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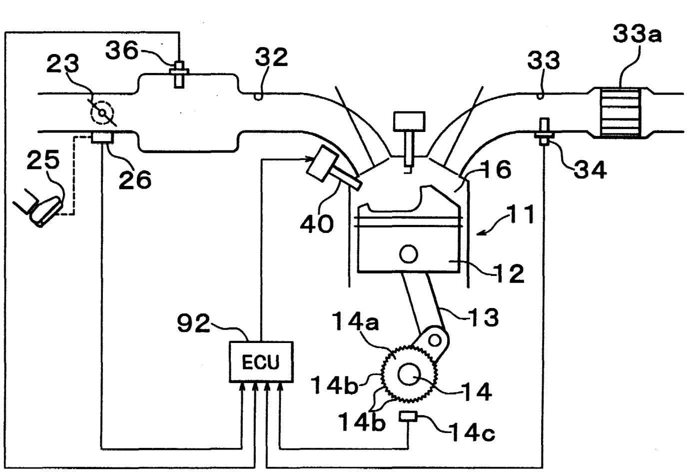
(54) **Internal combustion engine control apparatus and method for controlling the same**

(57) A forced stoichiometric combustion is executed every time a cumulative travel distance of a vehicle increases by a distance, thereby creating an opportunity to determine an air-fuel ratio value in a region in which a rich spike control is performed. Therefore, the determination of an air-fuel ratio value can be precisely calculated so that the air-fuel ratio value corresponds to a value that reflects a deviation of the actual air-fuel ratio and a proper value. Accordingly, it becomes possible to control, with high precision, correlation between the air-fuel ratio and a proper value based on the determined air-fuel ratio value during a fuel-rich combustion that is caused by the rich spike control.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

1. Field of Invention

[0001] The invention relates to a control apparatus of an internal combustion engine and a method for controlling the same.

2. Description of Related Art

[0002] Recently, in order to achieve both improved fuel economy and secured output of an automotive internal combustion engine, a type of internal combustion engine has been commercialized in which the combustion mode is changed between a lean combustion mode and a stoichiometric combustion mode based on the state of operation of the engine. An example of such an internal combustion engine is described in Japanese Patent Application Laid-Open No. HEI 7-332071.

[0003] In this type of engine, it is difficult to control oxides of nitrogen (NOx) by an ordinary three-way catalyst during the lean combustion mode. Therefore, a NOx storage-reduction catalyst is provided in the exhaust system so that NOx produced during the lean combustion mode is absorbed and stored thereby preventing degraded NOx emissions. If the amount of NOx stored in the NOx storage-reduction catalyst exceeds an allowable value, a rich spike control is performed that temporarily shifts the air-fuel ratio to a fuel-rich air-fuel ratio. Due to a fuel-rich combustion caused by the rich spike control, NOx stored in the NOx storage-reduction catalyst is reduced into nitrogen (N_2) by hydrocarbons (HCs) and the like that exist in exhaust gas, thereby preventing NOx saturation of the catalyst.

[0004] However, if the actual air-fuel ratio varies from a proper value during the fuel-rich combustion caused by the rich spike control, then proper reduction of NOx to N_2 becomes impossible. Furthermore, the amount of HCs emitted can increase, thus leading to deterioration of exhaust emission. It is therefore conceivable to maintain this proper value of the air-fuel ratio by controlling the actual air-fuel ratio during the rich spike control. This control is based on an air-fuel ratio value that is determined as a result of a deviation that occurs between the actual air-fuel ratio and the proper value throughout the air-fuel ratio feedback control during a stoichiometric combustion operation.

[0005] However, the determination of the air-fuel ratio value is performed only when a predetermined condition is met during the stoichiometric combustion operation. Therefore, the opportunity to determine this air-fuel ratio value decreases in an internal combustion engine in which the combustion mode is changed between the stoichiometric combustion mode and the lean combustion mode. Therefore, when the air-fuel ratio is controlled based on the determined air-fuel ratio value during the rich spike control, there is no assurance that this air-fuel ratio value is a value that corresponds to the deviation between the actual air-fuel ratio and the proper value of the ratio. If a precise determination of this air-fuel ratio value has not been accomplished, good precision in controlling the air-fuel ratio during the rich spike control cannot be secured, thereby degrading the exhaust emission.

