detail.

(Case 1-1-1) Case of compression end temperature T_t of verification subject cylinder lower than compression end reference temperature T_{ref}

[0143] In this case, the CPU 81 determines that the determination result is "Yes" in step 330, and proceeds to step 335. In step 335, the CPU 81 determines and acquires the application voltage correction amount E_{glcom} by applying the application voltage value E_{gl} at the current time point and the passage current value I_{gl} acquired by a current measuring device (not illustrated) to an application voltage correction amount table $MapE_{glcom}$ (E_{gl} , I_{gl}) in which the "relation between the application voltage value E_{gl} , the passage current value I_{gl} , and the application voltage correction amount E_{glcom} " is determined in advance. In the application voltage correction amount table $MapE_{glcom}$ (E_{gl} , I_{gl}), the application voltage correction amount E_{glcom} is designed to increase along with an increase of difference between the passage current value (ideal value) which may be obtained when the glow plug 23 is not degraded at all when a voltage of a certain application voltage value E_{gl} is applied to the glow plug 23 and the actual passage current value I_{gl} (measurement value) when the voltage of the application voltage value E_{gl} is applied to the glow plug 23. In other words, in the application voltage correction amount table $MapE_{glcom}$ (E_{gl} , I_{gl}), the application voltage correction amount E_{glcom} is designed to increase as the degree of degradation in the glow plug 23 increases.

[0144] Subsequently, the CPU 81 proceeds to step 340, and determines whether the application voltage correction amount E_{glcom} is larger than the application voltage upper limit correction amount $E_{glcommax}$.

[0145] When the application voltage correction amount E_{glcom} is equal to or smaller than the application voltage upper limit correction amount $E_{glcommax}$, the CPU 81 determines that the determination result is "No" in step 340, proceeds to step 345, and stores (updates) a value which may be obtained by adding the application voltage correction amount E_{glcom} to the application voltage value E_{gl} as the application voltage value E_{gl} in the RAM 83. Thus, the application voltage value E_{gl} is increased by the application voltage correction amount E_{glcom} .

[0146] On the other hand, when the application voltage correction amount E_{glcom} is larger than the application voltage upper limit correction amount $E_{glcommax}$, the CPU 81 determines that the determination result is "Yes" in step 340, and proceeds to step 350. In step 350, the CPU 81 stores the application voltage upper limit correction amount $E_{glcommax}$ as the value of the application voltage correction amount E_{glcom} . That is, when the value of the application voltage correction amount E_{glcom} is larger than the application voltage upper limit correction amount $E_{glcommax}$, the value of

the application voltage correction amount Eglcom is changed to the application voltage upper limit correction amount Eglcommax. That is, in the first device, the upper limit value of the application voltage correction amount Eglcom is set to the application voltage upper limit correction amount Eglcommax.

[0147] Subsequently, the CPU 81 proceeds to step 355, and stores "1" as the value of the abnormality occurrence flag XEMG. Then, in step 345 subsequent to step 355, the CPU 81 stores (updates) a value which may be obtained by adding the application voltage correction amount Eglcom (in practice, the application voltage upper limit correction amount Eglcommax) to the application voltage value Egl as the application voltage value Egl in the RAM 83.

(Case 1-1-2) Case of compression end temperature Tt of verification subject cylinder equal to or higher than compression end reference temperature Ttref

[0148] In this case, the CPU 81 determines that the determination result is "No" in step 330, and proceeds to step 360. In step 360, the CPU 81 stores zero as the value of the application voltage correction amount Eglcom, and proceeds to step 345.

[0149] In step 345, the CPU 81 stores (updates) a value which may be obtained by adding the application voltage correction amount Eglcom to the application voltage value Egl as the application voltage value Egl in the RAM 83. Incidentally, since the application voltage correction amount Eglcom at the current time point is zero, the application voltage value Egl is not increased. That is, the application voltage value Egl is not corrected.

[0150] As described above in the separate cases of "Case 1-1-1" and "Case 1-1-2", when the compression end temperature Tt of the verification subject cylinder is lower than the compression end reference temperature Ttref (that is, the case where the degradation degree of the glow plug 23 is the "second stage"), the application voltage value Egl is corrected in response to the application voltage value Egl and the passage current value Igl. Here, in this case, when the application voltage correction amount Eglcom exceeds the application voltage upper limit correction amount Eglcommax (that is, the degradation degree of the glow plug 23 is the "third stage"), the application voltage correction amount Eglcom is changed to the application voltage upper limit correction amount Eglcommax. Here, when the compression end temperature Tt of the verification subject cylinder is equal to or higher than the compression end reference temperature Ttref (that is, the degradation degree of the glow plug 23 is the "first stage"), the application voltage value Egl is not corrected. In addition, when the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage", the value of the abnormality occurrence flag XEMG is maintained at "0" stored in the initial routine. When the degradation degree is the "third stage", "1" is stored as the value of the abnormality occurrence flag XEMG.

[0151] Subsequently, as described above, when the application voltage value Egl is determined, the CPU 81 proceeds to step 325, and applies the voltage of the application voltage value Egl to the glow plug 23. Subsequently, the CPU 81 proceeds to step 395 so as to end the present routine once. Thus, the compression end temperature increasing operation of increasing the application voltage value Egl applied to the glow plug 23 is performed.

[0152] In addition, when the CPU 81 starts a process from step 800 of FIG. 8 at a predetermined timing, the CPU proceeds to step 810. Here, when the value of the abnormality occurrence flag XEMG at the current time point is "0" (in the routine of FIG. 3, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage"), the CPU 81 determines that the determination result is "Yes" in step 810, and directly proceeds to step 895 so as to end the present routine once.

[0153] Here, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "1" (in the routine of FIG. 3, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage"), the CPU 81 determines that the determination result is "No" in step 810, and proceeds to step 820. In step 820, the CPU 81 displays that the "glow plug 23 is in abnormal condition" on a display device (not illustrated) by turning on an alarm lamp or the like. Subsequently, the CPU 81 directly proceeds to step 895 so as to end the present routine once. The description above is the operation of the first device when the glow plug operation condition is satisfied (that is, Case 1-1).

(Case 1-2) Case of no satisfaction of glow plug operation condition

[0154] Here, a case where the glow plug operation conditions is not satisfied will be described below. In this case, when the CPU 81 starts a process from step 300 of FIG. 3 at a predetermined timing and proceeds to step 305, the CPU determines that the determination result is "No" in step 305, and proceeds to step 365.

[0155] In step 365, the CPU 81 stores "0" as the value of the glow plug operation flag XGLO. Subsequently, the CPU 81 directly proceeds to step 395 so as to end the present routine once.

[0156] In addition, when the CPU 81 starts a process from step 400 of FIG. 4 at a predetermined timing, the CPU proceeds to step 495 through step 410 to step 440 so as to end the present routine once as described above. Accordingly, even in a case where the glow plug operation conditions is not satisfied, the opening and closing timings of the intake

valve 26 and the exhaust valve 28 are controlled as in the case where the glow plug operation condition is satisfied.

[0157] In addition, when the CPU 81 starts a process from step 500 of FIG. 5 at a predetermined timing and proceeds to step 510, the CPU determines that the determination result is "No" in step 510 since the value of the glow plug operation flag XGLO is "0". Subsequently, the CPU 81 directly proceeds to step 595 so as to end the present routine once. Accordingly, when the glow plug operation condition is not satisfied, the compression end temperature T_t is not estimated.

[0158] In addition, when the CPU 81 starts a process from step 600 of FIG. 6 at a predetermined timing and proceeds to step 610, the CPU determines that the determination result is "No" in step 610 since the value of the glow plug operation flag XGLO is "0". Subsequently, the CPU 81 directly proceeds to step 695 so as to end the present routine once. Accordingly, when the glow plug operation condition is not satisfied, the compression end reference temperature T_{ref} is not acquired.

[0159] In addition, the CPU 81 starts a process from step 700 of FIG. 7 at a predetermined timing, the CPU performs the processes of step 710 to step 760. Accordingly, even in a case where the glow plug operation condition is not satisfied, fuel of a predetermined fuel injection amount (Q_p and Q_m) is supplied (injected) to the fuel injection cylinder at the predetermined fuel injection timing ($finjp$ and $finjm$) as in the case where the glow plug operation condition is satisfied.

[0160] In addition, when the CPU 81 starts a process from step 800 of FIG. 8 at a predetermined timing and proceeds to step 810, the CPU determines that the determination result is "Yes" in step 810 since the value of the abnormality occurrence flag XEMG is "0" set in the initial routine. Subsequently, the CPU 81 proceeds to step 895 so as to end the present routine once. Accordingly, when the glow plug operation condition is not satisfied, the notification of abnormality of the glow plug 23 is not performed. The description above is the operation of the first device in a case where the glow plug operation condition is not satisfied (that is, Case 1-2).

[0161] As separately described in "Case 1-1 and "Case 1-2", when the glow plug operation conditions is satisfied, the voltage of the application voltage value E_{gl} determined in response to the operation state of the engine 10 is applied to the glow plug 23, so that the glow plug 23 is operated. In addition, when the glow plug 23 is operated, the compression end temperatures (T_{t1} , T_{t2} , T_{t3} , and T_{t4}) of the respective cylinders are estimated, and the temperature lower by a predetermined temperature than the average value of the estimated compression end temperatures of the respective cylinders is acquired as the compression end reference temperature T_{ref} . Also, the degradation degree of the glow plug 23 provided in the verification subject cylinder is verified by comparing the compression end reference temperature T_{ref} with the compression end temperature T_t of the verification subject cylinder.

[0162] In addition, when it is verified that the degradation degree of the glow plug 23 is the "first stage" by the degradation verification, the voltage of the application voltage value E_{gl} is continuously applied to the glow plug 23. On the other hand, when it is verified that the degradation degree of the glow plug 23 is the "second stage" by the degradation verification, the "compression end temperature increasing operation," is performed in which the application voltage value E_{gl} increases by the application voltage correction amount E_{glcom} which is determined in response to the degradation degree of the glow plug 23.

[0163] In addition, when it is verified that the degradation degree of the glow plug 23 is the "third stage" by the degradation verification, the application voltage value E_{gl} is increased by the predetermined application voltage upper limit correction amount $E_{glcommax}$ and the display device displays that the "glow plug 23 is in an abnormal condition".

[0164] In contrast thereto, when the glow plug operation condition is not satisfied, the glow plug 23 is not operated. However, even when the glow plug 23 is not operated, the intake valve 26 and the exhaust valve 28 may be opened and closed at the timing in response to the operation state of the engine 10, and the injector 22 may inject the fuel of the amount in response to the operation state of the engine 10 at the timing in response to the operation state. Here, when the glow plug 23 is not operated, the compression end temperature T_t and the compression end reference temperature. T_{ref} are not acquired, so that the degradation verification of the glow plug 23 is not performed.

<operation and effect of device>

[0165] The first device verifies the degradation degree of the glow plug 23 of the verification subject cylinder by comparing the compression end reference temperature T_{ref} with the compression end temperature T_t of the verification subject cylinder when the glow plug 23 is operated. In addition, the first device performs the compression end temperature increasing operation of increasing the application voltage value E_{gl} to the glow plug 23 by the amount (the application voltage correction amount E_{glcom}) in response to the degradation degree. Thus, since the first device may appropriately increase the compression end temperature T_t in response to the degradation degree of the glow plug 23, the ignition of the fuel may be reliably performed even when the glow plug 23 is degraded.

[0166] In addition, since the first device employs a temperature lower by a predetermined temperature than the average value of the compression end temperatures the respective cylinders as the compression end reference temperature T_{ref} , the compression end temperatures of all cylinders may be maintained substantially at the same temperature by performing the above-described compression end temperature increasing operation. Thus, the first device may suppress

a variation in the combustion between the respective cylinders even when the glow plug is degraded. As a result, the first device may satisfactorily maintain the drivability and the emission of the engine.

[0167] In addition, the first device controls the application voltage value E_{gl} so that the increase amount (the application voltage correction amount E_{glcom}) of the application voltage value E_{gl} does not exceed the predetermined threshold value (application voltage upper limit correction amount $E_{glcommax}$). Thus, since an excessive voltage is prevented from being applied to the glow plug 23, the glow plug 23 may be prevented from being damaged.

[0168] In the first device, the "temperature lower by the predetermined temperature than the average value of the compression end temperatures of the respective cylinders" is employed as the compression end reference temperature T_{tref} . However, the compression end reference temperature T_{tref} is not limited to the temperature. For example, as the compression end reference temperature T_{tref} , the first device may employ any one of the "temperature lower by the predetermined temperature than the average value of the compression end temperatures of the cylinders other than the verification subject cylinder", the "temperature lower by the predetermined temperature than the compression end temperature of one cylinder among the cylinders other than the verification subject cylinder", the "average value of the compression end temperatures of the respective cylinders", the "average value of the compression end temperatures of the cylinders other than the verification subject cylinder", and the "compression end temperature of one cylinder among the cylinders other than the verification subject cylinder".

[0169] Further, in the first device, the "gas constant R of the ideal gas" is employed as the gas constant of the gas in the cylinder. However, the gas constant of the gas in the cylinder is not limited to the gas constant of the ideal gas, and the appropriate value obtained in consideration of the gas (for example, air, an exhaust gas, an uncombusted material, and the like) actually present in the cylinder may be employed as the gas constant of the gas in the cylinder.

(Second embodiment)

[0170] Next, a combustion control device (hereinafter, referred to as a "second device") of a second embodiment of the present invention will be described.

<Outline of devices>

[0171] The second device is applied to the internal combustion engine (see FIGS. 1 and 2) which is similar to the internal combustion engine 10 employing the first device. Accordingly, the specific description of the outline of the device will not be repeated.

<Outline of operation of device>

[0172] (T_{t1} to A_s in the first device, the second device acquires the compression end temperature (T_{t1} to T_{t4}) of the respective cylinders, and acquires the compression end reference temperature T_{tref} based on the compression end temperature. In addition, as in the first device, the second device verifies the degradation degree of the glow plug 23 of the verification subject cylinder by comparing the compression end temperature T_t of the verification subject cylinder with the compression end reference temperature T_{tref} .

[0173] The second device changes the "opening and closing timings of the intake valve 26" in response to the verified degradation degree of the glow plug 23. More specifically, as in the first device, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} , the second device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage". When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", the second device opens the intake valve 26 of the verification subject cylinder at the target valve opening timing V_{ino} determined in response to the operation state of the engine 10 and closes the intake valve 26 at the target valve closing timing V_{inc} determined in a similar way.

[0174] On the other hand, as in the first device, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} , the second device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage". When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the second device allows the "determined target valve closing timing V_{inc} of the intake valve 26" to be close to the air intake bottom dead center by an intake valve closing timing correction amount V_{inccom} determined in response to the degradation degree of the glow plug 23.

[0175] Here, when the intake valve closing timing correction amount V_{inccom} is larger than a predetermined intake valve closing timing upper limit correction amount $V_{inccommax}$, the second device verifies that the degradation degree of the glow plug of the verification subject cylinder is the "third stage". When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the second device allows the "determined target

valve closing timing Vinc of the intake valve 26" to be close to the air intake bottom dead center by the intake valve closing timing upper limit correction amount Vinccommax. In addition, at this time, the second device displays that the "flow plug is in an abnormal condition" on a display device (not illustrated) or the like. The description above is the outline of the operation of the second device.

<Combustion control method>

[0176] Subsequently, the combustion control method employed in the second device will be described prior to the description of the specific operation of the second device.

[0177] As described above, when the glow plug 23 is degraded, the compression end temperature Tt is degraded. Therefore, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the second device performs a change so that the "target valve closing timing Vinc of the intake valve 26 of the verification subject cylinder is close to the air intake bottom dead center by the intake valve closing timing correction amount Vinccom". The intake valve closing timing correction amount Vinccom is determined in response to the degradation degree of the glow plug 23.

[0178] When the target valve closing timing Vinc is changed so as to be close to the air intake bottom dead center, the amount of air suctioned into the verification subject cylinder increases, so that the compression ratio of the verification subject cylinder increases. The compression end temperature Tt increases as the compression ratio increases. In addition, since the intake valve closing timing correction amount Vinccom is determined in response to the degradation degree of the glow plug 23, the target valve closing timing Vinc is changed by the sufficient amount necessary for compensating a decrease in the compression end temperature Tt caused by degradation in the glow plug 23. As a result, the compression end temperature Tt of the verification subject cylinder may be increased to a temperature (that is, the temperature when the degradation degree of the glow plug 23 is the "first stage" and the temperature higher than the compression end reference temperature Ttref) for appropriately igniting the fuel by the right amount.

[0179] In addition, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the second device changes the intake valve closing timing correction amount Vinccom to the intake valve closing timing upper limit correction amount Vinccommax. That is, at this time, the intake valve closing timing correction amount Vinccom is controlled so as not to be larger than the intake valve closing timing upper limit correction amount Vinccommax. Thus, an excessive increase in the compression ratio of the verification subject cylinder may be prevented. As described above, the second device performs the "compression end temperature increasing operation for allowing the target valve closing timing Vinc of the intake valve 26 to be close to the air intake bottom dead center". The description above is the combustion control method employed in the second device.

<Actual operation>

[0180] Hereinafter, the actual operation of the second device will be described.

The second device is different from the first device only in that the "process indicated by the flowchart of FIG. 9" is performed instead of the process indicated by the flowchart of FIG. 3 in the first device and the "series of processes indicated by the flowcharts of FIGS. 10 and 11" are performed instead of the process indicated by the flowchart of FIG. 4 in the first device. Therefore, hereinafter, the differences will be mainly described.

[0181] The CPU 81 is configured to repeatedly perform the respective routines indicated by the flowcharts of FIGS. 5 to 11 at a predetermined timing. In the routines, the CPU 81 uses the glow plug operation flag XGLO and the abnormality occurrence flag XEMG as in the first device. Accordingly, the specific description of the glow plug operation flag XGLO and the abnormality occurrence flag XEMG will not be repeated.

[0182] Hereinafter, on the assumption that the "glow plug operation condition illustrated in FIG. 9 at the current time point is satisfied and the compression end reference temperature Ttref is already acquired by the routines illustrated in FIGS. 5 and 6", the respective routines performed by the CPU 81 will be specifically described.

[0183] The CPU 81 is configured to repeatedly perform the "glow plug control routine" indicated by the flowchart of FIG. 9 whenever a predetermined time elapses. By the routine, the CPU 81 determines whether to operate the glow plug 23 in response to the operation state of the engine 10. In addition, when the glow plug 23 is operated, the CPU 81 applies the voltage of the application voltage value Egl determined in response to the operation state of the engine 10 to the glow plug 23.

[0184] The routine illustrated in FIG. 9 is different from the routine illustrated in FIG. 3 only in that step 320 to step 360 are removed. Therefore, in the step for performing the same process as that of the step illustrated in FIG. 3 in the series of routines, the same reference numerals as those of the step of FIG. 3 are used. The specific description of the steps will not be appropriately repeated.

[0185] Specifically, the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing and proceeds to step 305 so as to determine whether the "glow plug operation condition" is satisfied as in the first device. According to

the above-described assumption, since the glow plug operation condition at the current time point is satisfied, the CPU 81 determines that the determination result is "Yes" in step 305, and proceeds to step 310.

[0186] In step 310, the CPU 81 stores "1" as the value of the glow plug operation flag XGLO and proceeds to step 315 so as to determine and acquire the application voltage value Egl by applying the cooling water temperature THW and the intake air temperature Tin at the current time point to the glow plug application voltage table MapEgl (TFW, Tin) as in the first device.

[0187] Subsequently, the CPU 81 proceeds to step 325 and applies the voltage of the application voltage value Egl to the glow plug 23. Subsequently, the CPU 81 proceeds to step 995 so as to end the present routine once.

[0188] In this way, in the second device, when the glow plug operation condition is satisfied, the voltage of the application voltage value Egl determined in response to the operation state of the engine 10 is applied to the glow plug 23. Thus, the glow plug 23 produces heat, so that the gas in the cylinder is heated. As a result, the compression end temperature Tt increases,

[0189] In addition, the CPU 81 is configured to repeatedly perform the "second-cylinder-internal-temperature correcting routine" indicated by the series of flowcharts of FIGS. 10 and 11 whenever a predetermined time elapses. By the routine, the CPU 81 verifies the degradation degree of the glow plug 23 and changes the "valve closing timing of the intake valve 26" in response to the degradation degree. Specifically, by the routine, the CPU 81 determines the target valve opening timing V_{ino} and the target valve closing timing V_{inc} of the intake valve 26 in response to the operation state of the engine 10, and controls the variable intake timing control device 26a so that the actual valve opening timing of the intake valve 26 is equal to the target valve opening timing V_{ino} and the actual valve closing timing of the intake valve 26 is equal to the target valve closing timing V_{inc}. Also, by the routine, the CPU 81 determines the target valve opening timing V_{exo} and the target valve closing timing V_{exc} of the exhaust valve 28 in response to the operation state of the engine 10, and controls the variable exhaust timing control device 28a so that the actual valve opening timing of the exhaust valve 28 is equal to the target valve opening timing V_{exo} and the actual valve closing timing of the exhaust valve 28 is equal to the target valve closing timing V_{exc}. In addition, by the routine, the CPU 81 allows the "valve closing timing of the intake valve 26" to be close to the air intake bottom dead center in response to the degradation degree of the glow plug 23 when the glow plug 23 is operated.

[0190] The series of routines illustrated in FIGS. 10 and 11 are different from the routine illustrated in FIG. 4 only in that step 1010 to step 1080 are added. Therefore, the same reference numeral as that of the step of FIG. 4 is given to the step for performing the same process as that of the step of FIG. 4 in the series of routines. The specific description of the steps will not be appropriately repeated.

[0191] More specifically, when the CPU 81 starts a process from step 1000 of FIG. 10 at a predetermined timing, the GPU acquires the intake valve target valve opening timing V_{ino} and the intake valve target valve closing timing V_{inc} in step 410, acquires the exhaust valve target valve opening timing V_{exo} and the exhaust valve target valve closing timing V_{exc} in step 420, and proceeds to step 1010.

[0192] Subsequently, in step 1010, the CPU 81 determines whether the compression end reference temperature T_{tref} is acquired at the current time point. According to the above-described assumption, since the compression end reference temperature T_{tref} is acquired, the CPU 81 determines that the determination result is "Yes" in step 1010, and proceeds to step 1020.

[0193] In step the CPU 81 whether compression end T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref}. Then, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref}, the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", and changes the target valve closing timing V_{inc} of the intake valve 26 of the verification subject cylinder to be close to the air intake bottom dead center. In addition, when the change amount of the target valve closing timing V_{inc} exceeds a predetermined threshold value, the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", and displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated). On the other hand, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref}, the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", and does not change the target valve closing timing V_{inc} of the intake valve 26 of the verification subject cylinder.

[0194] Hereinafter, the case will be separately described in more detail.

(Case 2-1) Case of compression end temperature T_t of verification subject cylinder lower than compression end reference temperature T_{tref}

[0195] In this case, the CPU 81 determines that the determination result is "Yes" in step 1020, and proceeds to step 1030. In step 1030, the CPU 81 determines and acquires the intake valve closing timing correction amount V_{inccom} by applying a temperature difference ΔT at the current time point to an intake valve closing timing correction amount table

MapVinc_{com} (ΔT) in which the "relation between the intake valve closing timing correction amount Vinc_{com} and the temperature difference ΔT as a difference between the compression end reference temperature T_{tref} and the compression end temperature T_f " is determined in advance. In the intake valve timing correction amount table MapVinc_{com} (ΔT), the intake valve closing timing correction amount Vinc_{com} is designed to increase as the temperature difference ΔT increases.

In other words, in the intake valve closing timing correction amount table MapVinc_{com} (ΔT), the intake valve closing timing correction amount Vinc_{com} is designed to increase as the degree of degradation in the glow plug 23 increases.

[0196] Subsequently, the CPU 81 proceeds to step 1040 and determines whether the intake valve closing timing correction amount Vinc_{com} is larger than the intake valve closing timing upper limit correction amount Vinc_{commax}.

[0197] When the intake valve closing timing correction amount Vinc_{com} is equal to or smaller than the intake valve closing timing upper limit correction amount Vinc_{commax}, the CPU 81 determines that the determination result is "No" in step 1040, and proceeds to step 1050 so as to change the target valve closing timing Vinc so that the target valve closing timing Vinc is close to the air intake bottom dead center by the intake valve closing timing correction amount Vinc_{com}.

[0198] On the other hand, when the intake valve closing timing correction amount Vinc_{com} is larger than the intake valve closing timing upper limit correction amount Vinc_{commax}, the CPU 81 determines that the determination result is "Yes" in step 1040, and proceeds to step 1060. In step 1060, the CPU 81 stores the intake valve closing timing upper limit correction amount Vinc_{commax} as the value of the intake valve closing timing correction amount Vinc_{com}. That is, when the value of the intake valve closing timing correction amount Vinc_{com} is larger than the intake valve closing timing upper limit correction amount Vinc_{commax}, the value of the intake valve closing timing correction amount Vinc_{com} is changed to the intake valve closing timing upper limit correction amount Vinc_{commax}. That is, in the second device, the upper limit value of the intake valve closing timing correction amount Vinc_{com} is set to the intake valve closing timing upper limit correction amount Vinc_{commax}.

[0199] Subsequently, the CPU 81 proceeds to step 1070, and stores "1" as the value of the abnormality occurrence flag XEMG. Then, in step 1050 subsequent to step 1070, the CPU 81 changes the target valve closing timing Vinc so that the target valve closing timing Vinc is close to the air intake bottom dead center by the intake valve closing timing correction amount Vinc_{com} (in practice, the intake valve closing timing upper limit correction amount Vinc_{commax}).

(Case 2-2) Case of compression end temperature T_t of verification subject cylinder equal to or higher than compression end reference temperature T_{tref}

[0200] In this case, the CPU 81 determines that the determination result is "No" in step 1020, and proceeds to step 1080. The CPU 81 stores zero as the value of the intake valve closing timing correction amount Vinc_{com} in step 1080, and proceeds to step 1050.

[0201] In step 1050, the CPU 81 changes the target valve closing timing Vinc so that the target valve closing timing Vinc is close to the air intake bottom dead center by the intake valve closing timing correction amount Vinc_{com} (in practice, zero). Incidentally, since the intake valve closing timing correction amount Vinc_{com} is zero at the current time point, the target valve closing timing Vinc may not become close to the air intake bottom dead center. That is, the target valve closing timing Vinc is not corrected.

[0202] As described above in the separate cases of "Case 2-1" and "Case 2-2", when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} (that is, the degradation degree of the glow plug 23 is the "second stage"), the target valve closing timing Vinc is corrected in response to the temperature difference ΔT . Here, in this case, when the intake valve closing timing correction amount Vinc_{com} exceeds the intake valve closing timing upper limit correction amount Vinc_{commax} (that is, the degradation degree of the glow plug 23 is the "third stage"), the intake valve closing timing correction amount Vinc_{com} is changed to the intake valve closing timing upper limit correction amount Vinc_{commax}. Here, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} (that is, the degradation degree of the glow plug 23 is the "first stage"), the target valve closing timing Vinc is not corrected. In addition, when the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage", the value of the abnormality occurrence flag XEMG is maintained at "0" stored in the initial routine, and when the degradation degree is the "third stage", "1" is stored as the value of the abnormality occurrence flag XEMG.

[0203] Subsequently, the CPU 81 proceeds to step 430 of FIG. 11 so as to open and close the intake valve 26 at the target valve opening timing V_{ino} and the target valve closing timing Vinc, proceeds to step 440 so as to open and close the exhaust valve 28 at the target valve opening timing V_{exo} and the target valve closing timing V_{exc}, and proceeds to step 1095 so as to end the present routine once. Thus, the compression end temperature increasing operation for allowing the valve closing timing of the intake valve 26 to be close to the air intake bottom dead center is performed.

[0204] In addition, the CPU 81 starts a process from step 700 of FIG. 7 at a predetermined timing, and performs the processes of step 710 to step 760. Thus, as in the first device, the fuel of the predetermined fuel injection amount (Q_p and Q_m) is supplied (injected) to the fuel injection cylinder at the predetermined fuel injection timing (finjp and finjm).

[0205] In addition, when the CPU 81 starts a process from step 800 of FIG. 8 at a predetermined timing, the CPU proceeds to step 810. Here, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "0" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage" in the series of routines illustrated in FIGS. 10 and 11), the CPU 81 determines that the determination result is "Yes" in step 810, and directly proceeds to step 895 so as to end the present routine once.

[0206] On the other hand, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "1" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage" in the series of routines illustrated in FIGS. 10 and 11), the CPU 81 determines that the determination result is "No" in step 810, and proceeds to step 820. In step 820, the CPU 81 displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated) by turning on an alarm lamp or the like. Subsequently, the CPU 81 directly proceeds to step 895 so as to end the present routine once.

[0207] In this way, when the glow plug operation condition is satisfied and the compression end reference temperature T_{ref} is acquired, the degradation degree of the glow plug 23 provided in the verification subject cylinder is verified by comparing the compression end reference temperature T_{ref} with the compression end temperature T_t of the verification subject cylinder.

[0208] When it is verified that the degradation degree of the glow plug 23 is the "first stage" by the degradation verification, the intake valve 26 is closed at the target valve closing timing V_{inc} . On the other hand, when it is verified that the degradation degree of the glow plug 23 is the "second stage" by the degradation verification, the "compression end temperature increasing operation" is performed in which the target valve closing timing V_{inc} of the intake valve 26 is close to the air intake bottom dead center by the intake valve closing timing correction amount V_{inccom} determined in response to the degradation degree of the glow plug 23.

[0209] In addition, when it is verified that the degradation degree of the glow plug 23 is the "third stage" by the degradation verification, the target valve closing timing V_{inc} of the intake valve 26 may become close to the air intake bottom dead center by the predetermined intake valve closing timing upper limit correction amount $V_{inccommax}$, and a display device displays that the "glow plug 23 is in an abnormal condition".

[0210] In contrast thereto, when the glow plug operation condition is not satisfied, the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing and proceeds to step 305, the CPU determines that the determination result is "No" in step 305 and proceeds to step 365. In step 365, the CPU 81 stores "0" as the value of the glow plug operation flag X_{GLO} . Subsequently, the CPU 81 directly proceeds to step 995 so as to end the present routine once. Accordingly, in this case, the glow plug 23 is not operated.

[0211] In addition, in this case, when the CPU 81 starts a process from step 1000 of FIG. 10 at a predetermined timing and proceeds to step 1010 through step 410 and step 420, the CPU determines that the determination result is "No" in step 1010 since the value of the glow plug operation flag X_{GLO} is "0". Then, the CPU 81 proceeds to step 1080 so as to store zero as the value of the intake valve closing timing correction amount V_{inccom} and proceeds to step 1050. Subsequently, the CPU 81 proceeds to step 1095 through step 430 and step 440 of FIG. 11 so as to end the present routine once. Accordingly, in this case, the target valve closing timing V_{inc} is not changed.

[0212] In addition, in this case, as in the first device, the compression end temperature T_t is not estimated, and the compression end reference temperature T_{ref} is not determined. Also, as in the first device, the fuel of the predetermined fuel injection amount (Q_p and Q_m) is supplied (injected) into the fuel injection cylinder at the predetermined fuel injection timing ($finjp$ and $finjm$) as in the case where the glow plug operation condition is satisfied. In addition, as in the first device, the notification of abnormality of the glow plug 23 is not performed.

<Operation and effect of device>

[0213] The second device verifies the degradation degree of the glow plug 23 as in the first device. Then, the second device performs the compression end temperature increasing operation for allowing the target valve closing timing V_{inc} of the intake valve 26 to be close to the air intake bottom dead center by the amount (the intake valve closing timing correction amount V_{inccom}) in response to the degradation degree of the glow plug 23. Thus, since the second device may appropriately increase the compression end temperature T_t in response to the degradation degree of the glow plug 23, the ignition of the fuel may be reliably performed even when the glow plug 23 is degraded.

[0214] In addition, the second device controls the target valve closing timing V_{inc} so that the intake valve closing timing correction amount V_{inccom} does not exceed the predetermined threshold value (intake valve closing timing upper limit correction amount $V_{inccommax}$). Thus, since the target valve closing timing V_{inc} of the intake valve 26 is prevented from becoming too close to the air intake bottom dead center, the compression ratio may be prevented from excessively increasing.

[0215] In addition, the second device may suppress a variation in the combustion between the cylinders even when the glow plug is degraded as in the first device. As a result, the second device may satisfactorily maintain the drivability and the emission of the engine.

[0216] In the second device, as the compression end temperature increasing operation, an "operation allowing the target valve closing timing Vinc of the intake valve 26 to be close to the air intake bottom dead center by the amount (intake valve closing timing correction amount Vinccom) in response to the "degradation degree of the glow plug 23" is performed. The operation includes an operation of retarding the target valve opening timing V_{ino} when the target valve opening timing V_{ino} is earlier than the air intake bottom dead center and an operation of advancing the target valve opening timing V_{ino} when the target valve opening timing V_{ino} is later than the air intake bottom dead center.

(Third embodiment)

[0217] Next, a combustion control device (hereinafter, referred to as a "third device") according to a third embodiment of the present invention will be described.

<Outline of device>

[0218] The third device is applied to the internal combustion engine (see FIGS. 1 and 2) which is similar to the internal combustion engine 10 employing the first device. Accordingly, the specific description of the outline of the device will not be repeated.

<Outline of operation of device>

[0219] The third device acquires the compression end temperatures (T_{t1} to T_{t4}) of the respective cylinders and acquires the compression end reference temperature T_{tref} based on the compression end temperature as in the first device. In addition, the third device verifies the degradation degree of the glow plug 23 of the verification subject cylinder by comparing the compression end temperature T_t of the verification subject cylinder with the compression end reference temperature T_{tref} as in the first device.

[0220] The third device changes the "opening and closing timings of the exhaust valve 28" in response to the verified degradation degree of the glow plug 23. More specifically, the third device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} as in the first device. When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", the third device opens the exhaust valve 28 of the verification subject cylinder at the target valve opening timing V_{exo} determined in response to the operation state of the engine 10 and closes the exhaust valve 28 at the target valve closing timing V_{exc} determined in a similar way.

[0221] On the other hand, the third device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage" when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} as in the first device. When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the second device allows the "determined target valve opening timing V_{exo} of the exhaust valve 28" to be away from the exhaust top dead center by the exhaust valve closing timing correction amount V_{exccom} determined in response to the degradation degree of the glow plug 23.

[0222] Here, the third device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage" when the exhaust valve closing timing correction amount V_{exccom} is larger than the predetermined exhaust valve closing timing upper limit correction amount V_{exccommax}. When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the third device allows the "determined target valve closing timing V_{exc} of the exhaust valve 28" to be away from the exhaust top dead center by the exhaust valve closing timing upper limit correction amount V_{exccommax}. In addition, at this time, the third device displays that the "glow plug is in an abnormal condition" on a display device (not illustrated) or the like. The description above is the outline of the operation of the third device.

<Combustion control method>

[0223] Subsequently, the combustion control method which is employed in the third device will be described before the description of the specific operation of the third device.

[0224] As described above, when the glow plug 23 is degraded, the compression end temperature T_t is degraded. Therefore, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the third device performs a change so that the "target valve closing timing V_{exc} of the exhaust valve 28 of the verification, subject cylinder is away from the exhaust top dead center by the exhaust valve closing timing correction amount V_{exccom}". The exhaust valve closing timing correction amount V_{exccom} is determined in response

to the degradation degree of the glow plug 23.

[0225] When the target valve closing timing V_{exc} is changed so as to be away from the exhaust top dead center, the amount (that is, the inner EGR amount) of the gas remaining in the cylinder among the combusted hot gas (the exhaust gas) increases. In addition, since the exhaust valve closing timing correction amount V_{exccom} is determined in response to the degradation degree of the glow plug 23, the target valve closing timing V_{exc} is changed by the sufficient amount necessary for compensating a decrease in the compression end temperature T_t due to degradation in the glow plug 23. As a result, the compression end temperature T_t of the verification subject cylinder may be increased to the temperature (that is, the temperature when the degradation degree of the glow plug 23 is the "first stage" and the temperature higher than the compression end reference temperature T_{ref}) for appropriately igniting the fuel by the right amount.

[0226] In addition, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the third device changes the exhaust valve closing timing correction amount V_{exccom} to the exhaust valve closing timing upper limit correction amount $V_{exccommax}$. That is, at this time, the exhaust valve closing timing correction amount V_{exccom} is controlled so as not to be larger than the exhaust valve closing timing upper limit correction amount $V_{exccommax}$. Thus, an excessive increase in the inner EGR amount of the verification subject cylinder is prevented. As described above, the third device performs the "compression end temperature increasing operation" for allowing the target valve closing timing V_{exc} of the exhaust valve 28 to be away from the exhaust top dead center". The description above is the combustion control method employed in the third device.

<Actual operation>

[0227] Hereinafter, the actual operation of the third device will be described.

As in the second device, the third device is different from the first device only in that the "process indicated by the flowchart of FIG. 9" is performed instead of the process indicated by the flowchart of FIG. 3 and the "series of processes indicated by the flowcharts of FIGS. 12 and 13" are performed instead of the process indicated by the flowchart of FIG.

4. Therefore, hereinafter, the difference will be mainly described.

[0228] The CPU 81 is configured to repeatedly perform the respective routines indicated by the flowcharts of FIGS. 5 to 9 and FIGS. 12 and 13 at a predetermined timing. The CPU 81 uses the glow plug operation flag X_{GLO} and the abnormality occurrence flag X_{EMG} in the routines as in the first device. Accordingly, the specific description of the glow plug operation flag X_{GLO} and the abnormality occurrence flag X_{EMG} will not be repeated.

[0229] Hereinafter, on the assumption that the "glow plug operation condition illustrated in FIG. 9 at the current time point is satisfied and the compression end reference temperature T_{ref} is already acquired by the routines illustrated in FIGS. 5 and 6", the respective routines performed by the CPU 81 will be described in detail.

[0230] As in the second device, when the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing, since the glow plug operation condition at the current time point is satisfied at the current time point, the application voltage value E_{gl} is determined and acquired by the routine, and the voltage of the application voltage value E_{gl} is applied to the glow plug 23. Thus, the glow plug 23 produces heat, so that the gas in the cylinder is heated. As a result, the compression end temperature T_t increases.

[0231] In addition, the CPU 81 is configured to repeatedly perform the "third cylinder-internal-temperature correcting routine" indicated by the series of flowcharts of FIGS. 12 and 13 whenever a predetermined time elapses. By the routine, the CPU 81 verifies the degradation degree of the glow plug 23, and changes the "valve closing timing of exhaust valve 28" in response to the degradation degree. Specifically, by the routine, the CPU 81 determines the target valve opening timing V_{ino} and the target valve closing timing V_{inc} of the intake valve 26 in response to the operation state of the engine 10, and controls the variable intake timing control device 26a so that the actual valve opening timing of the intake valve 26 is equal to the target valve opening timing V_{ino} and the actual valve closing timing of the intake valve 26 is equal to the target valve closing timing V_{inc} . Also, by the routine, the CPU 81 determines the target valve opening timing V_{exo} and the target valve closing timing V_{exc} of the exhaust valve 28 in response to the operation state of the engine 10, and controls the variable exhaust timing control device 28a so that the actual valve opening timing of the exhaust valve 28 is equal to the target valve opening timing V_{exo} and the actual valve closing timing of the exhaust valve 28 is equal to the target valve closing timing V_{exc} . In addition, by the routine, the CPU 81 allows the "valve closing timing of the exhaust valve 28" to be away from the exhaust top dead center in response to the degradation degree of the glow plug 23 during the operation of the glow plug 23.

[0232] The series of routines illustrated in FIGS. 12 and 13 are different from the routine illustrated in FIG. 4 only in that step 1210 to step 1280 are added. Therefore, in the step for performing the same process as that of the step illustrated in FIG. 4 in the series of routines, the same reference numerals as those of the step of FIG. 4 are used. The specific description of the steps will not be repeated appropriately.

[0233] More specifically, when the CPU 81 starts a process from step 1200 of FIG. 12 at a predetermined timing, the CPU acquires the intake valve target valve opening timing V_{ino} and the intake valve target valve closing timing V_{inc} in step 410, acquires the exhaust valve target valve opening timing V_{exo} and the exhaust valve target valve closing timing

Vexc in step 420, and proceeds to step 1210.

[0234] Subsequently, in step 1210, the CPU 81 determines whether the compression end reference temperature T_{ref} at the current time point is acquired. According to the above-described assumption, since the compression end reference temperature T_{ref} is acquired, the CPU 81 determines that the determination result is "Yes" in step 1210, and proceeds to step 1220.

[0235] In step 1220, the CPU 81 determines whether the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{ref} . Then, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{ref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", and changes the target valve closing timing Vexc of the exhaust valve 28 of the verification subject cylinder so as to be away from the exhaust top dead center. In addition, when the change amount of the target valve closing timing Vexc exceeds a predetermined threshold value, the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", and displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated). On the other hand, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{ref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", and does not change the target valve closing timing Vexc of the exhaust valve 28 of the verification subject cylinder.

[0236] Hereinafter, the case will be separately described in more detail.

(Case 3-1) Case of compression end temperature T_t of verification subject cylinder lower than compression end reference temperature T_{ref}

[0237] In this case, the CPU 81 determines that the determination result is "Yes" in step 1220, and proceeds to step 1230. In step 1230, the CPU 81 determines and acquires the exhaust valve closing timing correction amount Vexccom by applying the temperature difference ΔT at the current time point to an exhaust valve closing timing correction amount table MapVexccom (ΔT) in which the "relation between the exhaust valve closing timing correction amount Vexccom and the temperature difference ΔT as the difference between the compression end reference temperature T_{ref} and the compression end temperature T_t is determined in advance. In the exhaust valve closing timing correction amount table MapVexccom (ΔT), the exhaust valve closing timing correction amount Vexccom is designed to increase as the temperature difference ΔT increases. In other words, in the exhaust valve closing timing correction amount table MapVexccom (ΔT), the exhaust valve closing timing correction amount Vexccom is designed to increase as the degree of degradation in the glow plug 23 increases.

[0238] Subsequently, the CPU 81 proceeds to step 1240, and determines whether the exhaust valve closing timing correction amount Vexccom is larger than the exhaust valve closing timing upper limit correction amount Vexccommax.

[0239] When the exhaust valve closing timing correction amount Vexccom is equal to or smaller than the exhaust valve closing timing upper limit correction amount Vexccommax, the CPU 81 determines that the determination result is "No" in step 1240, and proceeds to step 1250 so as to change the target valve closing timing Vexc so that the target valve closing timing Vexc is away from the exhaust top dead center by the exhaust valve closing timing correction amount Vexccom.

[0240] On the other hand, when the exhaust valve closing timing correction amount Vexccom is larger than the exhaust valve closing timing upper limit correction amount Vexccommax, the CPU 81 determines that the determination result is "Yes" in step 1240, and proceeds to step 1260. In step 1260, the CPU 81 stores the exhaust valve closing timing upper limit correction amount Vexccommax as the value of the exhaust valve closing timing correction amount Vexccom. That is, when the value of the exhaust valve closing timing correction amount Vexccom is larger than the exhaust valve closing timing upper limit correction amount Vexccommax, the value of the exhaust valve closing timing correction amount Vexccom is changed to the exhaust valve closing timing upper limit correction amount Vexccommax. That is, in the third device, the upper limit value of the exhaust valve closing timing correction amount Vexccom is set to the exhaust valve closing timing upper limit correction amount Vexccommax.

[0241] Subsequently, the CPU 81 proceeds to step 1270, and stores "1" as the value of the abnormality occurrence flag XEMG. Then, in step 1250 subsequent to step 1270, the CPU 81 changes the target valve closing timing Vexc so that the target valve closing timing Vexc is away from the exhaust top dead center by the exhaust valve closing timing correction amount Vexccom (in practice, the exhaust valve closing timing upper limit correction amount Vexccommax).

(Case 3-2) Case of compression end temperature T_t of verification subject cylinder equal to or higher than compression end reference temperature T_{ref}

[0242] In this case, the CPU 81 determines that the determination result is "No" in step 1220, and proceeds to step 1280. In step 1280, the CPU 81 stores zero as the value of the exhaust valve closing timing correction amount Vexccom,

and proceeds to step 1250.

[0243] In step 1250, the CPU 81 changes the target valve closing timing Vexc so that the target valve closing timing Vexc is away from the exhaust top dead center by the exhaust valve closing timing correction amount Vexccom (in practice, zero). Incidentally, since the exhaust valve closing timing correction amount Vexccom at the current time point is zero, the target valve closing timing Vexc may not be away from the exhaust top dead center. That is, the target valve closing timing Vexc is not changed.

[0244] As described above in the separate cases of "Case 3-1" and "Case 3-2", when the compression end temperature Tt of the verification subject cylinder is lower than the compression end reference temperature Ttref (that is, the degradation degree of the glow plug 23 is the "second stage"), the target valve closing timing Vexc is corrected in response to the temperature difference ΔT . Here, in this case, when the intake valve closing timing correction amount Vinccom exceeds the intake valve closing timing upper limit correction amount Vinccommax (that is, the degradation degree of the glow plug 23 is the "third stage"), the intake valve closing timing correction amount Vinccom is changed to the intake valve closing timing upper limit correction amount Vinccommax. Here, when the compression end temperature Tt of the verification subject cylinder is equal to or higher than the compression end reference temperature Ttref (that is, the degradation degree of the glow plug 23 is the "first stage"), the target valve closing timing Vexc is not corrected. In addition, when the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage", the value of the abnormality occurrence flag XEMG is maintained at "0" stored in the initial routine, and when the degradation degree is the "third stage", "1" is stored as the value of the abnormality occurrence flag XEMG.

[0245] Subsequently, the CPU 81 proceeds to step 430 of FIG. 13 so as to open and close the intake valve 26 at the target valve opening timing Vino and the target valve closing timing Vinc, proceeds to step 440 so as to open and close the exhaust valve 28 at the target valve opening timing Vexo and the target valve closing timing Vexc, and proceeds to step 1295 so as to end the present routine once. Thus, the compression end temperature increasing operation for allowing the valve closing timing of the exhaust valve 28 to be away from the exhaust top dead center is performed.

[0246] In addition, the CPU 81 starts a process from step 700 of FIG. 7 at a predetermined timing so as to perform the processes of step 710 to step 760. Thus, as in the first device, the fuel of the predetermined fuel injection amount (Qp and Qm) is supplied (injected) into the fuel injection cylinder at the predetermined fuel injection timing (finjp and finjm).

[0247] In addition, when the CPU 81 starts a process from step 800 of FIG. 8 at a predetermined timing, the CPU proceeds to step 810. Here, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "0" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage" in the series of routines illustrated in FIGS. 12 and 13), the CPU 81 determines that the determination result is "Yes" in step 810, and directly proceeds to step 895 so as to end the present routine once.

[0248] On the other hand, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "1" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage" in the series of routines illustrated in FIGS. 12 and 13), the CPU 81 determines that the determination result is "No" in step 810, and proceeds to step 820. In step 820, the CPU 81 displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated) by turning on an alarm lamp or the like. Subsequently, the CPU 81 directly proceeds to step 895 so as to end the present routine once.

[0249] In this way, when the glow plug operation condition is satisfied and the compression end reference temperature Ttref is acquired, the degradation degree of the glow plug 23 provided in the verification subject cylinder is verified by comparing the compression end reference temperature Ttref with the compression end temperature Tt of the verification subject cylinder.

[0250] When it is verified that the degradation degree of the glow plug 23 is the "first stage" by the degradation verification, the exhaust valve 28 is closed at the target valve closing timing Vexc. On the other hand, when it is verified that the degradation degree of the glow plug 23 is the "second stage" by the degradation verification, the "(compression end temperature increasing operation)" is performed which allows the target valve closing timing Vexc of the exhaust valve 28 to be away from the exhaust top dead center by the exhaust valve closing timing correction amount Vexccom determined in response to the degradation degree of the glow plug 23.

[0251] In addition, when it is verified that the degradation degree of the glow plug 23 is the "third stage" by the degradation verification, the target valve closing timing Vexc of the exhaust valve 28 may be away from the exhaust top dead center by predetermined exhaust valve closing timing upper limit correction amount Vexccommax, and a display device displays that the "glow plug 23 is in an abnormal condition".

[0252] Here, when the glow plug operation condition is not satisfied, the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing and proceeds to step 305, the CPU determines that the determination result is "No" in step 305, and proceeds to step 365. In step 365, the CPU 81 stores "0" as the value of the glow plug operation flag XGLO. Subsequently, the CPU 81 directly proceeds to step 995 so as to end the present routine once. Accordingly, in this case, the glow plug 23 is not operated.

[0253] In addition, in this case, the CPU 81 starts a process from step 1200 of FIG. 12 at a predetermined timing, proceeds to step 1210 through step 410 and step 420, and determines that the determination result is "No" in step 1210

since the value of the glow plug operation flag XGLO is "0". Then, the CPU 81 proceeds to step 1280 so as to store zero as the value of the exhaust valve closing timing correction amount Vexccom, and proceeds to step 1250. Subsequently, the CPU 81 proceeds to step 1295 through step 430 and step 440 of FIG. 13 so as to end the present routine once. Accordingly, in this case, the target valve closing timing Vexc is not changed.

[0254] In addition, in this case, as in the first device, the compression end temperature T_t is not estimated, and the compression end reference temperature T_{tref} is not determined. Also, as in the first device, the fuel of the predetermined fuel injection amount (Q_p and Q_m) is supplied (injected) into the fuel injection cylinder at the predetermined fuel injection timing ($finjp$ and $finjm$) as in the case where the glow plug operation condition is satisfied. In addition, as in the first device, the notification of abnormality of the glow plug 23 is not performed.

<Operation and effect of device>

[0255] The third device verifies the degradation degree of the glow plug 23 as in the first device. Then, the third device performs the compression end temperature increasing operation for allowing the target valve closing timing Vexc of the exhaust valve 28 to be away from the exhaust top dead center by the amount (the exhaust valve closing timing correction amount Vexccom) in response to the degradation degree of the glow plug 23. Thus, since the third device may appropriately increase the compression end temperature T_t in response to the degradation degree of the glow plug 23, the ignition of the fuel may be reliably performed even when the glow plug 23 is degraded.

[0256] In addition, the third device controls the target valve closing timing Vexc so that the exhaust valve closing timing correction amount Vexccom does not exceed the predetermined threshold value (the exhaust valve closing timing upper limit correction amount Vexccommax). Thus, since the target valve closing timing Vexc of the exhaust valve 28 is prevented from being excessively away from the exhaust top dead center, the inner EGR amount may be prevented from excessively increasing.

[0257] In addition, the third device may suppress a variation in the combustion between the cylinders even when the glow plug is degraded as in the first device. As a result, the third device may satisfactorily maintain the drivability and the emission of the engine.