SUMMARY OF THE INVENTION

[0006] Accordingly, it is an object of the invention to provide a control apparatus and a control method of an internal combustion engine in which the combustion mode can be changed, and in which the control apparatus is capable of accurately controlling the air-fuel ratio in the rich spike control in order to curb deterioration of exhaust emission.

[0007] Means for achieving the aforementioned object and operation and advantages thereof will be described.

[0008] A first mode of the invention is applied to an internal combustion engine in which a NOx storage-reduction catalyst is provided in an exhaust system, and in which a combustion mode is changed between a lean combustion and a stoichiometric combustion in accordance with a state of operation of the engine. A control apparatus of the internal combustion engine in accordance with the first mode executes a rich spike control of temporarily shifting an air-fuel ratio to a fuel-rich air-fuel ratio when a condition for reducing NOx stored in the NOx storage-reduction catalyst is met. Furthermore, during the rich spike control, the control apparatus controls the air-fuel ratio based on an air-fuel ratio value that is determined through an air-fuel ratio feedback control during execution of a stoichiometric combustion, wherein the controller forcibly executes the stoichiometric combustion regardless of the state of operation of the engine, every time the internal combustion engine is operated for a predetermined period.

[0009] In some cases, the air-fuel ratio varies from a proper value due to over-time changes in a fuel supply system and an intake system of an internal combustion engine, and the like. However, in the first mode of the invention, this deviation between the actual air-fuel ratio and the proper value is reflected as an air-fuel ratio value through the air-fuel ratio feedback control during the stoichiometric combustion operation. This construction creates an opportunity to determine the air-fuel ratio value every time the internal combustion engine is operated for a predetermined time, so that the air-fuel ratio value is precisely determined as a value that corresponds to the deviation between the actual air-fuel ratio and the proper value. As a result, good precision of the air-fuel ratio control based on the determined air-fuel ratio value during the rich spike control can be secured, and a situation in which the determined air-fuel ratio value becomes an improper value, and therefore the exhaust emission deterioration can be prevented.

[0010] In the first mode of the invention, the controller may forcibly execute the stoichiometric combustion regardless of the state of operation of the engine, every time a cumulative travel distance of a vehicle in which the internal combustion engine is installed increases by a predetermined distance.

[0011] Therefore, every time the cumulative travel distance of the vehicle increases by this predetermined distance, the stoichiometric combustion is forcibly executed, thereby creating an opportunity to determine an air-fuel ratio value. Hence, the variation of the actual air-fuel ratio from the proper value due to over-time changes and the like can be accurately determined and reflected as an air-fuel ratio value.

[0012] In the first mode of the invention, the controller may forcibly execute the stoichiometric combustion regardless of the state of operation of the engine, every time a cumulative operation time of the internal combustion engine increases by a predetermined time.

[0013] Therefore, every time the cumulative operation time of the internal combustion engine increases by the predetermined time, the stoichiometric combustion is forcibly executed thereby creating an opportunity to determine an air-fuel ratio value. Hence, the variation of the actual air-fuel ratio from the proper value due to over-time changes and the like can be accurately determined and reflected as an air-fuel ratio value.

[0014] In the above-described mode of the invention, the controller may discontinue a forced stoichiometric combustion on a condition that the air-fuel ratio value converges with a predetermined value due to the determination performed through the feedback control.

[0015] Therefore, on the condition that the air-fuel ratio converges with a predetermined value after the stoichiometric combustion is forcibly executed, the stoichiometric combustion is discontinued, and switching from the stoichiometric combustion to a lean combustion is permitted. Hence, during execution of a forced stoichiometric combustion as described above, the air-fuel ratio value is more precisely determined to reflect a deviation between the actual air-fuel ratio and the proper value. Thus, it becomes possible to further improve the precision of the air-fuel ratio control based on the determined air-fuel ratio value during the rich spike control.

[0016] In the above-described mode of the invention, the air-fuel ratio value may be determined separately for each one of a plurality of air-fuel ratio determination regions that are set in an operation region in which a lean combustion is executed, and the controller may discontinue the forced stoichiometric combustion on a condition that all the determined air-fuel ratio values corresponding to the plurality of air-fuel ratio determination regions converge.

[0017] Therefore, the air-fuel ratio values that correspond to the air-fuel ratio determination regions can be precisely determined to reflect deviations between the actual air-fuel ratio and the proper value. Since one of the determined air-fuel ratio values that is suitable to the engine operation state can be used for the air-fuel ratio control during the rich spike control, the precision of the air-fuel ratio control can be further improved.