[0258] In the third device, as the compression end temperature increasing operation, an "operation for allowing the target valve closing timing Vexc of the exhaust valve 28 to be away from the exhaust top dead center by the amount (the exhaust valve closing timing correction amount Vexccom) in response to the "degradation degree of the glow plug 23" is performed. The operation includes an operation of advancing the target valve closing timing Vexc when the target valve closing timing Vexc is earlier than the exhaust top dead center, an operation of retarding the target valve closing timing Vexc when the target valve closing timing Vexc is later than the exhaust top dead center, an operation of retarding the target valve closing timing Vexc so as to exceed the exhaust top dead center when the target valve closing timing Vexc is earlier than the exhaust top dead center, and an operation of advancing the target valve closing timing Vexc so as to exceed the exhaust top dead center when the target valve closing timing Vexc is later than the exhaust top dead center.

(Fourth embodiment)

[0259] Next, a combustion control device (hereinafter, referred to as a "fourth device") according to a fourth embodiment of the present invention will be described.

<Outline of devices>

[0260] The fourth device is applied to the internal combustion engine (see FIGS. 1 and 2) which is similar to the internal combustion engine 10 employing the first device. Accordingly, the specific description of the outline of the device will not be repeated.

<Outline of operation of device>

[0261] The fourth device acquires the compression end temperatures (T_{t1} to T_{t4}) of the respective cylinders and acquires the compression end reference temperature T_{tref} based on the compression end temperature as in the first device. In addition, the fourth device verifies the degradation degree of the glow plug 23 of the verification subject cylinder by comparing the compression end temperature T_t of the verification subject cylinder with the compression end reference temperature T_{tref} as in the first devices.

[0262] The fourth device changes the "opening and closing timings of the intake valve 26" in response to the verified degradation degree of the glow plug 23. More specifically, the fourth device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" when the compression end temperature T_t of the

verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} as in the first device. When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", the fourth device opens the intake valve 26 of the verification subject cylinder at the target valve opening timing V_{ino} determined in response to the operation state of the engine 10, and closes the intake valve 26 at the target valve closing timing V_{inc} determined in a similar way.

[0263] On the other hand, the fourth device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage" when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} as in the first device. When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the fourth device advances the "determined target valve opening timing V_{ino} of the intake valve 26" relative to the exhaust top dead center by the intake valve opening timing correction amount V_{inocom} determined in response to the degradation degree of the glow plug 23.

[0264] Here, when the intake valve opening timing correction amount V_{inocom} is larger than the predetermined intake valve opening timing upper limit correction amount $V_{inocommax}$, the fourth device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage". When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the fourth device advances the determined target valve opening timing V_{ino} of the intake valve 26 relative to the exhaust top dead center by the intake valve opening timing upper limit correction amount $V_{inocommax}$. In addition, at this time, the fourth device displays that the "glow plug is in an abnormal condition" on a display device (not illustrated) or the like. The description above is the outline of the operation of the fourth device.

<Combustion control method>

[0265] Subsequently, the combustion control method which is employed in the fourth device will be described before the description of the specific operation of the fourth device.

[0266] As described above, when the glow plug 23 is degraded, the compression end temperature T_t is degraded. Therefore, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the fourth device performs a change so that the "target valve opening timing V_{ino} of the exhaust valve 28 of the verification, subject cylinder is advanced relative to the exhaust top dead center by the intake valve opening timing correction amount V_{inocom} ". The intake valve opening timing correction amount V_{inocom} is determined in response to the degradation degree of the glow plug 23.

[0267] When the target valve opening timing V_{ino} is changed so as to be earlier than the exhaust top dead center, the combusted hot gas (the exhaust gas) is pushed toward the intake passage during a period (that is, the exhaust stroke) until the piston in the cylinder reaches the exhaust top dead center from the opening of the intake valve 26. The amount of the exhaust gas pushed toward the intake passage increases with an increase in the amount of advancing the valve opening timing of the intake valve 26 relative to the exhaust top dead center. The exhaust gas pushed toward the intake passage is suctioned into the cylinder together with air (new air) in the intake stroke. As a result, as in the third device, a part of the hot exhaust gas remains in the cylinder. In addition, since the intake valve opening timing correction amount V_{inocom} is determined in response to the degradation degree of the glow plug 23, the target valve opening timing V_{ino} is changed by the sufficient amount necessary for compensating a decrease in the compression end temperature T_t due to degradation in the glow plug 23. As a result, the compression end temperature T_t of the verification subject cylinder may be increased to the temperature (that is, the temperature when the degradation degree of the glow plug 23 is the "first stage" and the temperature higher than the compression end reference temperature T_{tref}) for appropriately igniting the fuel by the right amount.

[0268] In addition, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the fourth device changes the intake valve opening timing correction amount V_{inocom} to the intake valve opening timing upper limit correction amount $V_{inocommax}$. That is, at this time, the intake valve opening timing correction amount V_{inocom} is controlled so as not to be larger than the intake valve opening timing upper limit correction amount $V_{inocommax}$. Thus, an excessive increase in the amount of the exhaust gas remaining in the verification subject cylinder is prevented. As described above, the fourth device performs the "compression end temperature increasing operation of advancing the target valve opening timing V_{ino} of the intake valve 26 relative to the exhaust top dead center". The description above is the combustion control method employed in the fourth device.

<Actual operation>

[0269] Hereinafter, the actual operation of the fourth device will be described.

As in the second device, the fourth device is different from the first device only in that the "process indicated by the flowchart of FIG. 9" is performed instead of the process indicated by the flowchart of FIG. 3 in the first device and the "series of processes indicated by the flowcharts of FIGS. 14 and 15" are performed instead of the process indicated by

the flowchart of FIG. 4 in the first device. Therefore, hereinafter, the difference will be mainly described.

[0270] The CPU 81 is configured to repeatedly perform the respective routines indicated by the flowcharts of FIGS. 5 to 9 and FIGS. 14 and 15 at a predetermined timing. The CPU 81 uses the glow plug operation flag XGLO and the abnormality occurrence flag XEMG in the routines as in the first device. Accordingly, the specific description of the glow plug operation flag XGLO and the abnormality occurrence flag XEMG will not be repeated.

[0271] Hereinafter, on the assumption that the "glow plug operation condition illustrated in FIG. 9 at the current time point is satisfied and the compression end reference temperature T_{tref} is already acquired by the routines illustrated in FIGS. 5 and 6", the respective routines performed by the CPU 81 will be described in detail.

[0272] As in the second device, when the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing, since the glow plug operation condition at the current time point is satisfied at the current time point, the application voltage value E_{gl} is determined and acquired by the routine, and the voltage of the application voltage value E_{gl} is applied to the glow plug 23. Thus, the glow plug 23 produces heat, so that the gas in the cylinder is heated. As a result, the compression end temperature T_t increases,

[0273] In addition, the CPU 81 is configured to repeatedly perform the "fourth cylinder-internal-temperature correcting routine" which is indicated by the series of flowcharts of FIGS. 14 and 15 whenever a predetermined time elapses. By the routine, the CPU 81 verifies the degradation degree of the glow plug 23, and changes the "valve opening timing of the intake valve 26" in response to the degradation degree. Specifically, by the routine, the CPU 81 determines the target valve opening timing V_{ino} and the target valve closing timing V_{inc} of the intake valve 26 in response to the operation state of the engine 10, and controls the variable intake timing control device 26a so that the actual valve opening timing of the intake valve 26 is equal to the target valve opening timing V_{ino} and the actual valve closing timing of the intake valve 26 is equal to the target valve closing timing V_{inc} . Also, by the routine, the CPU 81 determines the target valve opening timing V_{exo} and the target valve closing timing V_{exc} of the exhaust valve 28 in response to the operation state of the engine 10, and controls the variable exhaust timing control device 28a so that the actual valve opening timing of the exhaust valve 28 is equal to the target valve opening timing V_{exo} and the actual valve closing timing of the exhaust valve 28 is equal to the target valve closing timing V_{exc} . In addition, by the routine, the CPU 81 advances the "valve opening timing of the intake valve 26" relative to the exhaust top dead center in response to the degradation degree of the glow plug 23 during the operation of the glow plug 23.

[0274] The series of routines illustrated in FIGS. 14 and 15 are different from the routine illustrated in FIG. 4 only in that step 1410 to step 1470 are added. Therefore, in the step for performing the same process as that of the step illustrated in FIG. 4 in the series of routines, the same reference numerals as those of the step of FIG. 4 are used. The specific description of the steps will not be repeated appropriately.

[0275] More specifically, when the CPU 81 starts a process from step 1400 of FIG. 14 at a predetermined timing, the CPU acquires the intake valve target valve opening timing V_{ino} and the intake valve target valve closing timing V_{inc} in step 410, acquires the exhaust valve target valve opening timing V_{exo} and the exhaust valve target valve closing timing V_{exc} in step 420, and proceeds to step 1410.

[0276] Subsequent, in step 1410, the CPU 81 determines whether the compression end reference temperature T_{tref} at the current time point is acquired. According to the above-described assumption, since the compression end reference temperature T_{tref} is already acquired, the CPU 81 determines that the determination result is "Yes" in step 1410, and proceeds to step 1420.

[0277] In step 1420, the CPU 81 determines whether the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} . Then, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", and performs a change so that the target valve opening timing V_{ino} of the intake valve 26 of the verification subject cylinder is earlier than the exhaust top dead center. In addition, when the change amount of the target valve opening timing V_{ino} exceeds a predetermined threshold value, the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", and displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated). On the other hand, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", and does not change the target valve opening timing V_{ino} of the intake valve 26 of the verification subject cylinder.

[0278] When the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} , the CPU 81 determines that the determination result is "Yes" in step 1420, and proceeds to step 1430. In step 1430, the CPU 81 determines and acquires the intake valve opening timing correction amount V_{inocom} by applying the temperature difference ΔT and the target valve opening timing V_{ino} at the current time point to an intake valve opening timing correction amount table $Map_{V_{inocom}}(\Delta T, V_{ino})$ in which the "relation between the intake valve opening timing correction amount V_{inocom} , the target valve opening timing V_{ino} , and the temperature difference ΔT as a difference between the compression end reference temperature T_{tref} and the compression end

temperature T_t is determined in advance. In the intake valve opening timing correction amount table MapVinocom (ΔT , V_{ino}), the intake valve opening timing correction amount Vinocom is designed to satisfy the following (Condition 4-1 to Condition 4-3).

[0279]

(Condition 4-1) The intake valve opening timing correction amount Vinocom increases as the temperature difference ΔT increases.

(Condition 4-2) When the target valve opening timing V_{ino} is earlier than the exhaust top dead center, Condition 1 is satisfied when the intake valve opening timing correction amount Vinocom is earlier than the target valve opening timing V_{ino}.

(Condition 4-3) When the target valve opening timing V_{ino} is later than the exhaust top dead center, Condition 1 is satisfied when the intake valve opening timing correction amount Vinocom is earlier than the exhaust top dead center,

[0280] Subsequently, the CPU 81 proceeds to step 1440, and determines whether the intake valve opening timing correction amount Vinocom is larger than the intake valve opening timing upper limit correction amount Vinocommax.

[0281] When the intake valve opening timing correction amount Vinocom is equal to or smaller than the intake valve opening timing upper limit correction amount Vinocommax, the CPU 81 determines that the determination result is "No" in step 1440, and proceeds to step 1450 so as to change the target valve opening timing V_{ino} so that the target valve opening timing V_{ino} is earlier than the exhaust top dead center by the intake valve opening timing correction amount Vinocom.

[0282] On the other hand, when the intake valve opening timing correction amount Vinocom is larger than the intake valve opening timing upper limit correction amount Vinocommax, the CPU 81 determines that the determination result is "Yes" in step 1440, and proceeds to step 1460. In step 1460, the CPU 81 stores the intake valve opening timing upper limit correction amount Vinocommax. as the value of the intake valve opening timing correction amount Vinocom. That is, when the value of the intake valve opening timing correction amount Vinocom is larger than the intake valve opening timing upper limit correction amount Vinocommax, the value of the intake valve opening timing correction amount Vinocom is changed to the intake valve opening timing upper limit correction amount Vinocommax.. That is, in the fourth device, the upper limit value of the intake valve opening timing correction amount Vinocom is set to the intake valve opening timing upper limit correction amount Vinocommax.

[0283] Subsequently, the CPU 81 proceeds to step 1470, and stores "1" as the value of the abnormality occurrence flag XEMG. Then, in step 1450 subsequent to step 1470, the CPU 81 changes the target valve opening timing V_{ino} so that the target valve opening timing V_{ino} is earlier than the exhaust top dead center by the intake valve opening timing correction amount Vinocom (in practice, the intake valve opening timing upper limit correction amount Vinocommax). Subsequently, the CPU 81 proceeds to step 430 of FIG. 15.

[0284] On the other hand, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} , the CPU 81 determines that the determination result is "No" in step 1420, and directly proceeds to step 430 of FIG. 15.

[0285] As described above, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} (that is, the degradation degree of the glow plug 23 is the "second stage"), the target valve opening timing V_{ino} is corrected in response to the temperature difference ΔT and the target valve opening timing V_{ino}. Here, in this case, when the intake valve opening timing correction amount Vinocom exceeds the intake valve opening timing upper limit correction amount Vinocommax. (that is, the degradation degree of the glow plug 23 is the "third stage"), the intake valve opening timing correction amount Vinocom is changed to the intake valve opening timing upper limit correction amount Vinocommax. Here, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} (that is, the degradation degree of the glow plug 23 is the "first stage"), the target valve opening timing V_{ino} is not corrected. In addition, when the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage", the value of the abnormality occurrence flag XEMG is maintained at "0" stored in the initial routine, and when the degradation degree is the "third stage", "1" is stored as the value of the abnormality occurrence flag XEMG.

[0286] Subsequently, the CPU 81 opens and closes the intake valve 26 at the target valve opening timing V_{ino} and the target valve closing timing V_{inc} in step 430 of FIG. 15, proceeds to step 440 so as to open and close the exhaust valve 28 at the target valve opening timing V_{exo} and the target valve closing timing V_{exc}, and proceeds to step 1495 so as to end the present routine once. Thus, the compression end temperature increasing operation for allowing the valve opening timing of the intake valve 26 to be earlier than the exhaust top dead center is performed.

[0287] In addition, the CPU 81 starts a process from step 700 of FIG. 7 at a predetermined timing, and performs the processes of step 710 to step 760. Thus, as in the first device, the fuel of the predetermined fuel injection amount (Q_p and Q_m) is supplied (injected) into the fuel injection cylinder at the predetermined fuel injection timing (finjp and finjm).

[0288] In addition, when the CPU 81 starts a process from step 800 of FIG. 8 at a predetermined timing, the CPU

proceeds to step 810. Here, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "0" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage" in the series of routines illustrated in FIGS. 14 and 15), the CPU 81 determines that the determination result is "Yes" in step 810, and directly proceeds to step 895 so as to end the present routine once.

[0289] On the other hand, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "1" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage" in the series of routines illustrated in FIGS. 14 and 15), the CPU 81 determines that the determination result is "No" in step 810, and proceeds to step 820. In step 820, the CPU 81 displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated) by turning on an alarm lamp or the like. Subsequently, the CPU 81 directly proceeds to step 895 so as to end the present routine once.

[0290] In this way, when the glow plug operation condition is satisfied and the compression end reference temperature T_{ref} is acquired, the degradation degree of the glow plug 23 provided in the verification subject cylinder is verified by comparing the compression end reference temperature T_{ref} with the compression end temperature T_t of the verification subject cylinder.

[0291] When it is verified that the degradation degree of the glow plug 23 is the "first stage" by the degradation verification, the intake valve 26 is closed at the target valve opening timing V_{ino} . On the other hand, when it is verified that the degradation degree of the glow plug 23 is the "second stage" by the degradation verification, the "compression end temperature increasing operation" of allowing the valve opening timing of the intake valve 26 to be earlier than the exhaust top dead center by the intake valve opening timing correction amount V_{inocom} determined in response to the degradation degree of the glow plug 23.

[0292] In addition, when it is verified that the degradation degree of the glow plug 23 is the "third stage" by the degradation verification, the valve opening timing of the intake valve 26 becomes earlier than the exhaust top dead center by the predetermined intake valve opening timing upper limit correction amount $V_{inocommax}$, and a display device displays that the "glow plug 23 is in an abnormal condition".

[0293] Here, in a case where the glow plug operation condition is not satisfied, when the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing and proceeds to step 305, the CPU determines that the determination result is "No" in step 305, and proceeds to step 365. In step 365, the CPU 81 stores "0" as the value of the glow plug operation flag X_{GLO} . Subsequently, the CPU 81 directly proceeds to step 995 so as to end the present routine once. According, in this case, the glow plug 23 is not operated.

[0294] In addition, in this case, when the CPU 81 starts a process from step 1200 of FIG. 14 at a predetermined timing and proceeds to step 1410 through step 410 and step 420, the CPU determines that the determination result is "No" in step 1410 since the value of the glow plug operation flag X_{GLO} is "0". Then, the CPU 81 proceeds to step 1495 through step 430 and step 440 of FIG. 15 so as to end the present routine once. Accordingly, in this case, the target valve opening timing V_{ino} is not changed.

[0295] In addition, in this case, as in the first device, the compression end temperature T_t is not estimated, and the compression end reference temperature T_{ref} is not determined. Also, as in the first device, the fuel of the predetermined fuel injection amount (Q_p and Q_m) is supplied (injected) into the fuel injection cylinder at the predetermined fuel injection timing ($finjp$ and $finjm$) as in the case where the glow plug operation condition is satisfied. In addition, as in the first device, the notification of abnormality of the glow plug 23 is not performed.

<Operation and effect of device>

[0296] The fourth device verifies the degradation degree of the glow plug 23 as in the first device. Then, the fourth device performs the compression end temperature increasing operation for allowing the target valve opening timing V_{ino} of the intake valve 26 to be earlier than the exhaust top dead center by the amount (the intake valve opening timing correction amount V_{inocom}) in response to the degradation degree of the glow plug 23. Thus, since the fourth device may appropriately increase the compression end temperature T_t in response to the degradation degree of the glow plug 23, the ignition of the fuel may be reliably performed even when the glow plug 23 is degraded.

[0297] In addition, the fourth device controls the target valve opening timing V_{ino} so that the intake valve opening timing correction amount V_{inocom} does not exceed the predetermined threshold value (the intake valve opening timing upper limit correction amount $V_{inocommax}$). Thus, since the target valve opening timing V_{ino} of the intake valve 26 is prevented from being excessively earlier than the exhaust top dead center, the amount of the exhaust gas remaining in the cylinder may be prevented from excessively increasing.

[0298] In addition, the fourth device may suppress a variation in the combustion between the cylinders even when the glow plug is degraded as in the first device. As a result, the fourth device may satisfactorily maintain the drivability and the emission of the engine.

[0299] In the fourth device, there is an "operation for allowing the target valve opening timing V_{ino} of the intake valve 26 to be earlier than the exhaust top dead center by the amount (the intake valve opening timing correction amount

Vinocom) in response to the "degradation degree of the glow plug 23" as the compression end temperature increasing operation.

[0300] In the fourth device, as the compression end temperature increasing operation, the "operation for allowing the target valve opening timing V_{ino} of the intake valve 26 to be earlier than the exhaust top dead center by the amount (the intake valve opening timing correction amount Vinocom) in response to the degradation degree of the glow plug 23" is performed. The operation includes an operation of advancing the target valve opening timing V_{ino} when the target valve opening timing V_{ino} is earlier than the exhaust top dead center and an operation of advancing the target valve opening timing V_{ino} when the target valve opening timing V_{ino} is later than the exhaust top dead center.

(Fifth embodiment)

[0301] Next, a combustion control device (hereinafter, referred to as a "fifth device") according to a fifth embodiment of the present invention will be described.

<Outline of device>

[0302] The fifth device is applied to the internal combustion engine (see FIGS. 1 and 2) which is similar to the internal combustion engine 10 employing the first device. Accordingly, the specific description of the outline of the device will be omitted.

<Outline of operation of device>

[0303] The fifth device acquires the compression end temperatures (T_{t1} to T_{t4}) of the respective cylinders and acquires the compression end reference temperature T_{tref} based on the compression end temperature as in the first device. In addition, the fifth device verifies the degradation degree of the glow plug 23 of the verification subject cylinder by comparing the compression end temperature T_t of the verification subject cylinder with the compression end reference temperature T_{tref} as in the first device.

[0304] The fifth device changes the "pilot injection amount Q_p" in response to the verified degradation degree of the glow plug 23. More specifically, the fifth device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} as in the first device. When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", the fifth device injects the fuel of the injection amount (the pilot injection amount Q_p and the main injection amount Q_m) determined in response to the operation state of the engine 10 into the verification subject cylinder at the injection timing (the pilot injection timing fin_{jp} and the main injection timing fin_{jm}) determined in a similar way.

[0305] On the other hand, the fifth device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage" when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} as in the first device. When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the second device increases the "determined pilot injection amount Q_p" by the pilot injection correction amount Q_{pcom} determined in response to the degradation degree of the glow plug 23.

[0306] Here, when the pilot injection correction amount Q_{pcom} is larger than the predetermined pilot injection upper limit correction amount Q_{pcommax}, the fifth device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage". When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the fifth device increases the "determined pilot injection amount Q_p" by the pilot injection upper limit correction amount Q_{pcommax}. In addition, at this time, the fifth device displays that the "glow plug is in an abnormal condition" on a display device (not illustrated) or the like. The description above is the outline of the operation of the fifth device.

<Combustion control method>

[0307] Subsequently, the combustion control method which is employed in the fifth device will be described before the description of the specific operation of the fifth device.

[0308] As described above, when the glow plug 23 is degraded, the compression end temperature T_t is lowered. Therefore, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the fifth device performs a change so that the "pilot injection amount Q_p of the verification subject cylinder increases by the pilot injection correction amount Q_{pcom}". The pilot injection correction amount Q_{pcom} is determined in response to the degradation degree of the glow plug 23.

[0309] The pilot-injected fuel increases the mixture gas temperature by the pre-self-ignition reaction. For this reason, when the pilot injection amount Q_p is changed so as to increase, the increase amount of the temperature of the gas in the cylinder may be increased due to the pre-self-ignition reaction. In addition, since the pilot injection correction amount Q_{pcom} is determined in response to the degradation degree of the glow plug 23, the pilot injection amount Q_p is changed by the sufficient amount necessary for compensating a decrease in the compression end temperature T_t due to degradation in the glow plug 23. As a result, the compression end temperature T_t of the verification subject cylinder may be increased to the temperature (that is, the temperature when the degradation degree of the glow plug 23 is the "first stage" and the temperature higher than the compression end reference temperature T_{tref}) for appropriately igniting the fuel by the right amount.

[0310] In addition, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the fifth device changes the pilot injection correction amount Q_{pcom} to the pilot injection upper limit correction amount $Q_{pcommax}$. That is, at this time, the pilot injection correction amount Q_{pcom} is controlled so as not to be larger than the pilot injection upper limit correction amount $Q_{pcommax}$. Thus, since an excessive increase in the pilot injection amount Q_p is prevented, degradation in the fuel efficiency may be prevented. In this way, the fifth device performs the compression end temperature increasing operation of increasing the pilot injection amount Q_p . The description above is the combustion control method employed in the fifth device.

<Actual operation>

[0311] Hereinafter, the actual operation of the fifth device will be described, As in the second device, the fifth device is different from the first device only in that the "process indicated by the flowchart of FIG. 9" is performed instead of the process indicated by the flowchart of FIG. 3 in the first embodiment and the "series of processes indicated by the flowcharts of FIGS. 16 and 17" are performed instead of the process indicated by the flowchart of FIG. 7 in the first device. Therefore, hereinafter, the difference will be mainly described.

[0312] The CPU 81 is configured to repeatedly perform the respective routines indicated by the flowcharts of FIGS. 4 to 6 and FIGS. 8, 9, 16, and 17 at a predetermined timing. The GPU 81 uses the glow plug operation flag X_{GLO} and the abnormality occurrence flag X_{EMG} in the routines as in the first device. Accordingly, the specific description of the glow plug operation flag X_{GLO} and the abnormality occurrence flag X_{EMG} will be omitted.

[0313] Hereinafter, on the assumption that the "glow plug operation condition illustrated in FIG. 9 at the current time point is satisfied and the compression end reference temperature T_{tref} is already acquired by the routines illustrated in FIGS. 5 and 6", the respective routines performed by the CPU 81 will be described in detail.

[0314] As in the first device, when the CPU 81 starts a process from step 400 of FIG. 4 at a predetermined timing, the CPU determines and acquires the target opening and closing timings of the intake valve 26 and the exhaust valve 28, and controls a variable intake timing device 26a and a variable exhaust timing device 28a so that the intake valve 26 and the exhaust valve 28 are opened and closed at the target opening and closing timings.

[0315] In addition, as in the second device, when the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing, since the glow plug operation condition at the current time point is satisfied according to the assumption, the application voltage value E_{gl} is determined and acquired by the routine, and the voltage of the application voltage value E_{gl} is applied to the glow plug 23. Thus, the glow plug 23 produces heat, so that the gas in the cylinder is heated. As a result, the compression end temperature T_t increases.

[0316] In addition, the CPU 81 is configured to repeatedly perform the "fifth cylinder-internal-temperature correcting routine" indicated by the series of flowcharts of FIGS. 16 and 17 whenever a predetermined time elapses. By the routine, the CPU 81 verifies the degradation degree of the glow plug 23, and changes the "pilot injection amount Q_p " in response to the degradation degree. Specifically, by the routine, the CPU 81 determines the fuel injection amount (the pilot injection amount Q_p and the main injection amount Q_m) and the fuel injection timing (the pilot injection timing fin_{jp} and the main injection timing fin_{jm}) in response to the operation state of the engine 10, injects the fuel of the pilot injection amount Q_p from the injector 22 at the pilot injection timing fin_{jp} , and injects the fuel of the main injection amount Q_m from the injector 22 at the main injection timing fin_{jm} . In addition, by the routine, the CPU 81 increases the "pilot injection amount Q_p " in response to the degradation degree of the glow plug 23 during the operation of the glow plug 23.

[0317] The series of routines illustrated in FIGS. 16 and 17 are different from the routine illustrated in FIG. 7 only in that step 1610 to step 1680 are added. Therefore, in the step for performing the same process as that of the step illustrated in FIG. 7 in the series of routines, the same reference numerals as those of the step of FIG. 7 are used. The specific description of the steps will be appropriately omitted.

[0318] More specifically, when the CPU 81 starts a process from step 1600 of FIG. 16 at a predetermined timing, the CPU acquires the pilot injection amount Q_p and the main injection amount Q_m in step 710, acquires the pilot injection timing fin_{jp} and the main injection timing fin_{jm} in step 720, and proceeds to step 1610.

[0319] Subsequently, in step 1610, the CPU 81 determines whether the compression end reference temperature T_{tref} at the current time point is acquired. According to the above-described assumption, since the compression end reference

temperature T_{tref} is already acquired, the CPU 81 determines that the determination result is "Yes" in step 1610, and proceeds to step 1620.

[0320] In step 1620, the CPU 81 determines whether the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} . Then, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", and changes the pilot injection amount Q_p of the verification subject cylinder so that it increase. In addition, when the change amount of the pilot injection amount Q_p exceeds a predetermined threshold value, the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", and displays that the "glow plug 23 is in an abnormal conditions" on a display device (not illustrated). On the other hand, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", and does not change the pilot injection amount Q_p of the verification subject cylinder.

[0321] Hereinafter, the case will be separately described in more detail.

(Case 5-1) Case of compression end temperature T_t of verification subject cylinder lower than compression end reference temperature T_{tref}

[0322] In this case, the CPU 81 determines that the determination result is "Yes" in step 1620, and proceeds to step 1630. In step 1630, the CPU 81 determines and acquires the pilot injection correction amount Q_{pcom} by applying the temperature difference ΔT at the current time point to a pilot injection correction amount table $MapQ_{pcom}(\Delta T)$ in which the "relation between the pilot injection correction amount Q_{pcom} and the temperature difference ΔT as a difference between the compression end reference temperature T_{tref} and the compression end temperature T_t " is determined in advance. In the pilot injection correction amount table $MapQ_{pcom}(\Delta T)$, the pilot injection correction amount Q_{pcom} is designed to increase as the temperature difference ΔT increases. In other words, in the pilot injection correction amount table $MapQ_{pcom}(\Delta T)$, the pilot injection correction amount Q_{pcom} is designed to increase as the degree of degradation in the glow plug 23 increases.

[0323] Subsequently, the CPU 81 proceeds to step 1640, and determines whether the pilot injection correction amount Q_{pcom} is larger than the pilot injection upper limit correction amount $Q_{pcommax}$.

[0324] When the pilot injection correction amount Q_{pcom} is equal to or smaller than the pilot injection upper limit correction amount $Q_{pcommax}$, the CPU 81 determines that the determination result is "No" in step 1640, and proceeds to step 1650 so as to change the pilot injection amount Q_p so that the pilot injection amount Q_p increases by the pilot injection correction amount Q_{pcom} .

[0325] On the other hand, when the pilot injection correction amount Q_{pcom} is larger than the pilot injection upper limit correction amount $Q_{pcommax}$, the CPU 81 determines that the determination result is "Yes" in step 1640, and proceeds to step 1660. In step 1660, the CPU 81 stores the pilot injection upper limit correction amount $Q_{pcommax}$ as the value of the pilot injection correction amount Q_{pcom} . That is, when the value of the pilot injection correction amount Q_{pcom} is larger than the pilot injection upper limit correction amount $Q_{pcommax}$, the value of the pilot injection correction amount Q_{pcom} is changed to the pilot injection upper limit correction amount $Q_{pcommax}$. That is, in the fifth device, the upper limit value of the pilot injection correction amount Q_{pcom} is set to the pilot injection upper limit correction amount $Q_{pcommax}$.

[0326] Subsequently, the CPU 81 proceeds to step 1670 so as to store "1" as the value of the abnormality occurrence flag XEMG. Then, in step 1650 subsequent to step 1670, the CPU 81 changes the pilot injection amount Q_p so that the pilot injection amount Q_p increases by the pilot injection correction amount Q_{pcom} (in practice, the pilot injection upper limit correction amount $Q_{pcommax}$).

(Case 5-2) Case of compression end temperature T_t of verification subject cylinder equal to or higher than compression end reference temperature T_{tref}

[0327] In this case, the CPU 81 determines that the determination result is "No" in step 1620, and proceeds to step 1680. In step 1680, the CPU 81 stores zero as the value of the pilot injection correction amount Q_{pcom} , and proceeds to step 1650.

[0328] In step 1650, the CPU 81 changes the pilot injection amount Q_p so that the pilot injection amount Q_p increases by the pilot injection correction amount Q_{pcom} (in practice, zero). Incidentally, since the pilot injection correction amount Q_{pcom} at the current time point is zero, the pilot injection amount Q_p does not increase. That is, the pilot injection amount Q_p is not changed.

[0329] As described above in the separate cases of "Case 5-1" and "Case 5-2", when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} (that is, the degra-

gradation degree of the glow plug 23 is the "second stage"), the pilot injection amount Q_p is corrected in response to the temperature difference ΔT . Here, in this case, when the pilot injection correction amount Q_{pcom} exceeds the pilot injection upper limit correction amount $Q_{pcommax}$ (that is, the degradation degree of the glow plug 23 is the "third stage"), the pilot injection correction amount Q_{pcom} is changed to the pilot injection upper limit correction amount $Q_{pcommax}$. Here, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} (that is, the degradation degree of the glow plug 23 is the "first stage"), the pilot injection amount Q_p is not corrected. In addition, when the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage", the value of the abnormality occurrence flag XEMG is maintained at "0" stored in the initial routine, and when the degradation degree is the "third stage", "1" is stored as the value of the abnormality occurrence flag XEMG.

[0330] Subsequently, as in the first device, the CPU 81 performs the processes of step 730 to step 760 of FIG. 17, and injects the fuel of the fuel injection amount (the pilot injection amount Q_p and the main injection amount Q_m) at the fuel injection timing (the pilot injection timing $finjp$ and the main injection timing $finjm$) from the injector 22 provided in the fuel injection cylinder. Thus, the compression end temperature increasing operation of increasing the pilot injection amount Q_p is performed.

[0331] In addition, when the CPU 81 starts a process from step 800 of FIG. 8 at a predetermined timing, the CPU proceeds to step 810. Here, when the value of the abnormality occurrence flag XEMG at the current time point is "0" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage" in the series of routines of FIGS. 16 and 17), the CPU 81 determines that the determination result is "Yes" in step 810, and directly proceeds to step 895 so as to end the present routine once.

[0332] On the other hand, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "1" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage" in the series of routines of FIGS. 16 and 17), the CPU 81 determines that the determination result is "No" in step 810, and proceeds to step 820. In step 820, the CPU 81 displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated) by turning on an alarm lamp or the like. Subsequently, the CPU 81 directly proceeds to step 895 so as to end the present routine once.

[0333] In this way, when the glow plug operation condition is satisfied and the compression end reference temperature T_{tref} is acquired, the degradation degree of the glow plug 23 provided in the verification subject cylinder is verified by comparing the compression end reference temperature T_{tref} with the compression end temperature T_t of the verification subject cylinder.

[0334] When it is verified that the degradation degree of the glow plug 23 is the "first stage" by the degradation verification, the pilot injection amount Q_p is not changed. On the other hand, when it is verified that the degradation degree of the glow plug 23 is the "second stage" by the degradation verification, the "compression end temperature increasing operation" of increasing the pilot injection amount Q_p by the pilot injection correction amount Q_{pcom} determined in response to the degradation degree of the glow plug 23 is performed.

[0335] In addition, when it is verified that the degradation degree of the glow plug 23 is the "third stage" by the degradation verification, the pilot injection amount Q_p increases by the predetermined pilot injection upper limit correction amount $Q_{pcommax}$, and a display device displays that the "glow plug 23 is in an abnormal condition".

[0336] Here, when the glow plug operation conditions is not satisfied, the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing and proceeds to step 305, the CPU determines that the determination result is "No" in step 305, and proceeds to step 365. In step 365, the CPU 81 stores "0" as the value of the glow plug operation flag XGLO. Subsequently, the CPU 81 directly proceeds to step 995 so as to end the present routine once. Accordingly, in this case, the glow plug 23 is not operated.

[0337] In addition, in this case, when the CPU 81 starts a process from step 1600 of FIG. 16 at a predetermined timing and proceeds to step 1610 through step 710 and step 720, the CPU determines that the determination result is "No" in step 1610 since the value of the glow plug operation flag XGLO is "0". Then, the CPU 81 proceeds to step 1680 so as to store zero as the value of the pilot injection correction amount Q_{pcom} , and proceeds to step 1650. Subsequently, the CPU 81 performs the processes of step 730 to step 760 of FIG. 17, and proceeds to step 1695 so as to end the present routine once. Accordingly, in this case, the pilot injection amount Q_p is not changed.

[0338] In addition, in this case, as in the first device, the compression end temperature T_t is not estimated, and the compression end reference temperature T_{tref} is not determined. Also, as in the first device, the intake valve 26 and the exhaust valve 28 are opened and closed as in the case where the glow plug operation condition is satisfied. In addition, as in the first device, the notification of abnormality of the glow plug 23 is not performed.

<Operation and effect of device>

[0339] The fifth device verifies the degradation degree of the glow plug 23 as in the first device. Then, the fifth device performs the compression end temperature increasing operation of increasing the pilot injection amount Q_p by the

amount (the pilot injection correction amount Q_{pcom}) in response to the degradation degree of the glow plug 23. Thus, since the fifth device may appropriately increase the compression end temperature T_t in response to the degradation degree of the glow plug 23, the ignition of the fuel may be reliably performed even when the glow plug 23 is degraded.

[0340] In addition, the fifth device controls the pilot injection amount Q_p so that the pilot injection correction amount Q_{pcom} does not exceed the predetermined threshold value (the pilot injection upper limit correction amount $Q_{pcommax}$). Thus, since an excessive increase in the pilot injection amount Q_p is prevented, excessive degradation in the fuel efficiency may be prevented.

[0341] In addition, as in the first device, since the fifth device may suppress a variation in the combustion between the cylinders even when the glow plug is degraded, the drivability and the emission of the engine may be satisfactorily maintained.

(Sixth embodiment)

[0342] Next, a combustion control device (hereinafter, referred to as a "sixth device") according to a sixth embodiment of the present invention will be described.

<Outline of device>

[0343] The sixth device is applied to the internal combustion engine (see FIGS. 1 and 2) which is similar to the internal combustion engine 10 employing the first device. Accordingly, the specific description of the outline of the device will be omitted.

<Outline of operation of device>

[0344] The sixth device acquires the compression end temperatures (T_{t1} to T_{t4}) of the respective cylinders and acquires the compression end reference temperature T_{tref} based on the compression end temperature as in the first device. In addition, the sixth device verifies the degradation degree of the glow plug 23 of the verification subject cylinder by comparing the compression end temperature T_t of the verification subject cylinder with the compression end reference temperature T_{tref} as in the first device.

[0345] The sixth device changes the "main injection amount Q_m " in response to the verified degradation degree of the glow plug 23. More specifically, the sixth device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} as in the first device. When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", the second device injects the fuel of the injection amount (the pilot injection amount Q_p and the main injection amount Q_m) determined in response to the operation state of the engine 10 into the verification subject cylinder at the injection timing (the pilot injection timing $finjp$ and the main injection timing $finjm$) determined in a similar way.

[0346] On the other hand, the sixth device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage" when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} as in the first device. When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the second device increases the "determined main injection amount Q_m " by the main injection correction amount Q_{mcom} determined in response to the degradation degree of the glow plug 23.

[0347] Here, when the main injection correction amount Q_{mcom} is larger than the predetermined main injection upper limit correction amount $Q_{mcommax}$, the sixth device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage". When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the sixth device increases the "determined main injection amount Q_m " by the main injection upper limit correction amount $Q_{mcommax}$. In addition, at this time, the sixth device displays that the "glow plug is in an abnormal condition" on a display device (not illustrated) or the like. The description above is the outline of the operation of the sixth device.

<Combustion control method>

[0348] Subsequently, the combustion control method which is employed in the sixth device will be described before the description of the specific operation of the sixth device.

[0349] As described above, when the glow plug 23 is degraded, the compression end temperature T_t is lowered. Therefore, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the sixth device changes the main injection amount Q_m of the verification subject cylinder so that it

increases by the main injection correction amount Q_{mcom} . The main injection correction amount Q_{mcom} is determined in response to the degradation degree of the glow plug 23.

[0350] When the main injection amount Q_m increases, the amount of heat generated by the combustion of the main-injected fuel increases. For this reason, the temperature of the wall surface forming the cylinder increases. Also, since the main injection correction amount Q_{mcom} is determined in response to the degradation degree of the glow plug 23, the main injection amount Q_m is changed by the sufficient amount necessary for compensating a decrease in the compression end temperature T_t due to degradation in the glow plug 23. As a result, the compression end temperature T_t of the verification subject cylinder may be increased to the temperature (that is, the temperature when the degradation degree of the glow plug 23 is the "first stage" and the temperature higher than the compression end reference temperature T_{tref}) for appropriately igniting the fuel by the right amount.

[0351] In addition, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the sixth device changes the main injection correction amount Q_{mcom} to the main injection upper limit correction amount $Q_{mcommax}$. That is, at this time, the main injection correction amount Q_{mcom} is controlled so as not to be larger than the main injection upper limit correction amount $Q_{mcommax}$. Thus, since an excessive increase in the main injection amount Q_m is prevented, degradation in the fuel efficiency may be prevented. In this way, the sixth device performs the compression end temperature increasing operation of increasing the main injection amount Q_m . The description above is the combustion control method employed in the sixth device.

<Actual operation>

[0352] Hereinafter, the actual operation of the sixth device will be described.

As in the second device, the sixth device is different from the first device only in that the "process indicated by the flowchart of FIG. 9" is performed instead of the process indicated by the flowchart of FIG. 3 in the first device and the "series of processes indicated by the flowcharts of FIGS. 18 and 19" are performed instead of the process indicated by the flowchart of FIG. 7 in the first device. Therefore, hereinafter, the difference will be mainly described.

[0353] The CPU 81 is configured to repeatedly perform the respective routines indicated by the flowcharts of FIGS. 4 to 6 and FIGS. 8, 9, 18, and 19 at a predetermined timing. The CPU 81 uses the glow plug operation flag X_{GLO} and the abnormality occurrence flag X_{EMG} in the routines as in the first device. Accordingly, the specific description of the glow plug operation flag X_{GLO} and the abnormality occurrence flag X_{EMG} will be omitted.

[0354] Hereinafter, on the assumption that the "glow plug operation condition illustrated in FIG. 9 at the current time point is satisfied and the compression end reference temperature T_{tref} is already acquired by the routines illustrated in FIGS. 5 and 6", the respective routines performed by the CPU 81 will be described in detail.

[0355] As in the first device, when the CPU 81 starts a process from step 400 of FIG. 4 at a predetermined timing, the CPU determines and acquires the target opening and closing timings of the intake valve 26 and the exhaust valve 28, and controls the variable intake timing device 26a and the variable exhaust timing device 28a so that the intake valve 26 and the exhaust valve 28 are opened and closed at the target opening and closing timings.

[0356] In addition, as in the second device, when the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing, since the glow plug operation condition at the current time point is satisfied according to the assumption, the application voltage value E_{gl} is determined and acquired by the routine, and the voltage of the application voltage value E_{gl} is applied to the glow plug 23. Thus, the glow plug 23 produces heat, so that the gas in the cylinder is heated. As a result, the compression end temperature T_t increases.

[0357] In addition, the CPU 81 is configured to repeatedly perform the "sixth cylinder-internal-temperature correcting routine" which is indicated by the series of flowcharts of FIGS. 18 and 19 whenever a predetermined time elapses. By the routine, the CPU 81 verifies the degradation degree of the glow plug 23, and changes the "main injection amount Q_m " in response to the degradation degree. Specifically, by the routine, the CPU 81 determines the fuel injection amount (the pilot injection amount Q_p and the main injection amount Q_m) and the fuel injection timing (the pilot injection timing fin_{jp} and the main injection timing fin_{jm}) in response to the operation state of the engine 10, injects the fuel of the pilot injection amount Q_p at the pilot injection timing fin_{jp} from the injector 22, and injects the fuel of the main injection amount Q_m at the main injection timing fin_{jm} from the injector 22. In addition, by the routine, the CPU 81 increases the "main injection amount Q_m " in response to the degradation degree of the glow plug 23 during the operation of the glow plug 23.

[0358] The series of routines illustrated in FIGS. 18 and 19 are different from the routine illustrated in FIG. 7 only in that step 1810 to step 1880 are added. Therefore, in the step for performing the same process as that of the step illustrated in FIG. 7 in the series of routines, the same reference numerals as those of the step of FIG. 7 are used. The specific description of the steps will be appropriately omitted.

[0359] More specifically, when the CPU 81 starts a process from step 1800 of FIG. 18 at a predetermined timing, the CPU acquires the pilot injection amount Q_p and the main injection amount Q_m in step 710, acquires the pilot injection timing fin_{jp} and the main injection timing fin_{jm} in step 720, and proceeds to step 1810.

[0360] Subsequently, in step 1810, the CPU 81 determines whether the compression end reference temperature T_{tref}

at the current time point is acquired. According to the above-described assumption, since the compression end reference temperature T_{ref} is already acquired, the CPU 81 determines that the determination result is "Yes" in step 1810, and proceeds to step 1820.

[0361] In step 1820, the CPU 81 determines whether the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{ref} . Then, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{ref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", and changes the main injection amount Q_m of the verification subject cylinder so that it increases. In addition, when the change amount of the main injection amount Q_m exceeds a predetermined threshold value, the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", and displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated). On the other hand, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{ref} , the CPU 81 verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", and does not change the pilot injection amount Q_p of the verification subject cylinder.

[0362] Hereinafter, the case will be separately described in more detail.

(Case 6-1) Case of compression end temperature T_t of verification subject cylinder lower than compression end reference temperature T_{ref}

[0363] In this case, the CPU 81 determines that the determination result is "Yes" in step 1820, and proceeds to step 1830. In step 1830, the CPU 81 acquires the main injection correction amount Q_{mcom} by applying the temperature difference ΔT at the current time point to a main injection correction amount table $MapQ_{mcom}(\Delta T)$ in which the "relation between the main injection correction amount Q_{mcom} and the temperature difference ΔT as a difference between the compression end reference temperature T_{ref} and the compression end temperature T_t " is determined in advance. In the main injection correction amount table $MapQ_{mcom}(\Delta T)$, the main injection correction amount Q_{mcom} is designed to increase as the temperature difference ΔT increases. In other words, in the main injection correction amount table $MapQ_{mcom}(\Delta T)$, the main injection correction amount Q_{mcom} is designed to increase as the degree of degradation in the glow plug 23 increases.

[0364] Subsequently, the CPU 81 proceeds to step 1840, and determines whether the main injection correction amount Q_{mcom} is larger than the main injection upper limit correction amount $Q_{mcommax}$.

[0365] When the main injection correction amount Q_{mcom} is equal to or smaller than the main injection upper limit correction amount $Q_{mcommax}$, the CPU 81 determines that the determination result is "No" in step 1840, and proceeds to step 1850 so as to change the main injection amount Q_m so that the main injection amount Q_m increases by the main injection correction amount Q_{mcom} .

[0366] On the other hand, when the main injection correction amount Q_{mcom} is larger than the main injection upper limit correction amount $Q_{mcommax}$, the CPU 81 determines that the determination result is "Yes" in step 1840, and proceeds to step 1860. In step 1860, the CPU 81 stores the main injection upper limit correction amount $Q_{mcommax}$ as the value of the main injection correction amount Q_{mcom} . That is, when the value of the main injection correction amount Q_{mcom} is larger than the main injection upper limit correction amount $Q_{mcommax}$, the value of the main injection correction amount Q_{mcom} is changed to the main injection upper limit correction amount $Q_{mcommax}$. That is, in the sixth device, the upper limit value of the main injection correction amount Q_{mcom} is set to the main injection upper limit correction amount $Q_{mcommax}$.

[0367] Subsequently, the CPU 81 proceeds to step 1870, and stores "1" as the value of the abnormality occurrence flag XEMG. Then, in step 1850 subsequent to step 1870, the CPU 81 changes the main injection amount Q_m so that the main injection amount Q_m increases by the main injection correction amount Q_{mcom} (in practice, the main injection upper limit correction amount $Q_{mcommax}$).

(Case 6-2) Case of compression end temperature T_t of verification subject cylinder equal to or higher than compression end reference temperature T_{ref}

[0368] In this case, the CPU 81 determines that the determination result is "No" in step 1820, and proceeds to step 1880. The CPU 81 stores zero as the value of the main injection correction amount Q_{mcom} in step 1880, and proceeds to step 1850.

[0369] In step 1850, the CPU 81 changes the main injection amount Q_m so that the main injection amount Q_m increases by the main injection correction amount Q_{mcom} (in practice, zero). Incidentally, since the main injection correction amount Q_{mcom} at the current time point is zero, the main injection amount Q_m does not increase. That is, the main injection amount Q_m is not changed.

[0370] As described above in the separate cases of "Case 6-1" and "Case 6-2", when the compression end temperature

Tt of the verification subject cylinder is lower than the compression end reference temperature Ttref (that is, the degradation degree of the glow plug 23 is the "second stage"), the main injection amount Qm is corrected in response to the temperature difference ΔT . Here, in this case, when the main injection correction amount Qmcom exceeds the main injection upper limit correction amount Qmcommax (that is, the degradation degree of the glow plug 23 is the "third stage"), the main injection correction amount Qmcom is changed to the main injection upper limit correction amount Qmcommax. Here, when the compression end temperature Tt of the verification subject cylinder is equal to or higher than the compression end reference temperature Ttref (that is, the degradation degree of the glow plug 23 is the "first stage"), the main injection amount Qm is not corrected. In addition, when the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage", the value of the abnormality occurrence flag XEMG is maintained at "0" stored in the initial routine, and when the degradation degree is the "third stage", "1" is stored as the value of the abnormality occurrence flag XEMG.

[0371] Subsequently, as in the first device, the CPU 81 performs the processes of step 730 to step 760 of FIG. 19, and injects the fuel of the fuel injection amount (the pilot injection amount Qp and the main injection amount Qm) at the fuel injection timing (the pilot injection timing finjp and the main injection timing finjm) from the injector 22 provided in the fuel injection cylinder. Thus, the compression end temperature increasing operation of increasing the main injection amount Qm is performed.

[0372] In addition, when the CPU 81 starts a process from step 800 of FIG. 8 at a predetermined timing, the CPU proceeds to step 810. Here, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "0" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage" in the series of routines illustrated in FIGS. 18 and 19), the CPU 81 determines that the determination result is "Yes" in step 810, and directly proceeds to step 895 so as to end the present routine once.

[0373] On the other hand, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "1" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage" in the series of routines illustrated in FIGS. 18 and 19), the CPU 81 determines that the determination result is "No" in step 810, and proceeds to step 820. In step 820, the CPU 81 displays that the "glow plug 23 is in an abnormal condition" on a display device (not illustrated) by turning on an alarm lamp or the like. Subsequently, the CPU 81 directly proceeds to step 895 so as to end the present routine once.

[0374] In this way, when the glow plug operation condition is satisfied and the compression end reference temperature Ttref is acquired, the degradation degree of the glow plug 23 provided in the verification subject cylinder is verified by comparing the compression end reference temperature Ttref with the compression end temperature Tt of the verification subject cylinder.

[0375] When it is verified that the degradation degree of the glow plug 23 is the "first stage" by the degradation verification, the main injection amount Qm is not changed. On the other hand, when it is verified that the degradation degree of the glow plug 23 is the "second stage" by the degradation verification, the "compression end temperature increasing operation" of increasing the main injection amount Qm by the main injection correction amount Qmcom determined in response to the degradation degree of the glow plug 23 is performed.

[0376] In addition, when it is verified that the degradation degree of the glow plug 23 is the "third stage" by the degradation verification, the main injection amount Qm increases by the predetermined main injection upper limit correction amount Qmcommax, and a display device displays that the "glow plug 23 is in an abnormal condition".

[0377] Here, in a case where the glow plug operation condition is not satisfied, when the CPU 81 starts a process from step 900 of FIG. 9 at a predetermined timing and proceeds to step 305, the CPU determines that the determination result is "No" in step 305, and proceeds to step 365. In step 365, the CPU 81 stores "0" as the value of the glow plug operation flag XGLO. Subsequently, the CPU 81 directly proceeds to step 995 so as to end the present routine once. Accordingly, in this case, the glow plug 23 is not operated.