[0018] In the above-described mode of the invention, the controller may discontinue the forced stoichiometric combustion regardless of convergence of the determined air-fuel ratio values, if an execution time of the forced stoichiometric combustion equates to at least a predetermined time.

[0019] Therefore, it becomes possible to substantially prevent a situation where the execution time of the forced stoichiometric combustion becomes excessively long and the fuel economy deteriorates, for example, when the determined air-fuel ratio value does not readily converge, or the like.

[0020] The aforementioned predetermined time may be, for example, an upper limit time such that fuel economy deterioration due to the continuation of a forced stoichiometric combustion may be acceptable.

[0021] In the above-described mode of the invention, the controller may continue the stoichiometric combustion regardless of the execution time of the stoichiometric combustion until the determined air-fuel ratio values converge, if the forced stoichiometric combustion commences when the determined air-fuel ratio values equate to an initial value.

[0022] Therefore, if the determined air-fuel ratio value equates to an initial value for any reason, the determined air-fuel ratio value can be converged with a predetermined value as soon as possible, and can reflect the deviation between the air-fuel ratio and the proper value. Since the rich spike control is executed with the determined air-fuel ratio value equating to the initial value, deterioration of the precision of the air-fuel ratio control during the rich spike control can be curbed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The foregoing and further objects, features and advantages of the invention will become apparent from the following description of preferred embodiments with reference to the accompanying drawings, wherein like numerals are used to represent like elements and wherein:

FIG. 1 is a schematic diagram illustrating an overall construction of an engine to which a control apparatus in accordance with a first embodiment of the invention is applied;

FIG. 2 is a diagram indicating a region in which a lean combustion operation is performed, and a region in which a stoichiometric combustion operation is performed;

FIG. 3 is a flowchart illustrating a procedure of commanding execution of a forced stoichiometric combustion operation and a procedure of permitting a lean combustion operation in accordance with the first embodiment;

FIG. 4 is a flowchart illustrating a procedure of commanding execution of a forced stoichiometric combustion operation and a procedure of permitting a lean combustion operation in accordance with a second embodiment;

FIG. 5 is a flowchart illustrating a procedure of commanding execution of a forced stoichiometric combustion operation and a procedure of permitting a lean combustion operation in accordance with the second embodiment; and

FIG. 6 is a flowchart illustrating a procedure of determining a determined air-fuel ratio value in the second embodiment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0024] A first embodiment in which the invention is applied to an automotive engine will be described with reference to FIGS. 1 to 3.

[0025] As shown in FIG. 1, a piston 12 of an engine 11 is connected to a crankshaft 14 via a connecting rod 13 so that reciprocating movements of the piston 12 are converted into rotation of the crankshaft 14 by the connecting rod 13. The crankshaft 14 is provided with a signal rotor 14a that has a plurality of protrusions 14b. Provided at a side of the signal rotor 14a is a crank position sensor 14c that outputs a pulsed signal corresponding to each protrusion 14b as the crankshaft 14 turns.

[0026] An intake passage 32 and an exhaust passage 33 are connected to a combustion chamber 16 of the engine 11. A throttle valve 23 for adjusting the amount of air taken into the engine 11 is provided in an upstream portion of the intake passage 32. The degree of opening of the throttle valve 23 is adjusted based on an amount of depression of an accelerator pedal 25 (accelerator depression amount) detected by an accelerator position sensor 26. A vacuum sensor 36 for detecting the pressure in the intake passage 32 (intake pressure) is provided in the intake passage 32 downstream of the throttle valve 23.

[0027] The engine 11 is provided with a fuel injection valve 40 that directly injects fuel into the combustion chamber 16 so as to form a mixture of fuel and air. Due to combustion of air-fuel mixture in the combustion chamber 16, the piston 12 reciprocates, and the crankshaft 14 turns, thereby driving the engine 11. A mixture gas existing after combustion in the combustion chamber 16 is discharged, as exhaust, out into the exhaust passage 33.

[0028] The exhaust passage 33 is provided with a NOx storage-reduction catalyst 33a that absorbs oxides of nitrogen (NO_x) from exhaust gas when air-fuel mixture burns at an air-fuel ratio that is on a fuel-lean side of the stoichiometric air-fuel ratio. NOx stored in the NOx storage-reduction catalyst 33a is reduced into nitrogen (N_2) by hydrocarbons (HCs) present in exhaust gas when air-fuel mixture burns at an air-fuel ratio that is on a fuel-rich side of the stoichiometric air-fuel ratio. Provided in the exhaust passage 33 upstream of the NOx storage-reduction catalyst 33a is an oxygen (02) sensor 34 that detects oxygen contained in exhaust gas and outputs a detection signal corresponding to the concentration of oxygen.

[0029] An electrical construction of a control apparatus of the engine 11 in accordance with the embodiment will be described.

[0030] The control apparatus includes an electronic control unit (hereinafter, referred to as "ECU") 92 for controlling the state of operation of the engine 11, such as the mode of combustion, the amount of fuel injected, etc. The ECU 92 has a RAM, that is, a memory for temporarily storing data inputted from various sensors and the like, a backup RAM, that is, a non-volatile memory for storing data and the like that need to be retained, during a stop of the engine 11, etc. The ECU 92 is connected to the crank position sensor 14c, the accelerator position sensor 26, the oxygen sensor 34, the vacuum sensor 36, the fuel injection valve 40, etc.

[0031] The ECU 92 switches the mode of combustion of air-fuel mixture between a stoichiometric combustion mode in which mixture is burned at the stoichiometric air-fuel ratio, and a lean combustion mode in which mixture is burned at an air-fuel ratio on the lean side of the stoichiometric air-fuel ratio, in accordance with the state of operation of the engine. For example, if the state of operation of the engine 11 is in a high-speed and high-load region, i.e., stoichiometric combustion region as indicated by A in FIG. 2, the stoichiometric combustion operation is performed so as to produce a necessary engine output.

[0032] If the state of operation of the engine 11 is in a low-speed and low-load region, i.e., lean combustion region as indicated by B in FIG. 2, the lean combustion operation is performed to improve the fuel economy of the engine 11. The combustion mode of the engine 11 is not necessarily determined in correspondence with the region of operation of the engine 11 as mentioned above. For example, if the engine 11 is in an operation state that is different from a normal state, for example, immediately after the engine 11 is started, the stoichiometric combustion operation is performed even when the operation state of the engine 11 is in the low-speed and low-load region, i.e., lean combustion region indicated in by B in FIG. 2.

[0033] During the lean combustion operation of the engine 11, the NOx storage-reduction catalyst 33a absorbs NOx from exhaust gas, so that the amount of NOx stored in the catalyst 33a gradually increases. The ECU 92 estimates a current amount of Nox stored based on the state of engine operation. When the estimated amount of Nox stored exceeds an allowable value, the ECU 92 performs a rich spike control in which the air-fuel ratio of mixture is temporarily shifted to a fuel-rich side of the stoichiometric air-fuel ratio e.g., to "12". Due to the fuel-rich mixture combustion caused by the rich spike control, NOx stored in the NOx storage-reduction catalyst 33a is reduced into N_2 by HCs present in exhaust gas, thereby preventing NOx saturation of the NOx storage-reduction catalyst 33a.

[0034] During execution of the rich spike control, the ECU 92 calculates a final amount of fuel injection Qfin based on equation (1), and drives and controls the fuel injection valve 40 so that an amount of fuel corresponding to the final amount of fuel injection Qfin is injected into the combustion chamber 16.

$$Qfin = Qbse*FAF*KG(i)*A \quad (1)$$

Qbse: basic amount of fuel injection
FAF: feedback correction factor
KG(i): determined air-fuel ratio value
A: increasing factor

[0035] The basic amount of fuel injection Qbse, a feedback correction factor FAF, a determined air-fuel ratio value KG(i), and an increasing factor A used to calculate the final amount of fuel injection Qfin will be described.

a. BASIC AMOUNT OF FUEL INJECTION Qbse

[0036] The basic amount of fuel injection Qbse is a value calculated by the ECU 92 based on a load rate KL and an engine revolution speed NE such that the air-fuel ratio becomes equal to the stoichiometric air-fuel ratio during the stoichiometric combustion operation. The basic amount of fuel injection Qbse increases with increases in the load rate KL under the condition that the engine revolution speed NE is constant. The engine revolution speed NE is detected based on detection signals from the crank position sensor 14c.