[0378] In addition, in this case, when the CPU 81 starts a process from step 1800 of FIG. 18 at a predetermined timing and proceeds to step 1810 through step 710 and step 720, the CPU determines that the determination result is "No" since the value of the glow plug operation flag XGLO is "0". Then, the CPU 81 proceeds to step 1880 so as to store zero as the value of the main injection correction amount Qmcom, and proceeds to step 1850. Subsequently, the CPU 81 performs the processes of step 730 to step 760 of FIG. 19, and proceeds to step 1895 so as to end the present routine once. Accordingly, in this case, the main injection amount Qm is not changed.

[0379] In addition, in this case, as in the first device, the compression end temperature Tt is not estimated, and the compression end reference temperature Ttref is not determined. Also, as in the first device, the intake valve 26 and the exhaust valve 28 are opened and closed as in the case where the glow plug operation condition is satisfied. In addition, as in the first device, the notification of abnormality of the glow plug 23 is not performed.

<Operation and effect of device>

[0380] The sixth device verifies the degradation degree of the glow plug 23 as in the first device. Then, the sixth device

performs the compression end temperature increasing operation of increasing the main injection correction amount Q_{mcom} by the amount (the main injection correction amount Q_{mcom}) in response to the degradation degree of the glow plug 23. Thus, since the sixth device may appropriately increase the compression end temperature T_t in response to the degradation degree of the glow plug 23, the ignition of the fuel may be reliably performed even when the glow plug 23 is degraded.

[0381] In addition, the sixth device controls the main injection amount Q_m so that the main injection correction amount Q_{mcom} does not exceed the predetermined threshold value (the main injection upper limit correction amount $Q_{mcommax}$). Thus, since an excessive increase in the main injection amount Q_m is prevented, excessive degradation in the fuel efficiency may be prevented.

[0382] In addition, as in the first device, since the sixth device may suppress a variation in the combustion between the cylinders even when the glow plug is degraded, the drivability and the emission of the engine may be satisfactorily maintained.

[0383] Further, as described above, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", that is, the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} , the sixth device changes the main injection amount Q_m of the verification subject cylinder so that it increases by the main injection correction amount Q_{mcom} . However, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", in addition to changing the main injection amount Q_m as described above, the sixth device may be configured so that the target valve opening timing V_{exo} of the exhaust valve 28 is later than the exhaust top dead center by the exhaust valve closing timing correction amount V_{exccom} determined in response to the degradation degree of the glow plug 23 as in the third device.

[0384] Accordingly, the following effect may be obtained in addition to the effect obtained in the sixth device. That is, as described above, when the main injection amount Q_m increases, the amount of heat generated by the combustion of the main-injected fuel increases, so that the temperature of the exhaust gas increases. On the other hand, when the target valve opening timing V_{exo} of the exhaust valve 28 may become away from the exhaust top dead center, the amount (that is, the inner EGR amount) of the gas remaining in the cylinder among the combusted hot gas (the exhaust gas) increases. Accordingly, when the main injection amount Q_m increases and the target valve opening timing V_{exo} of the exhaust valve 28 may become away from the exhaust top dead center, the more exhaust gas of which the temperature increases with an increase in the main injection amount Q_m remains in the cylinder. For this reason, there is an effect that the compression end temperature T_t of the verification subject cylinder increases to the temperature (that is, the temperature when the degradation degree of the glow plug 23 is the "first stage" and the temperature higher than the compression end reference temperature T_{tref}) for more reliably and appropriately igniting the fuel.

[0385] Further, in this case, when the main injection correction amount Q_{mcom} is larger than the predetermined main injection upper limit correction amount $Q_{mcommax}$ (that is, it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage"), the main injection amount Q_m increases by the main injection upper limit correction amount $Q_{mcommax}$, and a display device (not illustrated) or the like displays that the glow plug 23 is in an abnormal condition. Alternatively, when the exhaust valve closing timing correction amount V_{exccom} is larger than the predetermined exhaust valve closing timing upper limit correction amount $V_{exccommax}$ (that is, it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage"), the target valve opening timing V_{exo} of the exhaust valve 28 may become away from the exhaust top dead center by the exhaust valve closing timing upper limit correction amount $V_{xccommax}$, and a display device (not illustrated) or the like displays that the glow plug 23 is in an abnormal condition.

[0386] Further, when it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", that is, the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} , the sixth device changes the main injection amount Q_m as described above so that the target valve opening timing V_{ino} of the intake valve 26 is earlier than the exhaust top dead center by the intake valve opening timing correction amount V_{inocom} determined in response to the degradation degree of the glow plug 23 as in the fourth device.

[0387] Accordingly, the following effect may be obtained in addition to the effect obtained in the sixth device. That is, as described above, when the main injection amount Q_m increases, the amount of heat generated by the combustion of the main-injected fuel increases, so that the temperature of the exhaust gas increases. On the other hand, when the target valve opening timing V_{ino} of the intake valve 26 is earlier than the exhaust top dead center, the combusted hot gas (the exhaust gas) is pushed toward the intake passage during a period (that is, the exhaust stroke) until the piston in the cylinder reaches the exhaust top dead center after the intake valve 26 is opened. The amount of the exhaust gas pushed toward the intake passage increases by the amount in which the valve opening timing of the intake valve 26 is earlier than the exhaust top dead center. Then, the exhaust gas pushed toward the intake passage is suctioned into the cylinder together with air (new air) in the intake stroke. As a result, a part of the hot exhaust gas remains in the cylinder. For this reason, there is an effect that the compression end temperature of the verification subject cylinder increases to

the temperature (that is, the temperature when the degradation degree of the glow plug 23 is the "first stage" and the temperature higher than the compression end reference temperature T_{tref}) for more reliable and appropriate ignition of the fuel.

[0388] Further, in this case, when the main injection correction amount Q_{mcom} is larger than the predetermined main injection upper limit correction amount $Q_{mcommax}$ (that is, it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage"), the main injection amount Q_m increases by the main injection upper limit correction amount $Q_{mcommax}$, and a display device (not illustrated) or the like displays that the glow plug 23 is in an abnormal condition. Alternatively, when the intake valve opening timing correction amount V_{inocom} is larger than the predetermined intake valve opening timing upper limit correction amount $V_{inocommax}$ (that is, it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage"), the target valve opening timing V_{ino} of the intake valve 26 becomes earlier than the exhaust top dead center by the intake valve opening timing upper limit correction amount $V_{inocommax}$, and a display device (not illustrated) or the like displays that the glow plug 23 is in an abnormal condition.

(Seventh embodiment)

[0389] Next, a combustion control device (hereinafter, referred to as a "seventh device") according to a seventh embodiment of the present invention will be described.

<Outline of device>

[0390] The seventh device is applied to the internal combustion engine (see FIGS. 1 and 2) which is similar to the internal combustion engine 10 to which the first device is applied. Accordingly, the specific description of the outline of the device will be omitted.

<Outline of operation of device>

[0391] The seventh device estimates the compression end temperature T_t of the verification subject cylinder as in the first device. In addition, the first device acquires the compression end reference temperature T_{tref} which is a temperature lower by a predetermined temperature ΔT_{th2} than a temperature obtained by adding the temperature change amount (the compression-induced temperature change amount ΔT_{comp}) caused by the compression of the gas in the cylinder in the compression stroke, the temperature change amount (the heating-induced temperature change amount ΔT_{gl}) caused by the heating of the gas in the cylinder using the glow plug 23, and the temperature change amount (the thermal-loss-induced temperature change amount ΔT_{loss}) caused by the thermal loss of the wall surface or the like of the cylinder to the temperature of the gas before the compression of the gas in a cylinder. Then, the seventh device verifies the degradation degree of the glow plug 23 of the verification subject cylinder by comparing the compression end temperature T_t of the verification subject cylinder with the compression end reference temperature T_{tref} as in the first device.

[0392] As in the first device, the seventh device changes the application voltage E_{gl} of the glow plug 23 in response to the verified degradation degree of the glow plug 23. Specifically, when the compression end temperature T_t of the verification subject cylinder is equal to or higher than the compression end reference temperature T_{tref} , the seventh device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage". When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage", the seventh device applies the voltage of the application voltage value E_{gl} which is determined in response to the operation state of the engine 10 to the glow plug 23.

[0393] On the other hand, when the compression end temperature T_t of the verification subject cylinder is lower than the compression end reference temperature T_{tref} , the seventh device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage". When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "second stage", the seventh device increases the determined application voltage value E_{gl} by the application voltage correction amount E_{glcom} .

[0394] Here, when the application voltage correction amount E_{glcom} is larger than the predetermined application voltage upper limit correction amount $E_{glcommax}$, the seventh device verifies that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage". When it is verified that the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage", the seventh device increases the determined application voltage value E_{gl} by the application voltage upper limit correction amount $E_{glcommax}$. In addition, at this time, the seventh device displays that the "glow plug is in an abnormal condition" on a display device (not illustrated) or the like. The description above is the outline of the operation of the seventh device.

<Combustion control method>

[0395] As described above, the seventh device employs the same combustion control method as that of the first device. Accordingly, the specific description of the combustion control method will be omitted.

<Actual operation>

[0396] Hereinafter, the actual operation of the seventh device will be described.

The seventh device is different from the first device only in that the "process indicated by the flowchart of FIG. 20" is performed instead of the process indicated by the flowchart of FIG. 6 in the first device. Therefore, hereinafter, the difference will be mainly described.

[0397] The CPU 81 is configured to repeatedly perform the respective routines indicated by the flowcharts of FIGS. 3 to 5 and FIGS. 7, 8, and 20 at a predetermined timing. The CPU 81 uses the glow plug operation flag XGLO and the abnormality occurrence flag XEMG in the routines as in the first device. Therefore, the specific description of the glow plug operation flag XGLO and the abnormality occurrence flag XEMG will be omitted.

[0398] Hereinafter, on the assumption that the "glow plug operation condition illustrated in FIG. 3 at the current time point is satisfied and the compression end reference temperature T_{tref} is not acquired yet", the respective routines performed by the CPU 81 will be described in detail.

[0399] As in the first device, when the CPU 81 starts a process from step 300 of FIG. 3 at a predetermined timing, the CPU 81 proceeds to step 395 through step 305, step 310, step 315, step 320, and step 325 according to the above-described assumption so as to end the present routine once. Thus, the voltage of the application voltage value E_{gl} determined in response to the operation state of the engine 10 is applied to the glow plug 23, so that the gas in a cylinder is heated. Further, at this time, the value of the glow plug operation flag XGLO is set to "1" by the process of step 310.

[0400] In addition, as in the first device, when the CPU 81 starts a process from step 400 of FIG. 4 at a predetermined timing, the CPU 81 determines and acquires the target opening and closing timings of the intake valve 26 and the exhaust valve 28, and controls the variable intake timing device 26a and the variable exhaust timing device 28a so that the intake valve 26 and the exhaust valve 28 are opened and closed at the target opening and closing timings.

[0401] In addition, as in the first device, when the CPU 81 starts a process from step 500 of FIG. 5 at a predetermined timing, the CPU 81 estimates the compression end temperature T_t of the verification subject cylinder.

[0402] In addition, the CPU 81 is configured to repeatedly perform the "second compression-end-reference-temperature acquiring routine" indicated by the flowchart of FIG. 20 whenever a predetermined time elapses. By the routine, the CPU 81 acquires the compression end reference temperature T_{tref} which is an index for verifying the degradation degree of the glow plug 23.

[0403] Specifically, when the CPU 81 starts a process from step 2000 of FIG. 20 at a predetermined timing, the CPU 81 proceeds to step 2010 so as to determine whether the value of the glow plug operation flag XGLO is "1". As described above, since the value of the glow plug operation flag XGLO at the current time point is "1", the CPU 81 determines that the determination result is "Yes" in step 2010, and proceeds to step 2020.

[0404] In step 2020, the CPU 81 determines whether the crank angle CA at the current time point of the verification subject cylinder matches the target valve closing timing V_{inc} of the intake valve 26. When the crank angle CA at the current time point does not match the target valve closing timing V_{inc} of the intake valve 26, the CPU 81 determines that the determination result is "No" in step 2020, and directly proceeds to step 2095 so as to end the present routine once. On the other hand, when the crank angle CA at the current time point matches the target valve closing timing V_{inc} of the intake valve 26, the CPU 81 determines that the determination result is "Yes" in step 2020, and proceeds to step 2030. Hereinafter, the description will be continued on the assumption that the crank angle CA at the current time point "matches" the target valve closing timing V_{inc} of the intake valve 26.

[0405] According to the above-described assumption, the CPU 81 proceeds to step 2030, acquires the intake air temperature T_{in} based on the output value of the intake air temperature sensor 72, and stores the intake air temperature T_{in} as the intake valve closing timing cylinder gas temperature T_c in the RAM 83. In addition, in step 2030, the CPU 81 acquires the intake pressure P_{in} based on the output value of the intake air pressure sensor 73, and stores the intake pressure P_{in} as the intake valve closing timing cylinder gas pressure P_c in the RAM 83.

[0406] Subsequently, the CPU 81 proceeds to step 2040, and acquires the cylinder gas amount n (mole number) by applying the intake valve closing timing cylinder gas temperature T_c and the intake valve closing timing cylinder gas pressure P_c acquired in step 2030, the gas constant of the ideal gas R stored in advance in the ROM 82, and the intake valve closing timing cylinder volume V_c obtained by applying the target valve closing timing V_{inc} of the intake valve 26 to the "relation between the crank angle CA and the cylinder volume V " stored in advance in the ROM 82 to the above-described equation (1) employed in the routine of FIG. 5.

[0407] Subsequently, the CPU 81 proceeds to step 2050, and acquires the compression-induced temperature change amount ΔT_{comp} by applying the intake valve closing timing cylinder internal gas temperature T_c acquired in step 2030,

the compression top dead center timing cylinder volume V_t obtained by applying the compression top dead center to the "relation between the crank angle CA and the cylinder volume V", the intake valve closing timing cylinder volume V_c in step 2040, and the specific heat ratio k of the air stored in advance in the ROM 82 to the following equation (5).
[0408]

$$\Delta T_{\text{comp}} = T_c \cdot \{V_t/V_c\}^{k-1} - 1 \} \dots (5)$$

[0409] Further, the above-described equation (5) is derived from the Poisson equation illustrated in the following equation (6) and the state equation of the ideal gas illustrated in the above-described equation (2).
[0410]

$$P \cdot V^k = \text{const.} \dots (6)$$

[0411] Subsequently, the CPU 81 proceeds to step 2060, and determines and acquires a heating-induced temperature change amount ΔT_{gl} by applying the application voltage value E_{gl} , the engine rotation speed NE, and the target valve closing timing Vinc at the current time point, the cylinder gas amount n acquired in step 2040, and the air constant volume specific heat C_v stored in advance in the ROM 82 to a heat causing temperature change amount table Map ΔT_{gl} (E_{gl} , NE, Vinc, n , C_v) in which the "relation between the application voltage value E_{gl} to the glow plug 23, the engine rotation speed NE, the target valve closing timing Vinc of the intake valve 26, the cylinder gas amount n , the air constant volume specific heat C_v , and the heating-induced temperature change amount ΔT_{gl} is determined in advance. In the heat causing temperature change amount table Map ΔT_{gl} (E_{gl} , NE, Vinc, n , C_v), the heating-induced temperature change amount ΔT_{gl} is designed to satisfy the following conditions 7-1 to 7-3.

[0412]

(Condition 7-1) The "time (compression time) necessary until the piston 29 reaches the compression top dead center after the intake valve 26 is closed" is calculated based on the engine rotation speed NE and the target valve closing timing Vinc.

(condition 7-2) The "amount of heat (supply heat amount) supplied from the glow plug 23 into the gas in the cylinder in the compression time" is calculated based on the application voltage value E_{gl} and the compression time calculated in the above-described condition 7-1.

(Condition 7-3) The heating-induced temperature change amount ΔT_{gl} increases as the supply heat amount calculated in the above-described equation 7-2 increases, and decreases as the cylinder gas amount n and the constant volume specific heat C_v increase.

[0413] Subsequently, the CPU 81 proceeds to step 2070, and determines and acquires a temperature change amount ΔT_{loss} caused by thermal loss by applying the cooling water temperature THW, the engine rotation speed NE, and the target valve closing timing Vinc at the current time point, the cylinder gas amount n acquired in step 2040, and the air constant volume specific heat C_v stored in advance in the ROM 82 to a thermal loss causing temperature change amount table Map ΔT_{loss} (THW, NE, Vinc, n , C_v) in which the "relation between the cooling water temperature THW, the engine rotation speed NE, the target valve closing timing Vinc of the intake valve 26, the cylinder gas amount n , the air constant volume specific heat C_v , and the temperature change amount ΔT_{loss} caused by the thermal loss" is determined in advance. In the thermal loss causing temperature change amount table Map ΔT_{loss} (THW, NE, Vinc, n , C_v), the temperature change amount ΔT_{loss} caused by the thermal loss is designed to satisfy the following conditions 7-4 to 7-7.

[0414]

(Condition 7-4) The thermal-loss-induced temperature change amount ΔT_{loss} is a negative number.

(Condition 7-5) The "time (compression time) necessary until the piston 29 reaches the compression top dead center after the intake valve 26 is closed" is calculated based on the engine rotation speed NE and the target valve closing timing Vinc.

(Condition 7-6) The "amount of heat (the amount of heat loss) discharged to the wall surface or the like of the cylinder from the gas in the cylinder in the compression time" is calculated based on the cooling water temperature THW and the compression time calculated in the above-described condition 7-5.

(Condition 7-7) The thermal-loss-induced temperature change amount ΔT_{loss} decreases as the thermal loss calculated in the above-described condition 7-6 increases, and increases as the cylinder gas amount n and the constant

volume specific heat Cv increase.

[0415] Subsequently, the CPU 81 proceeds to step 2080, and acquires the compression end reference temperature T_{tref} by applying the intake valve closing timing cylinder gas temperature T_c, the compression-induced temperature change amount ΔT_{comp}, the heating-induced temperature change amount ΔT_{gl}, and the thermal-loss-induced temperature change amount ΔT_{loss} acquired as described above to the following equation (7). In the following equation (7), ΔT_{th2} indicates a predetermined threshold value. ΔT_{th2} may be an appropriate value obtained in consideration of the degradation degree of the glow plug 23 and the like which may be allowed in the engine 10.

[0416]

$$T_{tref} = T_c + (\Delta T_{comp} + \Delta T_{gl} + \Delta T_{loss}) - \Delta T_{th2} \dots (7)$$

[0417] As illustrated in the above-described equation (7), as the compression end reference temperature T_{tref}, the seventh device employs a "temperature lower by a predetermined temperature (ΔT_{th2}) than the sum of the intake valve closing timing cylinder gas temperature T_c, the compression-induced temperature change amount ΔT_{comp}, the heating-induced temperature change amount ΔT_{gl}, and the thermal-loss-induced temperature change amount ΔT_{loss} of the verification subject cylinder". In step 2080, the CPU 81 acquires the compression end reference temperature T_{tref}, and proceeds to step 2095 so as to end the present routine once.

[0418] In this way, when the glow plug operation condition is satisfied, the CPU 81 acquires the compression end reference temperature T_{tref} based on the heat balance of the gas in the cylinder.

[0419] As described above, when the CPU 81 starts a process from step 300 of FIG. 3 at a predetermined timing after the compression end reference temperature T_{tref} is acquired, as in the first device, the CPU 81 verifies the degradation degree of the glow plug 23 by comparing the compression end temperature T_t of the verification subject cylinder with the compression end reference temperature T_{tref}. In addition, the CPU 81 performs the compression end temperature increasing operation as an operation of increasing the application voltage value E_{gl} in response to the degradation degree of the glow plug 23.

[0420] In addition, as in the first device, the CPU 81 starts a process from step 700 of FIG. 7 at a predetermined timing, and performs the processes of step 710 to step 760. Thus, as in the first device, the fuel of the predetermined fuel injection amount (Q_p and Q_m) is supplied (injected) into the fuel injection cylinders at the predetermined fuel injection timing (fin_{jp} and fin_{jm}).

[0421] In addition, when the CPU 81 starts a process from step 800 of FIG. 8 at a predetermined timing, the CPU 81 proceeds to step 810. Here, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "0" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "first stage" or the "second stage" in the routine illustrated in FIG. 3), the CPU 81 determines that the determination result is "Yes" in step 810, and directly proceeds to step 895 so as to end the present routine once.

[0422] On the other hand, when it is verified that the value of the abnormality occurrence flag XEMG at the current time point is "1" (the degradation degree of the glow plug 23 of the verification subject cylinder is the "third stage" in the routine illustrated in FIG. 3), the CPU 81 determines that the determination result is "No" in step 810, and proceeds to step 820. In step 820, the CPU 81 displays that the "glow plug 23 is in an abnormal conditions" on a display device (not illustrated) by turning on an alarm lamp or the like. Subsequently, the CPU 81 directly proceeds to step 895 so as to end the present routine once.

[0423] In this way, when the glow plug operation condition is satisfied and the compression end reference temperature T_{tref} is acquired, the degradation degree of the glow plug 23 provided in the verification subject cylinder is verified by comparing the compression end reference temperature T_{tref} with the compression end temperature T_t of the verification subject cylinder.

[0424] When it is verified that the degradation degree of the glow plug 23 is the "first stage" by the degradation verification, the voltage of the application voltage value E_{gl} is applied to the glow plug 23. On the other hand, when it is verified that the degradation degree of the glow plug 23 is the "second stage" by the degradation verification, the "compression end temperature increasing operation" of increasing the application voltage value E_{gl} by the application voltage correction amount E_{glcom} determined in response to the degradation degree of the glow plug 23 is performed.

[0425] In addition, when it is verified that the degradation degree of the glow plug 23 is the "third stage" by the degradation verification, the application voltage value E_{gl} increases by the predetermined application Voltage upper limit correction amount E_{glcommax}, and a display device displays that the "glow plug 23 is in an abnormal condition".

[0426] In addition, in this case, when the CPU 81 starts a process from step 2000 of FIG. 20 at a predetermined timing and proceeds to step 2010, since the value of the glow plug operation flag XGLO is "0", the CPU 81 determines that the determination result is "No" in step 2010, and directly proceeds to step 2095 so as to end the present routine once.

Accordingly, in this case, the compression end reference temperature T_{tref} is not acquired. Also, in this case, as in the first device, the compression end temperature T_t is not estimated. For this reason, the degradation verification of the glow plug 23 is not performed.

[0427] In addition, in this case, as in the first device, the compression end temperature T_t is not estimated, and the compression end reference temperature T_{tref} is not determined. Also, as in the first device, the fuel of the predetermined fuel injection amount (Q_p and Q_m) is supplied (injected) into the fuel injection cylinder at the predetermined fuel injection timing (finjp and finjm) as in the case where the glow plug operation condition is satisfied. In addition, as in the first device, the glow plug 23 is not operated, and the notification of abnormality of the glow plug 23 is not performed.

<Operation and effect of device>

[0428] The seventh device acquires the compression end reference temperature T_{tref} based on the heat balance of the gas in the cylinder during the operation of the glow plug 23. The seventh device verifies the degradation degree of the glow plug 23 by comparing the compression end reference temperature T_{tref} , with the compression end temperature T_t of the verification subject cylinder, and performs the compression end temperature increasing operation of increasing the application voltage value E_{gl} applied to the glow plug 23 by the amount (the application voltage correction amount E_{glcom}) in response to the degradation degree as in the first device. Thus, since the first device may appropriately increase the compression end temperature T_t in response to the degradation degree of the glow plug 23, the ignition of the fuel may be reliably performed even when the glow plug 23 is degraded.

[0429] In addition, the seventh device acquires the compression end reference temperature T_{tref} based on the heat balance of the gas inside one cylinder. For this reason, even when the glow plugs 23 of all cylinders are degraded by the same degree, the compression end temperature T_t for each cylinder may be appropriately increased.

[0430] In addition, the seventh device controls the application voltage value E_{gl} so that the increase amount (the application voltage correction amount E_{glcom}) of the application voltage value E_{gl} does not exceed a predetermined threshold value (the application voltage upper limit correction amount E_{glcommax}). Thus, since the application of the excessive voltage to the glow plug 23 is prevented, the breakage of the glow plug 23 may be prevented.

[0431] In the seventh device, as the compression end reference temperature T_{tref} , a "temperature lower by a predetermined temperature (ΔT_{th2}) than the sum of the intake valve closing timing cylinder gas temperature T_c , the compression-induced temperature change amount ΔT_{comp} , the heating-induced temperature change amount ΔT_{gl} , and the thermal-loss-induced temperature change amount ΔT_{toss} of the verification subject cylinder" is employed. However, the compression end reference temperature T_{tref} is not limited to the temperature. For example, as the compression end reference temperature T_{tref} , the "sum of the intake valve closing timing cylinder gas temperature T_c , the compression-induced temperature change amount ΔT_{comp} , the heating-induced temperature change amount ΔT_{gl} , and the thermal-loss-induced temperature change amount ΔT_{toss} of the verification subject cylinder" may be employed.

[0432] In addition, the seventh device performs the compression end temperature increasing operation as in the first device. However, the seventh device may employ the compression end temperature increasing operation other than the compression end temperature increasing operation as in the first device. That is, the seventh device may employ the compression end temperature increasing operation as in the second device to the sixth device instead of the compression end temperature increasing operation as in the first device.

[0433] Also, in the seventh device, the air constant volume specific heat C_v is used when acquiring the heating-induced temperature change amount $-\Delta T_{\text{gl}}$ and the thermal-loss-induced temperature change amount ΔT_{toss} . However, the specific heat employed when acquiring the heating-induced temperature change amount ΔT_{gl} and the thermal-loss-induced temperature change amount ΔT_{toss} is not limited to the air constant volume specific heat C_v . For example, as the specific heat, the seventh device may employ an appropriate value obtained in consideration of the amount (EGR amount) of the exhaust gas remaining in the cylinder, the fuel supplied into the cylinder in the pilot injection, and the air suctioned into the cylinder.