[0037] The load rate KL is a value that indicates the proportion of a current load to the maximum engine load of the engine 11. The load rate KL is calculated from the engine revolution speed NE and a parameter corresponding to the amount of air taken into the engine 11. Examples of the parameter corresponding to the amount of intake air include an intake pressure PM determined based on a detection signal from the vacuum sensor 36, an accelerator depression amount ACCP determined based on a detection signal from the accelerator position sensor 26, etc.

b. FEEDBACK CORRECTION FACTOR FAF

[0038] The feedback correction factor FAF is a value that is used for correcting the amount of fuel injection performed via the ECU 92 so that the air-fuel ratio becomes equal to the stoichiometric air-fuel ratio during the stoichiometric combustion operation. During the stoichiometric combustion operation, the ECU 92 increases or decreases the feedback correction factor FAF, with "1.0" being a center value, in accordance with whether the value indicated by the detection signal from the oxygen sensor 34 is on the fuel-rich side or on the fuel-lean side of the value corresponding to the stoichiometric air-fuel ratio. That is, if the value indicated by the detection signal from the oxygen sensor 34 is on the rich side of the value corresponding to the stoichiometric air-fuel ratio, the ECU 92 decreases the feedback correction factor FAF to decrease the amount of fuel injected.

[0039] If the value indicated by the detection signal from the oxygen sensor 34 is on the lean side of the value corresponding to the stoichiometric air-fuel ratio, the ECU 92 increases the feedback correction factor FAF to increase the amount of fuel injected. By correcting the amount of fuel injected based on the feedback correction factor FAF, the air-fuel ratio is brought closer to the stoichiometric air-fuel ratio during the stoichiometric combustion operation. During execution of the rich spike control, the feedback correction factor FAF used to calculate the final amount of fuel injection Qfin in equation (1) is set to "1.0" regardless of the value of the feedback correction factor FAF set during the stoichiometric combustion operation.

c. DETERMINED AIR-FUEL RATIO VALUE KG(i)

[0040] The determined air-fuel ratio value KG(i) is a value that is increased or decreased, with "1.0" being a center value, based on an average value FAFAV of the feedback correction factor FAF during the stoichiometric combustion operation, in such a fashion that the average value FAFAV converges into a predetermined range that contains "1.0", which is a reference value of the average value FAFAV. During the stoichiometric combustion operation, the ECU 92 increases the determined air-fuel ratio value KG(i) if the average value FAFAV deviates from the predetermined range to an increase side. If the average value FAFAV deviates from the predetermined range to a decrease side, the ECU 92 decreases the determined air-fuel ratio value KG(i). By increasing or decreasing the determined air-fuel ratio value KG(i) based on the average value FAFAV in this manner, the average value FAFAV is converged into the predetermined range, and the determination of the air-fuel ratio value KG(i) is completed. The air-fuel ratio value KG(i) is provided as a determined value that corresponds to the deviation between the actual air-fuel ratio and the appropriate value.

[0041] The ECU 92 sets a plurality of air-fuel ratio determination regions i, i.e., i = 1, 2, 3, ..., in accordance with the engine load, i.e., load rate KL, of the engine 11, and sets a determined air-fuel ratio value KG(i) for each air-fuel ratio determination region. Of the air-fuel ratio determination regions i, a low load-side air-fuel ratio determination region i exists in the low-speed and low-load region, i.e., lean combustion region, indicated by B in FIG. 2. In this embodiment, the air-fuel ratio determination regions i are set in accordance with the load rate KL so that only one air-fuel ratio determination region i exists in the lean combustion region indicated by B in FIG. 2. Separately for each air-fuel ratio determination region i, the ECU 92 increases or decreases the determined air-fuel ratio value KG(i) so that the average value FAFAV becomes equal to a value within the aforementioned predetermined range, and stores into a predetermined area of the backup RAM the determined air-fuel ratio value KG(i) that brings the average value FAFAV to a value within the predetermined range. For the calculation of a final amount of fuel injection Qfin in equation (1), the ECU 92 uses the determined air-fuel ratio value KG(i) corresponding to the air-fuel ratio determination region i (i=1) present in the lean combustion region indicated by B in FIG. 2, i.e., determined air-fuel ratio value KG(1). The reason is because the rich spike control, which uses the final amount of fuel injection Qfin, is executed when the state of operation of the engine 11 is in the lean combustion region indicated by B in FIG. 2.

d. INCREASING FACTOR A

[0042] The increasing factor A is set to a value that is greater than "1.0" by the ECU 92, and is multiplied by the term "Qbse*FAF*KG(i)" indicated in equation (1). By multiplying the increasing factor A by the term "Qbse*FAF*KG(i)," the final amount of fuel injection Qfin is increased so that the air-fuel ratio provided when the rich spike control is executed assumes a value on the rich side of the stoichiometric air-fuel ratio e.g., "12". Due to the rich combustion caused by the rich spike control, NOx stored in NOx storage-reduction catalyst 33a is reduced into N_2 by HCs in exhaust gas.

[0043] The rich spike control is executed when the operation state of the engine 11 is in the low-speed and low-load region indicated by B in FIG. 2, i.e., the lean combustion region. In the lean combustion region, stoichiometric combustion operation is performed only when the engine 11 is in an operation state that is different from a normal state, for example, immediately after the engine 11 is started, or the like. Therefore, the opportunity to execute the stoichiometric combustion operation decreases, and the opportunity of determining the air-fuel ratio value KG(i) (i=1) during the stoichiometric combustion operation also decreases.

[0044] If the opportunity of determining the air-fuel ratio value KG(i) decreases, the air-fuel ratio value KG(i) may not always correspond to the deviation between the actual air-fuel ratio and the proper value. If the determined air-fuel ratio value KG(i) is not accurate, the final amount of fuel injection Qfin calculated from the determined value KG(i) as in equation (1) also reflects an inappropriate value. As a result, during the rich combustion operation caused by the rich spike control, execution of a fuel injection amount control based on the final amount of fuel injection Qfin fails to control the air-fuel ratio to a proper value e.g., to "12". Variation between the air-fuel ratio and the proper value during the rich combustion operation causes NOx stored in the NOx storage-reduction catalyst 33a to not be appropriately reduced into N_2, or that the amount of HCs emitted increases, thus leading to degraded exhaust emission.

[0045] In this embodiment, therefore, the stoichiometric combustion operation is forcibly performed, regardless of the engine operation state, every time the operation of the engine 11 continues for a predetermined period. For example, every time the cumulative travel distance of a vehicle in which the engine 11 is installed increases by a predetermined distance, then the stoichiometric combustion operation is forcibly performed. Forced execution of the stoichiometric combustion operation in this manner creates an opportunity to determine an air-fuel ratio value KG(i) (i=1) that corresponds to the air-fuel ratio determination region i (i=1) present in the lean combustion region as indicated by B in FIG. 2. As the determination of the air-fuel ratio value KG(i) proceeds during the stoichiometric combustion operation in the lean combustion region, the determined air-fuel ratio value KG(i) converges toward a predetermined value, and thus becomes equal to a value that corresponds to the deviation between the actual air-fuel ratio and the proper value.

[0046] The determination of the air-fuel ratio value KG (i) is more easily calculated if the execution period of a forced stoichiometric combustion operation is longer. However, an excessively elongated execution period of the operation becomes disadvantageous with regard to fuel economy of the engine 11. Therefore, this embodiment adopts, as an execution period of each forced stoichiometric combustion operation, a period of time that is needed before the total execution time of the stoichiometric combustion operation in the lean combustion region indicated by B in FIG. 2 reaches a time t that is suitable to achieve both the determination of the air-fuel ratio value KG(i) and improvement of fuel economy of the engine 11. An example of the time t may be a minimum time, e.g., 2 or 3 minutes, that is needed before the determined air-fuel ratio value KG(1) converges as described above.

[0047] As described above, by forcibly executing the stoichiometric combustion operation every time the engine 11 is operated for the predetermined period, an opportunity to determine the air-fuel ratio value KG(i) in the lean combustion region indicated by B in FIG. 2 is created so that the determined air-fuel ratio value KG(i) can correspond to a value that reflects the deviation between the actual air-fuel ratio and the proper value. Then, by calculating a final amount of fuel injection Qfin from the determined air-fuel ratio value KG(i) as in equation (1), and by performing the fuel injection amount control based on the final amount of fuel injection Qfin at the time of the rich combustion operation caused by the rich spike control, the air-fuel ratio can be prevented from deviating from a proper value, e.g., "12". Therefore, it is possible to prevent a situation where, due to deviation of the air-fuel ratio from the proper value during the rich combustion operation, NOx stored in the NOx storage-reduction catalyst 33a is not properly reduced into N_2 or the amount of HCs emitted increases thereby deteriorating exhaust emission.