<Review of embodiments>

[0434] As described above in the first embodiment to the seventh embodiment, the combustion control device of the invention is a combustion control device applied to an internal combustion engine 10 having a glow plug 23, the glow plug heating a gas in a cylinder, the combustion control device comprising:

a compression end temperature estimating means for estimating a compression end temperature T_t which is a temperature of the gas in a cylinder when a position 29 of a piston moving in the cylinder in a reciprocating manner is at the compression top dead center ATDC (see the routine of FIG. 5); and

a compression end temperature changing means for causing the internal combustion engine 10 to perform a compression end temperature increasing operation in the case where the compression end temperature T_t estimated

by the compression end temperature estimating means is lower than a predetermined compression end reference temperature T_{ref} during the operation of the glow plug, the compression end temperature increasing operation changing the compression end temperature to be equal to or higher than the predetermined compression end reference temperature (see the routines of FIGS. 3, 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19).

[0435] In one embodiment of the combustion control device of the invention, the combustion control device further includes:

a cylinder internal gas amount acquiring means for acquiring a cylinder internal gas amount n which is an amount of the gas in a cylinder (step 530 of FIG. 5);

a compression end cylinder internal pressure acquiring means for acquiring a compression end cylinder internal pressure P_t which is a pressure of the gas in a cylinder when the position of the piston 29 is at the compression top dead center ATDC (step 560 of FIG. 5); and

a compression end cylinder internal gas volume acquiring means for acquiring a compression end cylinder internal gas volume V_t which is a volume of the gas in a cylinder when the position of the piston 29 is at the compression top dead center ATDC (step 570 of FIG. 5).

[0436] In the combustion control device of the embodiment, the compression end temperature estimating means is configured to estimate the compression end temperature T_t by applying the cylinder internal gas amount n acquired by the cylinder internal gas amount estimating means, the compression end cylinder internal pressure P_t acquired by the compression end cylinder internal pressure acquiring means, the compression end cylinder internal gas volume V_t acquired by the compression end cylinder internal gas volume acquiring means, and a gas constant R of the gas in a cylinder to a gas state equation (see the equations (1) and (2)) (step 570 of FIG. 5).

[0437] In addition, in another embodiment of the combustion control device of the invention, the internal combustion engine has a plurality of the cylinders (in the above-described respective embodiments, four cylinders of the first cylinder to the fourth cylinder).

[0438] In the combustion control device of the embodiment, the compression end temperature changing means employs, as the predetermined compression end reference temperature T_{ref} , any one of the followings:

a temperature lower than an average value of the compression end temperatures (T_{t1} , T_{t2} , T_{t3} , and T_{t4}) of the respective cylinders by a predetermined temperature ΔT_{th1} (step 620 of FIG. 6);

a temperature lower than an average value of the compression end temperatures (T_{t2} , T_{t3} , and T_{t4}) of the cylinders (the second cylinder to the fourth cylinder) other than the subject cylinder (for example, the first cylinder) for estimating the compression end temperature with the compression end temperature estimating means by a predetermined temperature;

a temperature lower than the compression end temperature (any one of T_{t2} , T_{t3} , and T_{t4}) of one cylinder among the cylinders (any one of the second cylinder to the fourth cylinder) other than the subject cylinder (for example, the first cylinder) for estimating the compression end temperature with the compression end temperature estimating means by a predetermined temperature;

the average value of the compression end temperatures (T_{t1} , T_{t2} , T_{t3} , and T_{t4}) of the respective cylinders;

the average value of the compression end temperatures (T_{t2} , T_{t3} , and T_{t4}) of the cylinders other than the subject cylinder (for example, the first cylinder) for estimating the compression end temperature with the compression end temperature estimating means; and

the compression end temperature (any one of T_{t2} , T_{t3} , and T_{t4}) of one cylinder among the cylinders other than the subject cylinder (for example, the first cylinder) for estimating the compression end temperature with the compression end temperature estimating means.

[0439] In addition, in still another embodiment of the combustion control device of the invention, the combustion control device includes a pre-compression temperature acquiring means (step 2030 of FIG. 20) for acquiring a pre-compression temperature T_c which is a temperature of the gas in a cylinder at a time point before the gas is compressed by the piston 29.

[0440] In the combustion control device of the embodiment, as the predetermined compression end reference temperature T_{ref} , the compression end temperature changing means estimates the followings:

a compression-induced temperature change amount which is a change amount in the temperature of the gas caused by a compression, based on one or plural operation parameters (T_c , V_t , V_c , and k) of the internal combustion engine involved with the compression of the gas in a cylinder by the piston (step 2050 of FIG. 20);

a heating-induced temperature change amount which is a change amount in the temperature of the gas caused by heating, based on one or plural operation parameters (E_{gl} , NE , V_{inc} , n , and C_v) of the internal combustion engine

involved with the heating of the gas in a cylinder by the glow plug (step 2060 of FIG. 20); and a thermal-loss-induced temperature change amount which is a change amount in the temperature of the gas caused by a thermal loss, based on one or plural operation parameters (THW, NE, Vinc, n, and Cv) of the internal combustion engine involved with the thermal loss of the gas in a cylinder (step 2070 of FIG. 20),
 5 and
 the compression end temperature changing means employs, as the predetermined compression end reference temperature T_{tref} , one of the followings:

10 a temperature $(T_c + \Delta T_{comp} + \Delta T_{gl} + \Delta T_{loss} - \Delta T_{th2})$ lower by a predetermined temperature ΔT_{th2} than a sum of the pre-compression temperature, the compression-induced temperature change amount ΔT_{comp} , the heating-induced temperature change amount ΔT_{gl} , and the thermal-loss-induced temperature change amount ΔT_{loss} ; and
 the sum $(T_c + \Delta T_{comp} + \Delta T_{loss})$ of the pre-compression temperature T_c , the compression-induced temperature change amount ΔT_{comp} , the heating-induced temperature change amount ΔT_{gl} , and the thermal-loss-induced temperature change amount ΔT_{loss} (step 2080 of FIG. 20).

[0441] In addition, in the combustion control device of the above-described embodiments, as the compression end temperature increasing operation, the compression end temperature changing means is configured to perform at least one of the following operations:

20 a glow plug application voltage increasing operation in which a voltage E_{gl} applied to the glow plug 23 is increased by a predetermined correction voltage value E_{glcom} when the glow plug 29 generates heat by the application of the voltage (see the routine of FIG. 3);
 an intake valve closing timing correcting operation in which a valve closing timing V_{inc} of an intake valve 26 is changed to be close to an air intake bottom dead center by a predetermined first correction amount V_{inccom} (see the routines of FIGS. 10 and 11);
 25 an exhaust valve closing timing correcting operation in which a valve closing timing V_{exc} of an exhaust valve 28 is changed to be away from an exhaust top dead center by a predetermined second correction amount V_{exccom} (see the routines of FIGS. 12 and 13);
 an intake valve opening timing advancing operation in which a valve opening timing V_{ino} of the intake valve 26 is advanced relative to the exhaust top dead center by a predetermined third correction amount V_{inocom} (see the routines of FIGS. 14 and 15);
 30 a pilot injection amount increasing operation, when a main injection of injecting main fuel Q_m from a fuel injecting valve into a cylinder and a pilot injection of injecting preliminary fuel Q_p from the fuel injecting valve into the cylinder prior to the main injection are performed, in which an amount of fuel Q_p injected in the pilot injection is increased by a predetermined first correction fuel amount $Opcom$ (see the routines of FIGS. 16 and 17); and
 35 a main injection amount increasing operation, when a main injection of injecting main fuel Q_m from a fuel injecting valve into a cylinder and a pilot injection of injecting preliminary fuel Q_p from the fuel injecting valve into the cylinder prior to the main injection is performed, in which an amount Q_m of fuel injected in the main injection is increased by a predetermined second correction fuel amount Q_{mcom} (see the routines of FIGS. 18 and 19).

[0442] The combustion control device of the invention may employ at least one of the above-described plural compression end temperature increasing operations in consideration of the performance and the like required in the engine 10. For example, from the viewpoint of satisfactorily maintaining the fuel efficiency, it is desirable to employ the "operation of increasing the voltage E_{gl} applied to the glow plug 23 by the predetermined correction voltage value E_{glcom} ". On the other hand, for example, from the viewpoint of preventing a variation in torque when the compression end temperature increasing operation is performed, it is desirable to employ the "operation of increasing the voltage E_{gl} applied to the glow plug 23 by the predetermined correction voltage value E_{glcom} ", the "operation of increasing the amount Q_p of the fuel injected in the pilot injection by the predetermined first correction fuel amount Q_{pcom} ", and the like. In addition, for example, from the viewpoint of reducing a burden on the degraded glow plug 23, it is desirable to employ the operation other than the "operation of increasing the voltage E_{gl} applied to the glow plug 23 by the predetermined correction voltage value E_{glcom} ".

[0443] Further, it is desirable to perform the exhaust valve closing timing correcting operation or the intake valve opening timing advancing operation (that is, a so-called inner EGR operation) when the main injection amount increasing operation is performed.

[0444] In addition, the combustion control device includes an abnormality display means (see the routine of FIG. 8) for displaying that the glow plug 23 is in an abnormal condition when at least one of the following conditions is satisfied (see the routine of FIG. 8):

the correction voltage value Eglcom is larger than a predetermined correction voltage threshold value Eglcommax during the glow plug application voltage increasing operation (when the determination result is "Yes" in step 340 of FIG. 3);

the first correction amount Vinccom is larger than a predetermined first correction threshold amount Vinccommax during the intake valve closing timing correcting operation (when the determination result is "Yes" in step 1040 of FIG. 10);

the second correction amount Vexccom is larger than a predetermined second correction threshold amount Vexccommax during the exhaust valve closing timing correcting operation (when the determination result is "Yes" in step 1240 of FIG. 12);

the third correction amount Vinocom is larger than a predetermined third correction threshold amount Vinocommax during the intake valve opening timing advancing operation (when the determination result is "Yes" in step 1440 of FIG. 14);

the first correction fuel amount Qpcom is larger than a predetermined first correction fuel threshold amount Qpcommax during the pilot injection amount increasing operation (when the determination result is "Yes" in step 1640 of FIG. 16); and

the second correction fuel amount Qmcom is larger than a predetermined second correction fuel threshold amount Qmcommax during the main injection amount increasing operation (when the determination result is "Yes" in step 1840 of FIG. 18).

[0445] While the invention has been described in detail by referring to the specific embodiments, it is apparent that various modifications or corrections may be made by the person skilled in the art without departing from the spirit and the scope of the invention.

[0446] For example, in the above-described respective embodiments, the glow plug 23 is operated during the operation of the compression end temperature increasing operation. However, in the second embodiment to the seventh embodiment, the glow plug 23 may not be necessarily operated during the compression end temperature increasing operation,

Claims

1. A combustion control device applied to an internal combustion engine having a glow plug, the glow plug heating a gas in a cylinder, the combustion control device comprising:

a compression end temperature estimating means for estimating a compression end temperature which is a temperature of the gas in a cylinder when a position of a piston moving in the cylinder in a reciprocating manner is at the compression top dead center, and

a compression end temperature changing means for causing the internal combustion engine to perform a compression end temperature increasing operation in the case where the compression end temperature estimated by the compression end temperature estimating means is lower than a predetermined compression end reference temperature during the operation of the glow plug, the compression end temperature increasing operation changing the compression end temperature to be equal to or higher than the predetermined compression end reference temperature.

2. The combustion control device according to claim 1, comprising:

a cylinder internal gas amount acquiring means for acquiring a cylinder internal gas amount which is an amount of the gas in a cylinder;

a compression end cylinder internal pressure acquiring means for acquiring a compression end cylinder internal pressure which is a pressure of the gas in a cylinder when the position of the piston is at the compression top dead center; and

a compression end cylinder internal gas volume acquiring means for acquiring a compression end cylinder internal gas volume which is a volume of the gas in a cylinder when the position of the piston is at the compression top dead center,

wherein the compression end temperature estimating means estimates the compression end temperature by applying the cylinder internal gas amount acquired by the cylinder internal gas amount estimating means, the compression end cylinder internal pressure acquired by the compression end cylinder internal pressure acquiring means, the compression end cylinder internal gas volume acquired by the compression end cylinder internal gas volume acquiring means, and a gas constant of the gas in a cylinder to a gas state equation.

3. The combustion control device according to claim 1 or 2,
wherein the internal combustion engine has a plurality of the cylinders, and
wherein the compression end temperature changing means employs, as the predetermined compression end reference temperature, any one of the followings:

a temperature lower than an average value of the compression end temperatures of the respective cylinders by a predetermined temperature;
a temperature lower than an average value of the compression end temperatures of the cylinders other than the subject cylinder for estimating the compression end temperature with compression end temperature estimating means by a predetermined temperature;
a temperature lower than the compression end temperature of one cylinder among the cylinders other than the subject cylinder for estimating the compression end temperature with the compression end temperature estimating means by a predetermined temperature;
the average value of the compression end temperatures of the respective cylinders;
the average value of the compression end temperatures of the cylinders other than the subject cylinder for estimating the compression end temperature with the compression end temperature estimating means; and
the compression end temperature of one cylinder among the cylinders other than the subject cylinder for estimating the compression end temperature with the compression end temperature estimating means.

4. The combustion control device according to claim 1 or 2, comprising:

a pre-compression temperature acquiring means for acquiring a pre-compression temperature which is a temperature of the gas in a cylinder at a time point before the gas is compressed by the piston,
wherein the compression end temperature changing means estimates the followings:

a compression-induced temperature change amount which is a change amount in the temperature of the gas caused by a compression, based on one or plural operation parameters of the internal combustion engine involved with the compression of the gas in a cylinder by the piston;
a heating-induced temperature change amount which is a change amount in the temperature of the gas caused by heating, based on one or plural operation parameters of the internal combustion engine involved with the heating of the gas in a cylinder by the glow plug; and
a thermal-loss-induced temperature change amount which is a change amount in the temperature of the gas caused by a thermal loss, based on one or plural operation parameters of the internal combustion engine involved with the thermal loss of the gas in a cylinder,
and
the compression end temperature changing means employs, as the predetermined compression end reference temperature, one of the followings:

a temperature lower by a predetermined temperature than a sum of the pre-compression temperature, the compression-induced temperature change amount, the heating-induced temperature change amount, and the thermal-loss-induced temperature change amount; and
the sum of the pre-compression temperature, the compression-induced temperature change amount, the heating-induced temperature change amount, and the thermal-loss-induced temperature change amount.

5. The combustion control device according to any one of claims 1 to 4,
wherein the compression end temperature changing means performs, as the compression end temperature increasing operation, at least one of the following operations:

a glow plug application voltage increasing operation in which a voltage applied to the glow plug is increased by a predetermined correction voltage value when the glow plug generates heat by the application of the voltage;
an intake valve closing timing correcting operation in which a valve closing timing of an intake valve is changed to be close to an air intake bottom dead center by a predetermined first correction amount;
an exhaust valve closing timing correcting operation in which a valve closing timing of an exhaust valve is changed to be away from an exhaust top dead center by a predetermined second correction amount;
an intake valve opening timing advancing operation in which a valve opening timing of the intake valve is advanced relative to the exhaust top dead center by a predetermined third correction amount;
a pilot injection amount increasing operation, when a main injection of injecting main fuel from a fuel injecting valve into a cylinder and a pilot injection of injecting preliminary fuel from the fuel injecting valve into the cylinder

prior to the main injection are performed, in which an amount of fuel injected in the pilot injection is increased by a predetermined first correction fuel amount; and
a main injection amount increasing operation, when a main injection of injecting main fuel from a fuel injecting valve into a cylinder and a pilot injection of injecting preliminary fuel from the fuel injecting valve into the cylinder
prior to the main injection is performed, in which an amount of fuel injected in the main injection is increased by a predetermined second correction fuel amount.

6. The combustion control device according to claim 5,
wherein the exhaust valve closing timing correcting operation or the intake valve opening timing advancing operation is performed when performing the main injection amount increasing operation.

7. The combustion control device according to any one of claims 5 and 6, comprising:

an abnormality display means for displaying that the glow plug is in an abnormal condition when at least one of the following conditions is satisfied:

the correction voltage value is larger than a predetermined correction voltage threshold value during the glow plug application voltage increasing operation;
the first correction amount is larger than a predetermined first correction threshold amount during the intake valve closing timing correcting operation;
the second correction amount is larger than a predetermined second correction threshold amount during the exhaust valve closing timing correcting operation;
the third correction amount is larger than a predetermined third correction threshold amount during the intake valve opening timing advancing operation;
the first correction fuel amount is larger than a predetermined first correction fuel threshold amount during the pilot injection amount increasing operation; and
the second correction fuel amount is larger than a predetermined second correction fuel threshold amount during the main injection amount increasing operation.

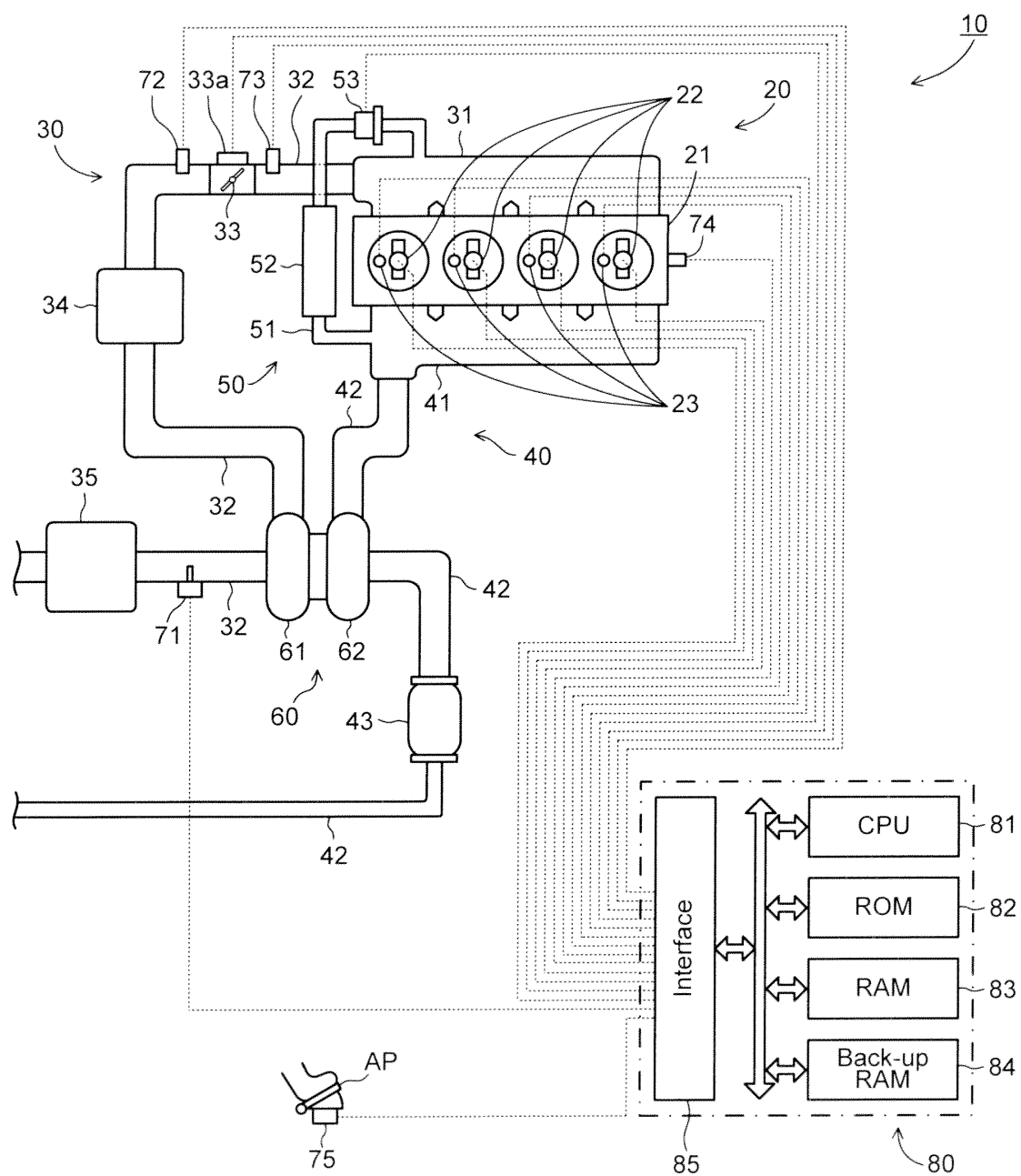


FIG. 1

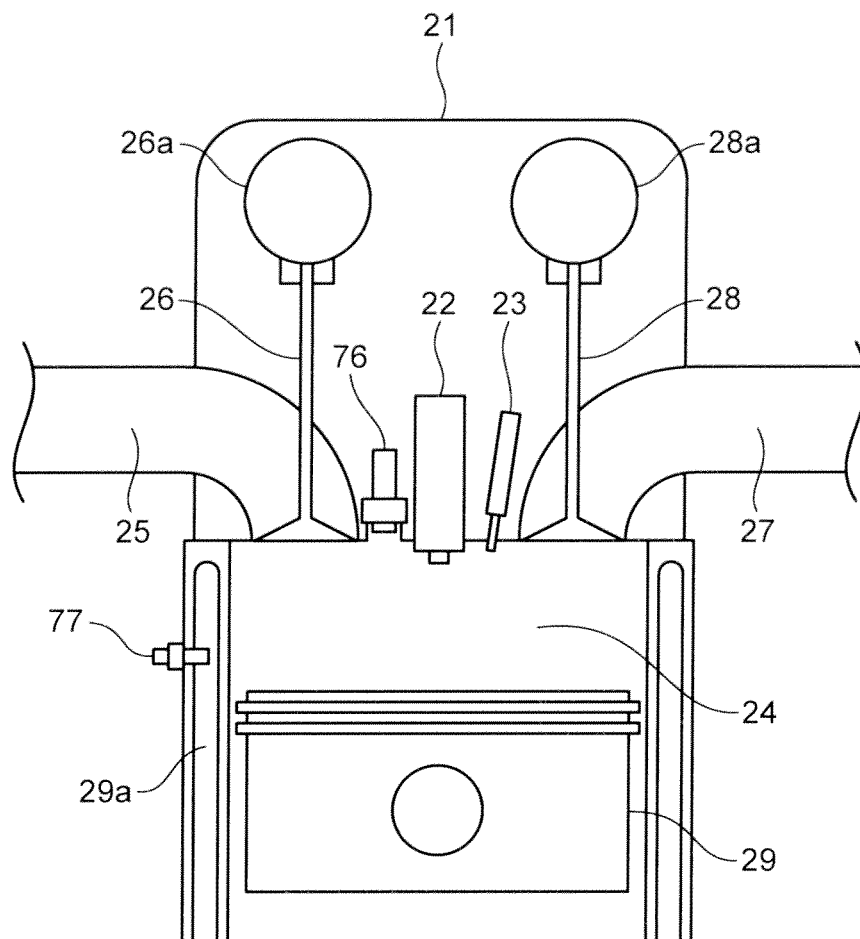


FIG. 2

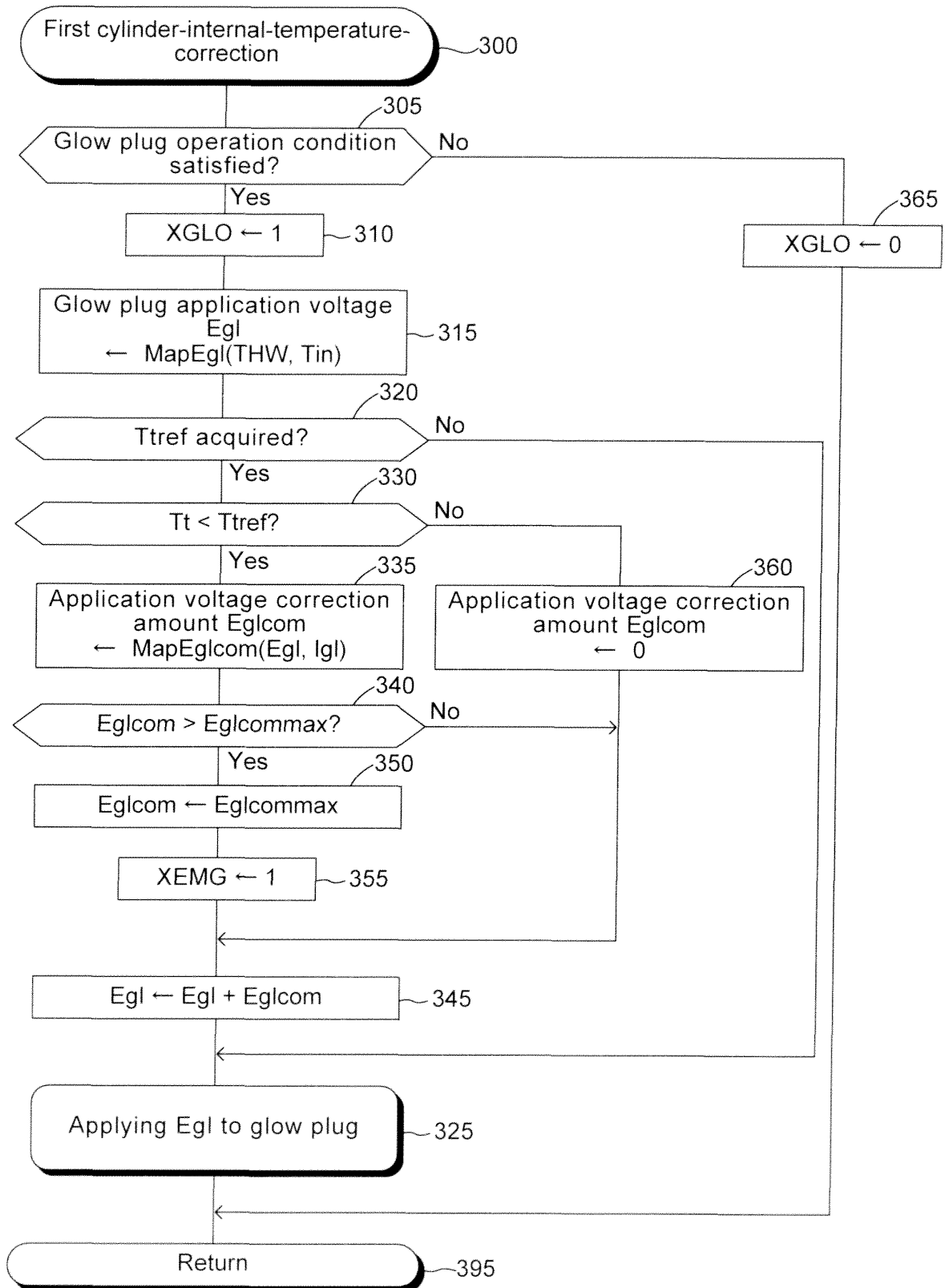


FIG. 3

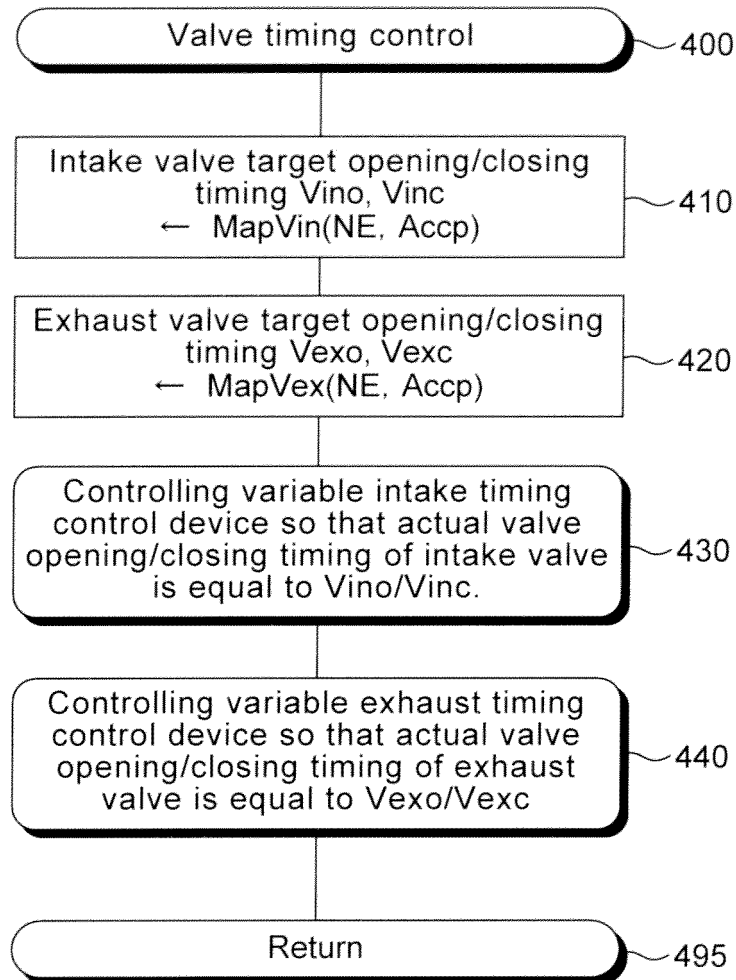


FIG. 4

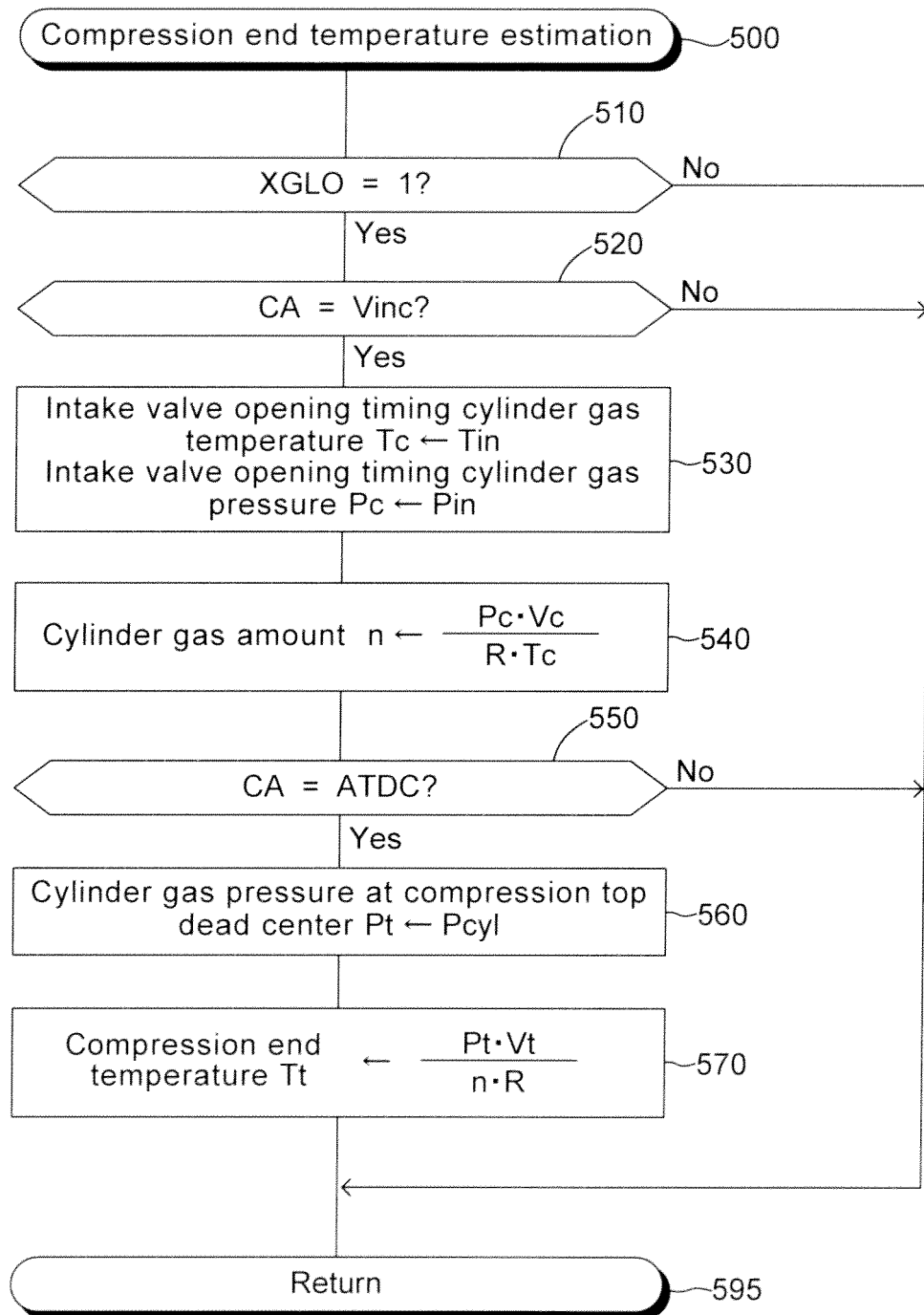


FIG. 5

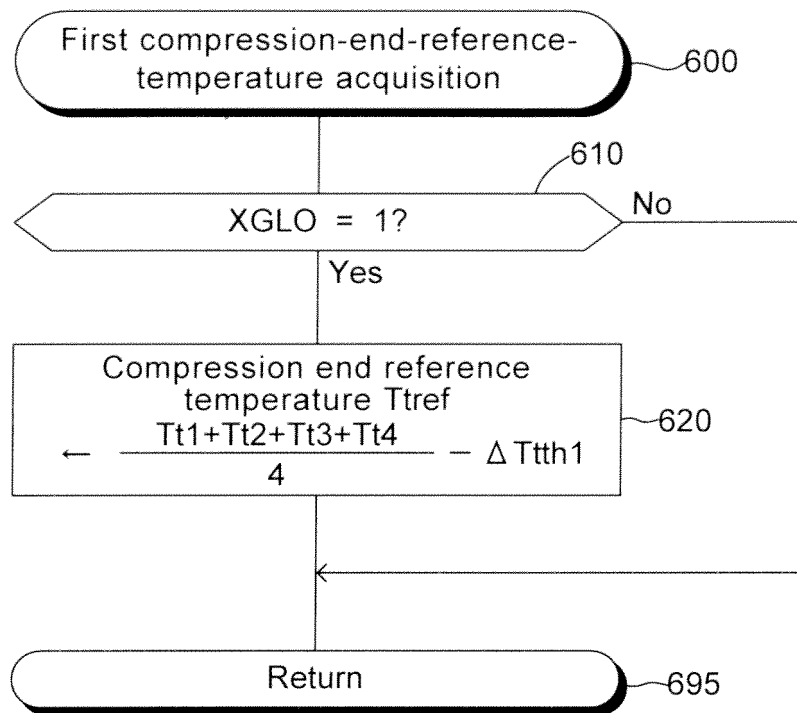


FIG. 6

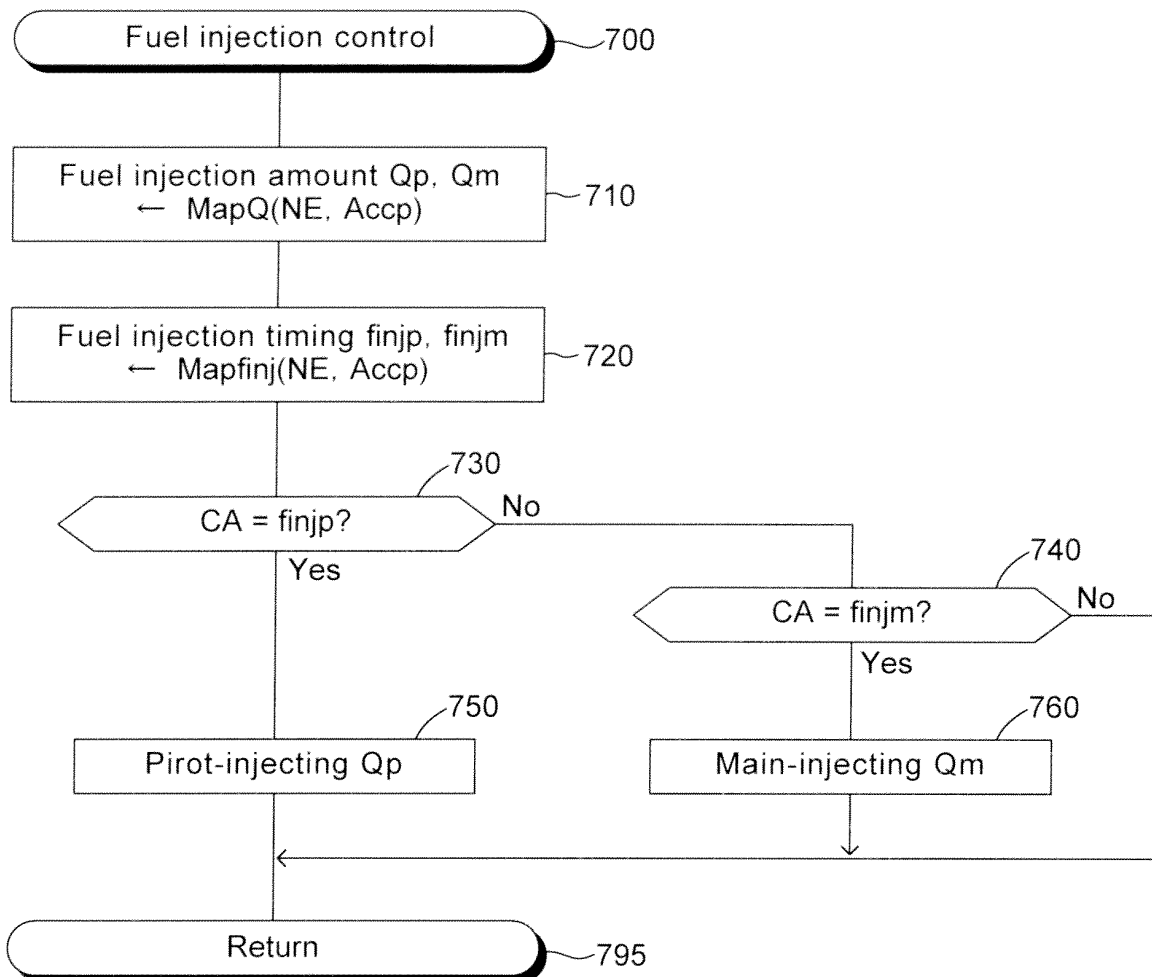


FIG. 7

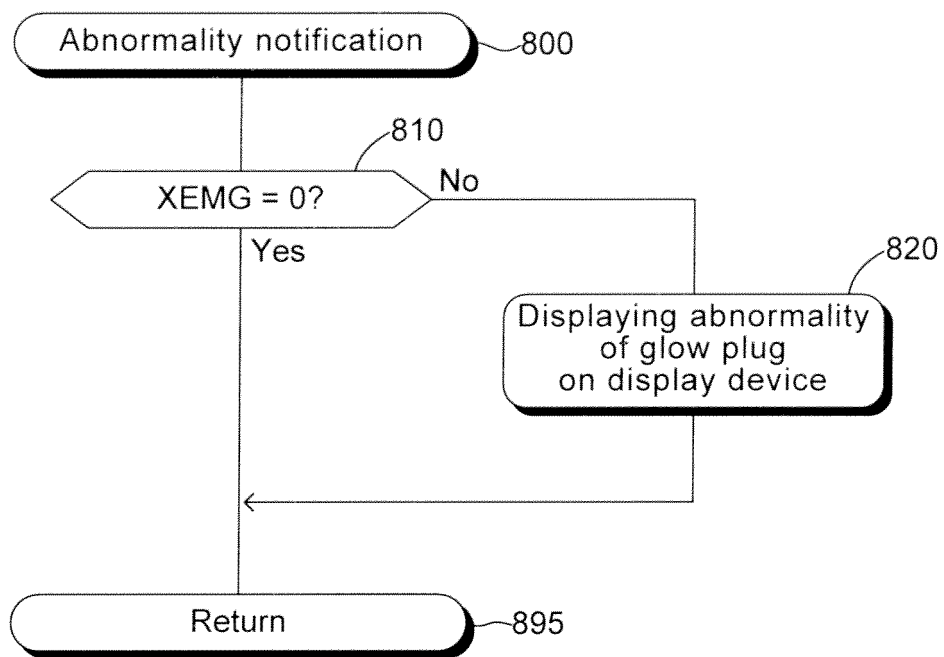


FIG. 8

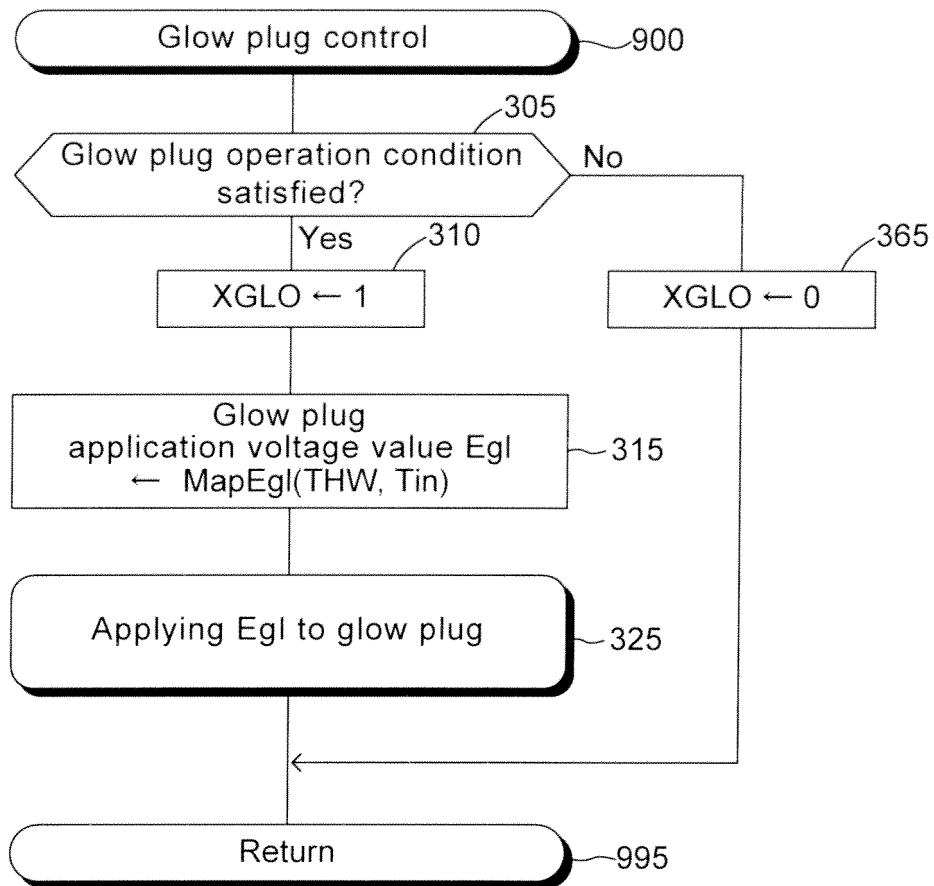


FIG. 9

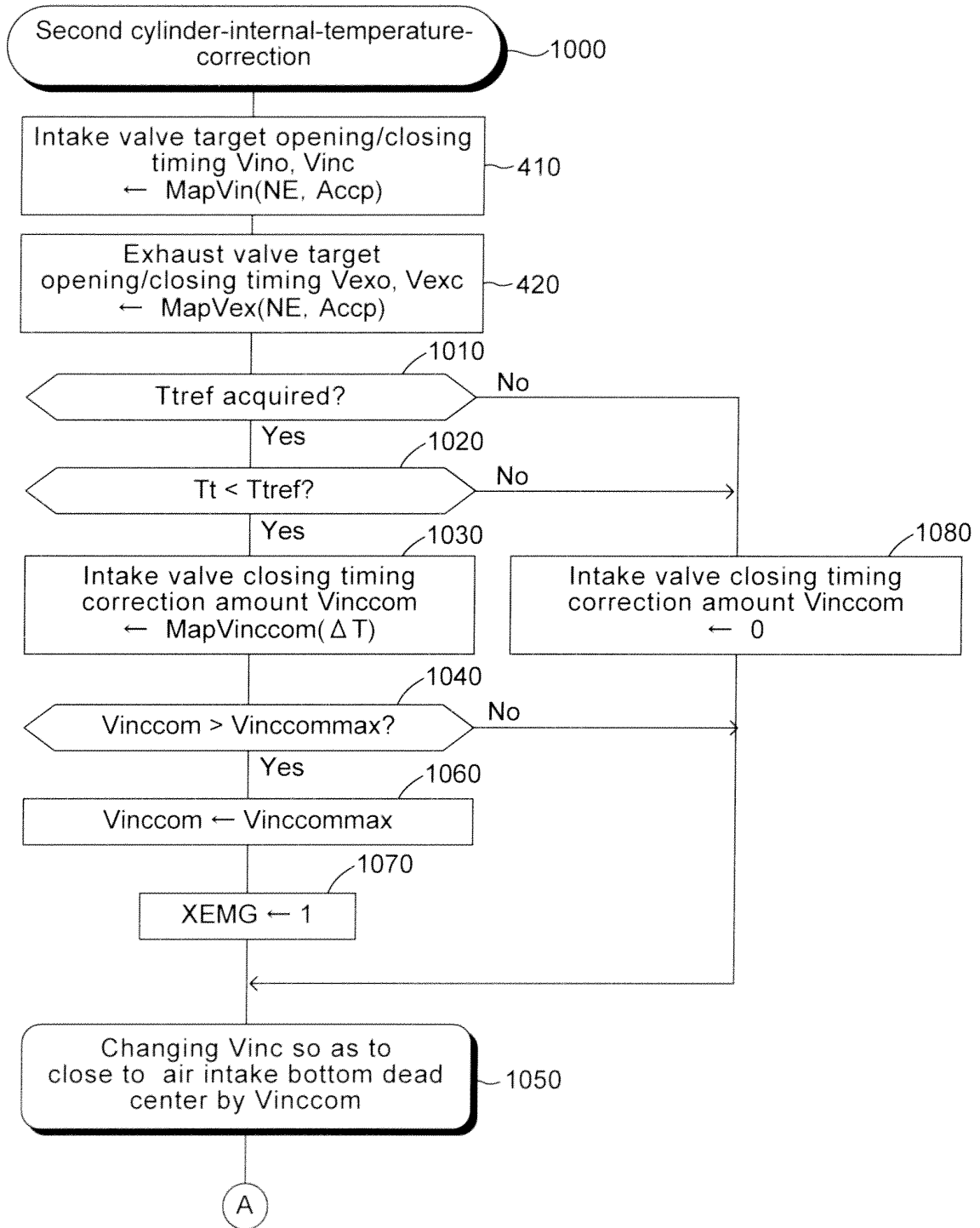


FIG. 10

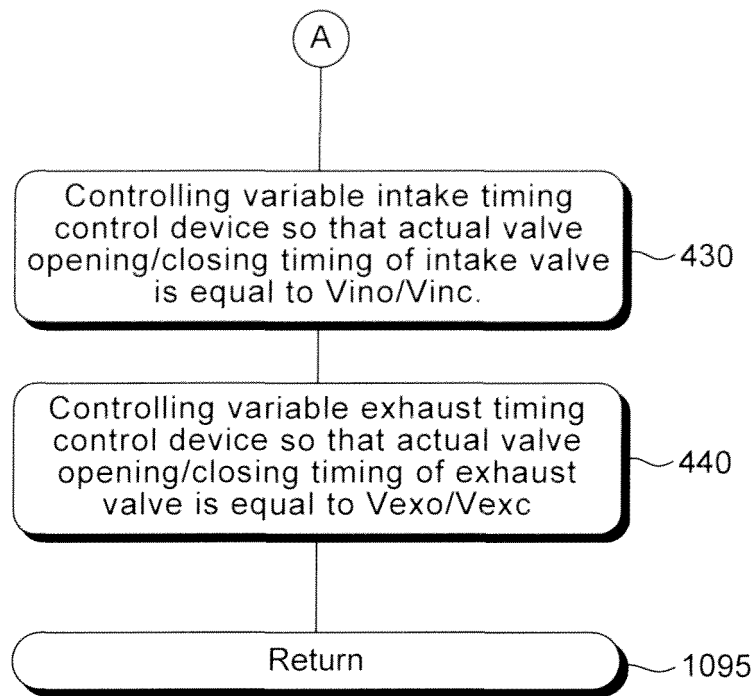


FIG. 11

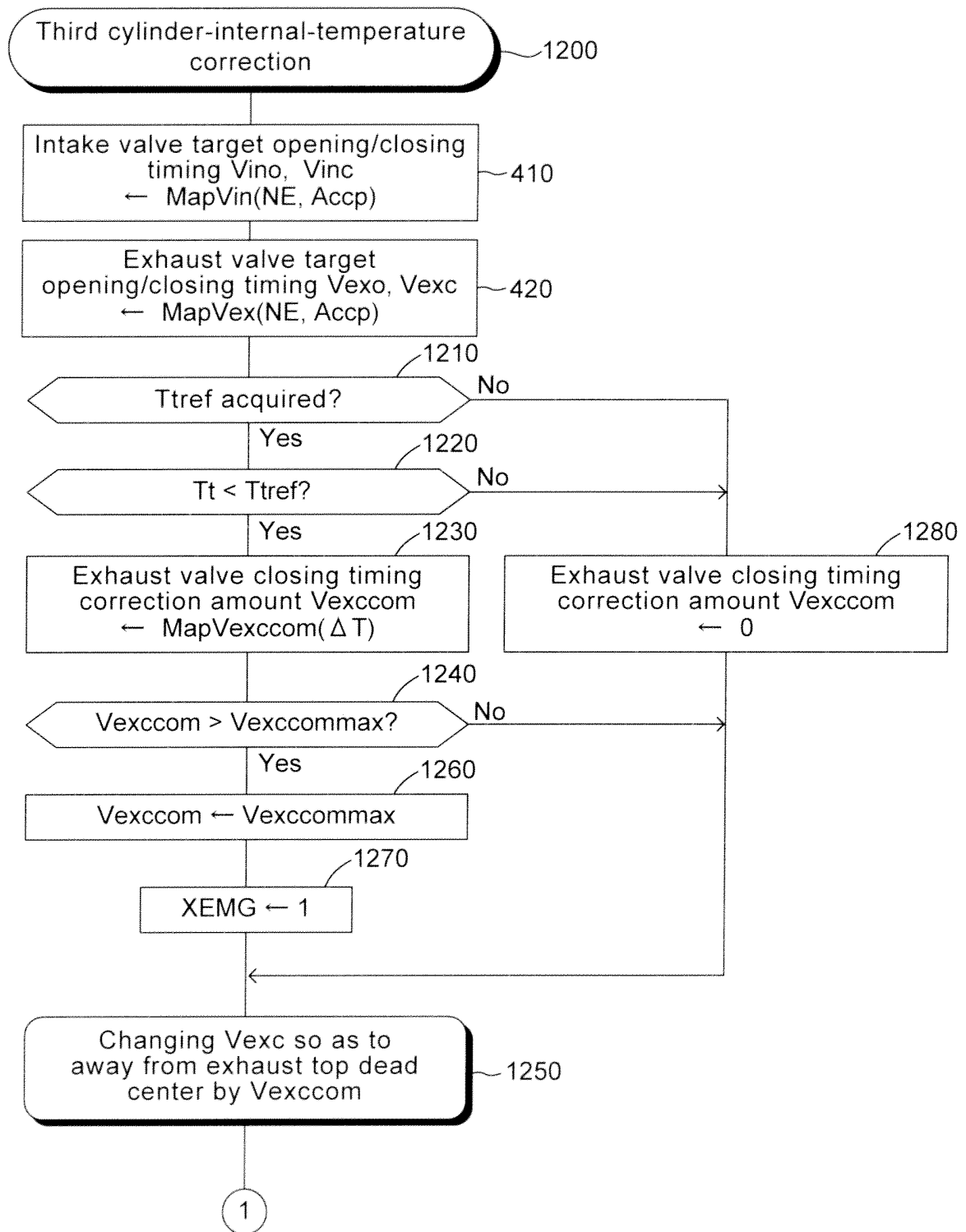


FIG. 12

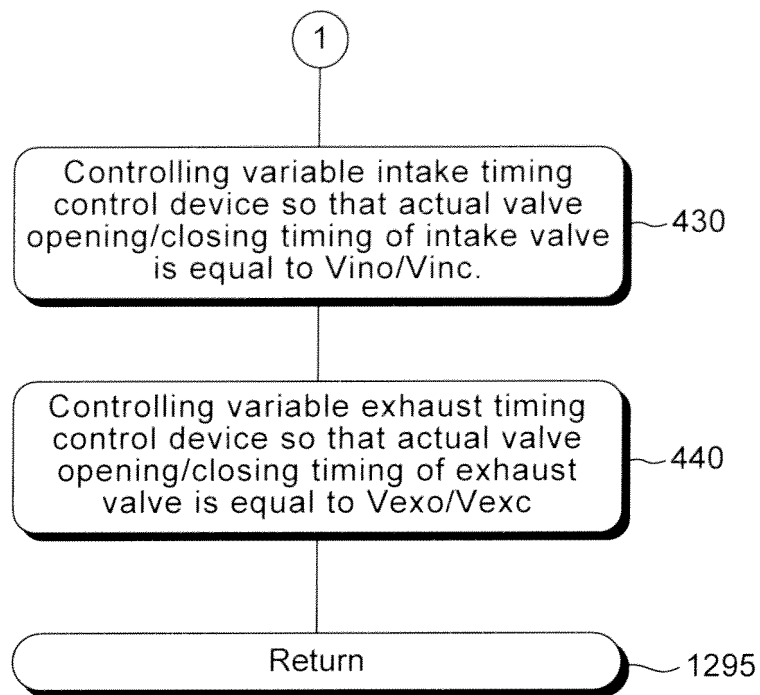


FIG. 13

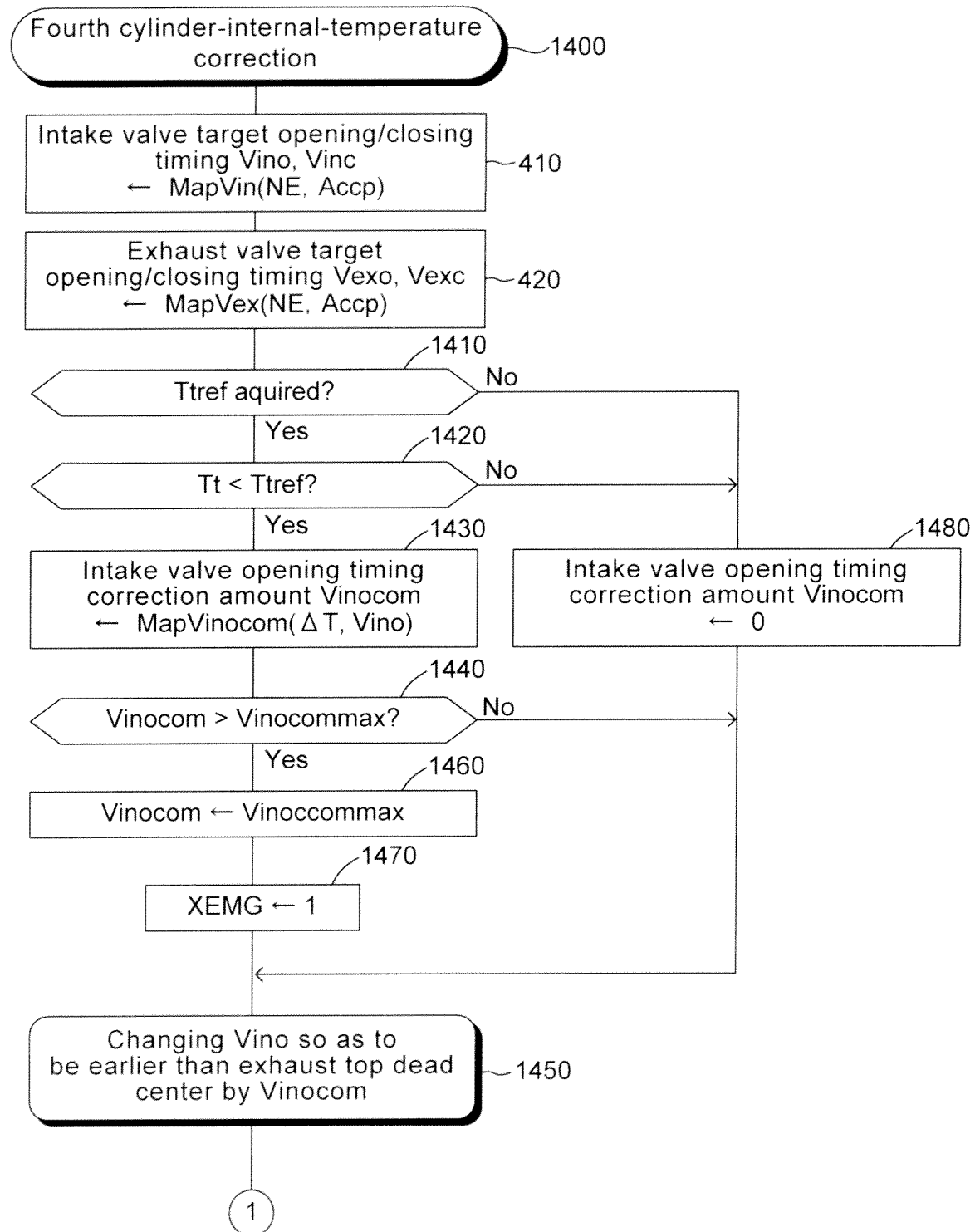


FIG. 14

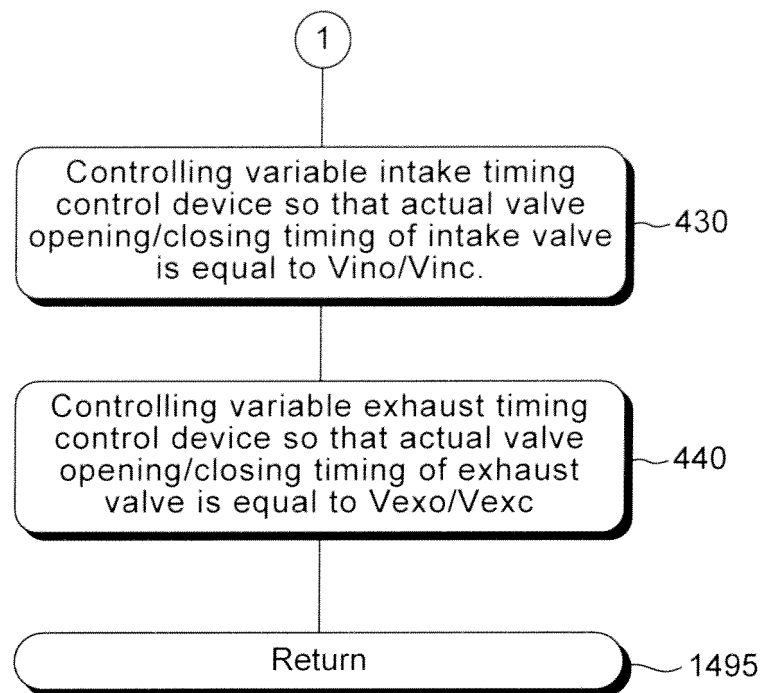


FIG. 15

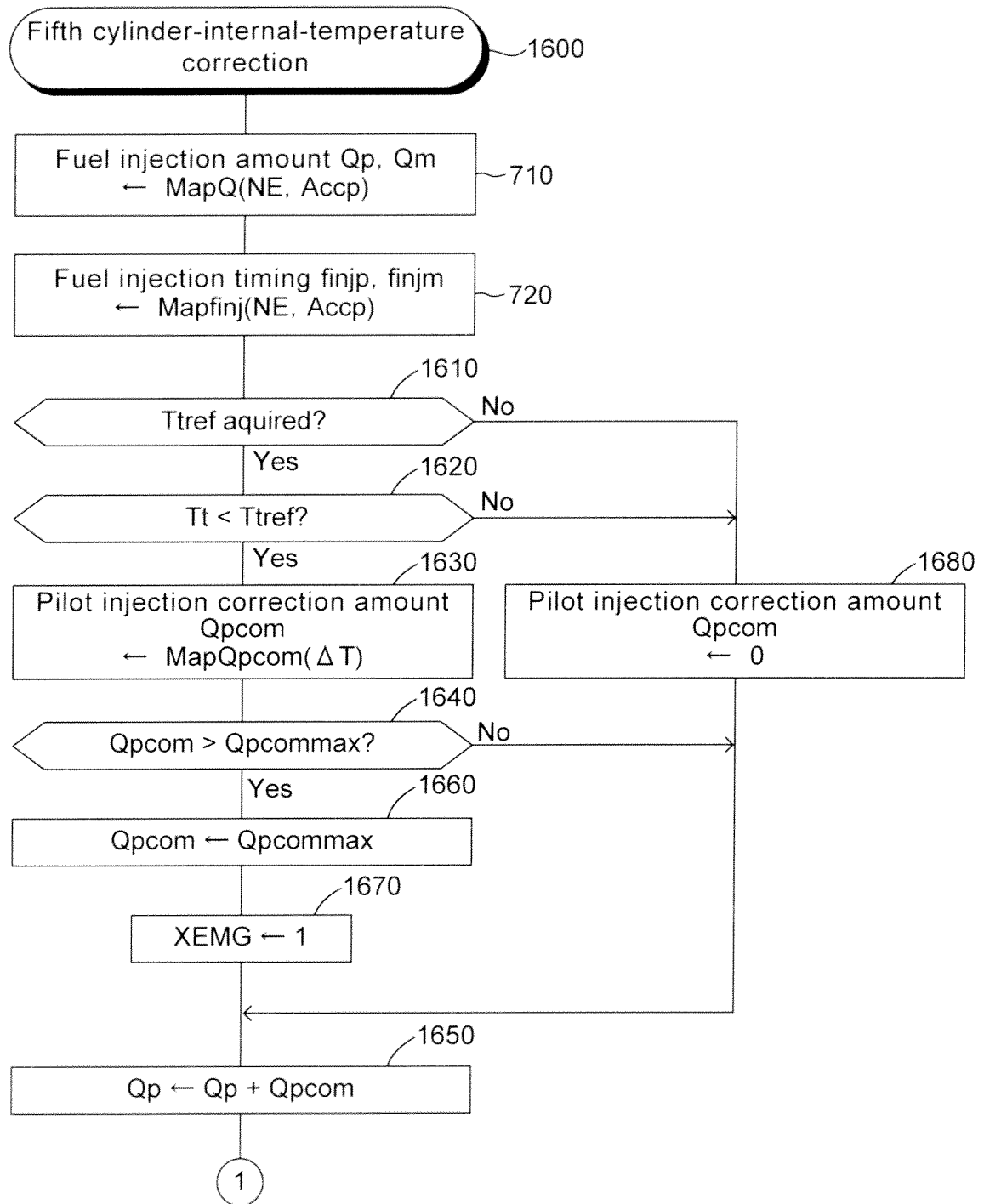


FIG. 16

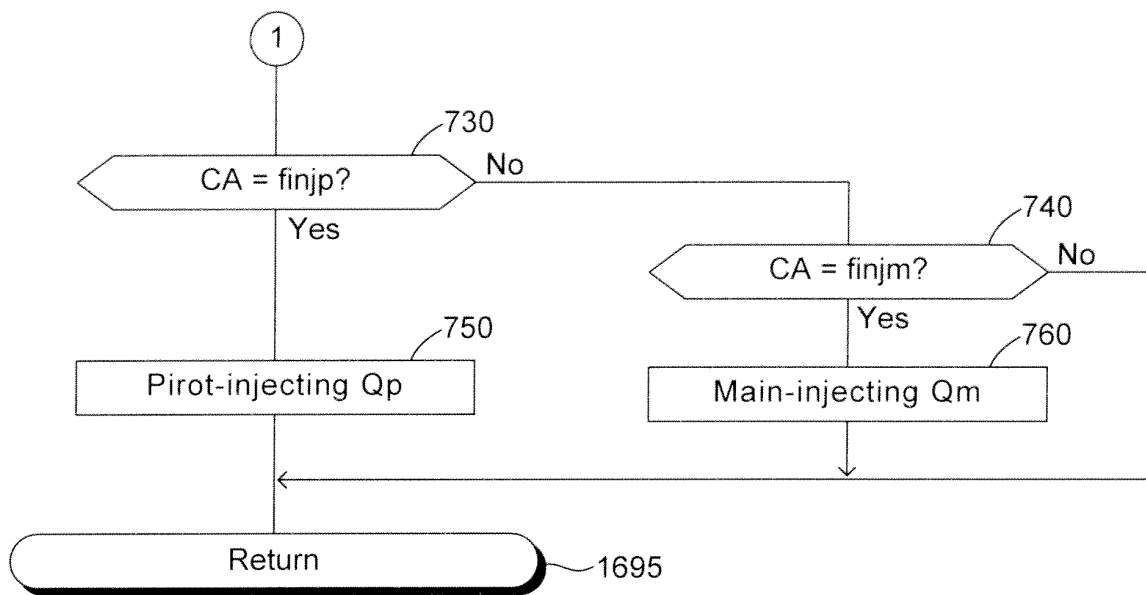


FIG. 17

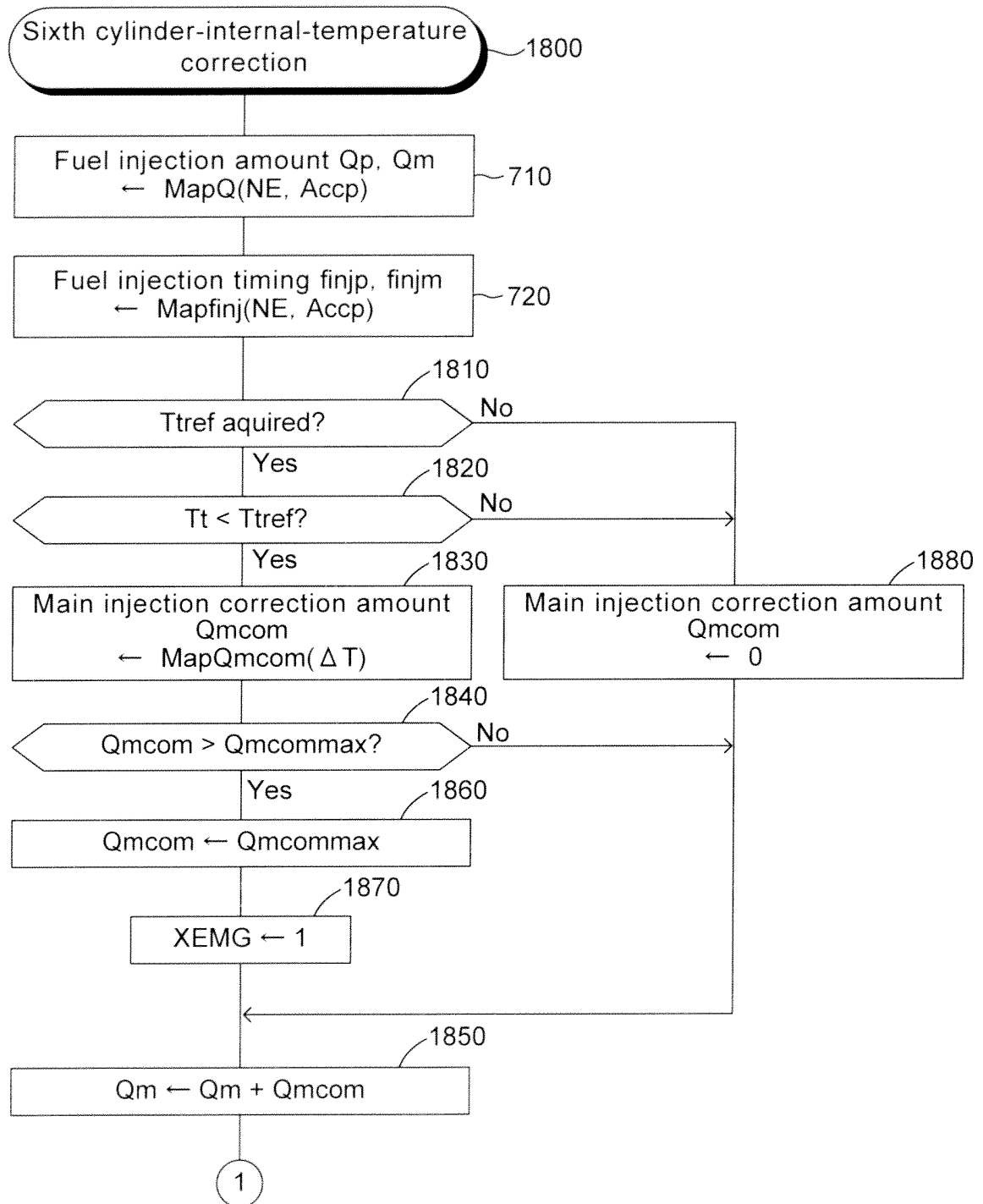


FIG. 18

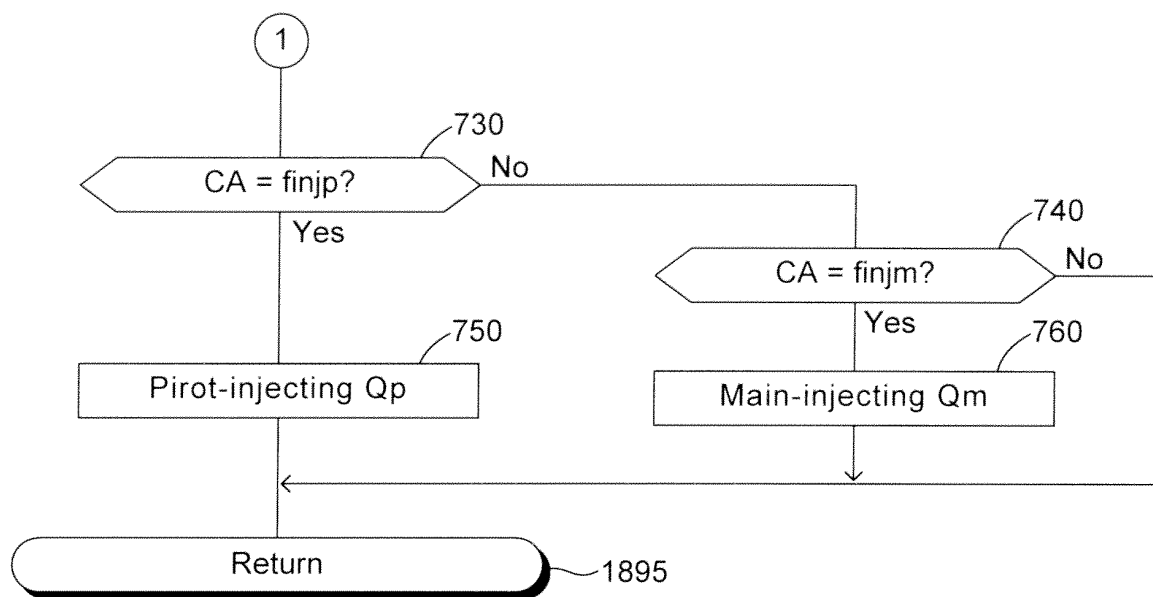


FIG. 19

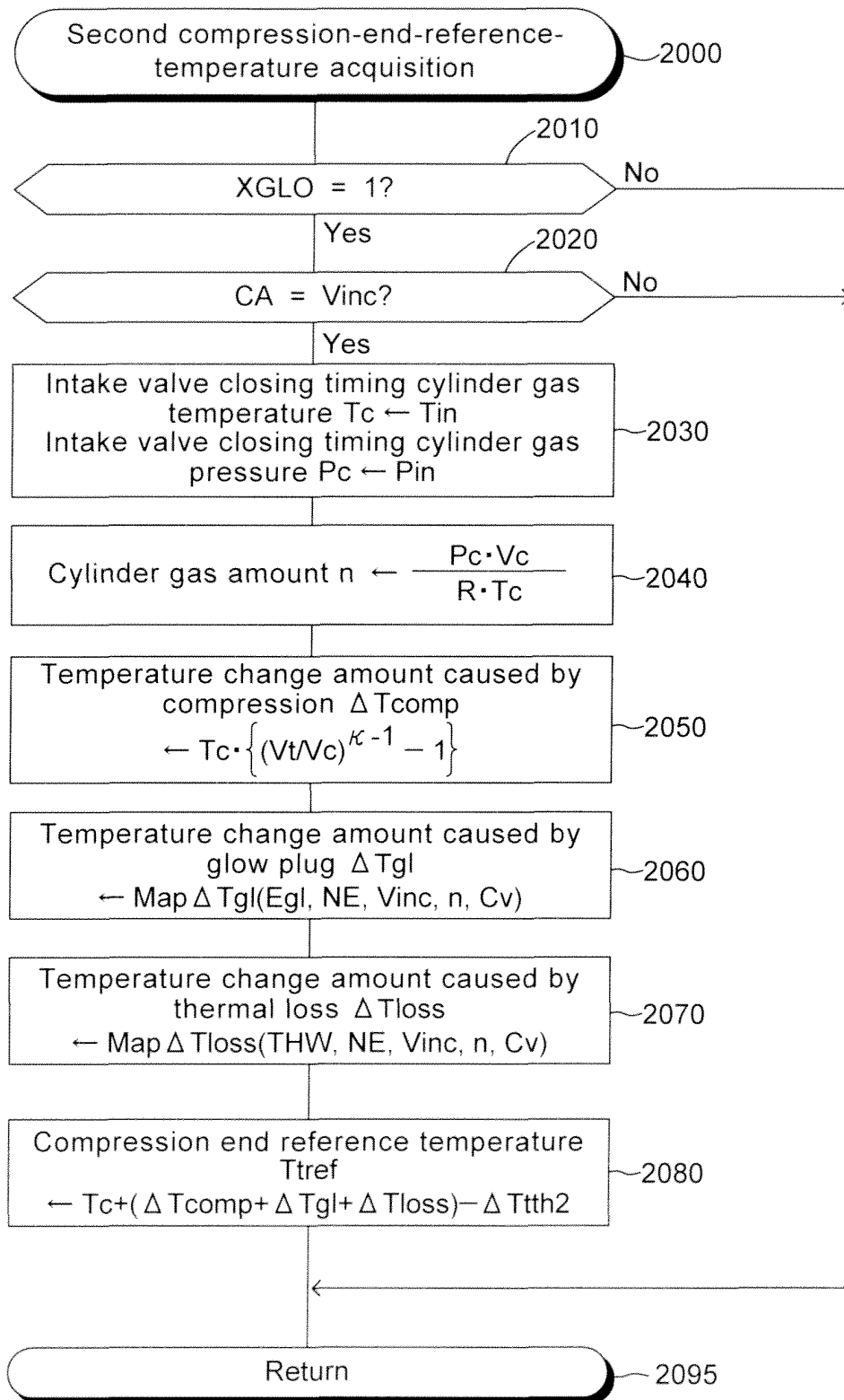


FIG. 20

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2010/052128

A. CLASSIFICATION OF SUBJECT MATTER

F02D45/00 (2006.01) i, F02D43/00 (2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F02D45/00, F02D43/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2010

Kokai Jitsuyo Shinan Koho 1971-2010 Toroku Jitsuyo Shinan Koho 1994-2010

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2009-7966 A (Honda Motor Co., Ltd.), 15 January 2009 (15.01.2009), abstract; paragraphs [0017], [0041], [0042], [0047] & EP 2009268 A1	1-7
Y	JP 2009-62960 A (Mazda Motor Corp.), 26 March 2009 (26.03.2009), paragraph [0064] (Family: none)	1-7
Y	JP 2008-267207 A (Toyota Motor Corp.), 06 November 2008 (06.11.2008), paragraphs [0015], [0018] (Family: none)	5-7

☐

Further documents are listed in the continuation of Box C.

☐

See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"I" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

19 March, 2010 (19.03.10)

Date of mailing of the international search report

06 April, 2010 (06.04.10)

Name and mailing address of the ISA/

Japanese Patent Office

Authorized officer

Facsimile No.

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2007303423 A [0057]
- JP 2004150397 A [0057]