[0048] Next, a procedure of commanding execution of a forced stoichiometric combustion operation will be described with reference to the flowchart of FIG. 3 illustrating a stoichiometric combustion commanding routine. The stoichiometric combustion commanding routine is executed via the ECU 92, for example, by a time interrupt of every predetermined time.

[0049] In the stoichiometric combustion commanding routine, "1" is stored into a predetermined area of the RAM, as a flag F for commanding the forced stoichiometric combustion operation (S102, S103), when the cumulative travel distance of the vehicle equipped with the engine 11 increases by a distance d, e.g., 1000 km, after the previous execution of the forced stoichiometric combustion operation. Furthermore, a value of a counter C is reset to "0" when F=1 is set and is increased by "1" at every predetermined time on condition that the operation state of the engine 11 is in the lean combustion region indicated by B in FIG. 2 and the stoichiometric combustion operation is being performed (S105, S106). The counter C indicates a total amount of time of execution of the stoichiometric combustion operation in the lean combustion region indicated by B in FIG. 2. When the value of the counter C becomes equal to or greater than a predetermined value x, i.e., a value corresponding to the time t, "0" is stored as the flag F into a predetermined area of the RAM (S107, S108). If the flag F is "1", execution of the forced stoichiometric combustion operation is commanded. If the flag F is "0", execution of the lean combustion operation is permitted (S109 to S111).

[0050] In step S101, the ECU 92 determines whether the flag F is "0," i.e., permitting the lean combustion operation. If F=1, i.e., commanding the stoichiometric combustion operation, the ECU 92 skips steps S102 to S104, and goes to step S105. If F=0, the ECU 92 goes to step S102. At step S102, the ECU 92 determines whether the cumulative travel distance has increased by the distance d, e.g., 1000 km, from the value occurring at the time of the previous execution of the forced stoichiometric combustion operation. If negative determination is made in step S102, the ECU 92 skips steps S103 to S108, and goes to the step S109. If affirmative determination is made in step S102, the ECU 92 goes to step S103. The ECU 92 sets the flag F to "1," i.e., commanding the stoichiometric combustion operation," in step S103, and resets the counter C to "0" in step S104. Then, the ECU 92 goes to step S105.

[0051] In step S105, the ECU 92 determines whether the state of operation of the engine 11 is within the lean combustion region indicated by B in FIG. 2, and the flag F is "1," i.e., commanding the stoichiometric combustion operation, for example, whether all the following conditions (a) to (c) are met.

(a) the engine revolution speed NE is a value between the range of a predetermined value a and a predetermined b;
(b) the load rate KL is a value between the range of a predetermined value α and a predetermined value β; and
(c) the flag F is "1," i.e., commanding the stoichiometric combustion operation.

[0052] In condition (a), the predetermined value a is set to, for example, an idle revolution speed, and the predetermined value b is set to, for example, a value that is slightly to a low revolution speed side of a value that is farthest toward a high revolution speed side within the lean combustion region indicated by B in FIG. 2. In condition (b), the predetermined value α is set to the load rate KL occurring during idle operation, and the predetermined value β is set to a value that is slightly to a low load side of a value that is farthest toward the high load side in the lean combustion region indicated by B in FIG. 2.

[0053] In step S105, if any one of the aforementioned conditions is unmet, step S106 is skipped, and the process proceeds to step S107. If all the conditions are met, the process proceeds to step S106. In step S106, the ECU 92 increases the value of the counter C by "1". After that, the ECU 92 goes to step S107.

[0054] In step S107, the ECU 92 determines whether the value of the counter C is at least a predetermined value x, i.e., value corresponding to the time t. If $C \geq x$ is not the case, then the ECU 92 skips step S108, and goes to step S109. If $C \geq x$ is the case, then the ECU 92 goes to step S108, in which the ECU 92 sets the flag F to "0."

[0055] The ECU 92, in step S109, determines whether the flag F is "1" i.e., commanding the stoichiometric combustion operation. If F=1, the ECU 92 commands execution of the stoichiometric combustion operation in step S 110. If F=0, the ECU 92 permits execution of the lean combustion operation in step S111. After executing step S110 or step S111, the ECU 92 temporarily ends the stoichiometric combustion commanding routine.

[0056] The above-described embodiment achieves the following advantages.

[0057] Every time the cumulative travel distance of the motor vehicle increases by the distance d, the forced stoichiometric combustion operation is performed, thereby creating an opportunity to determine an air-fuel ratio value KG(i) in the lean combustion region indicated by B in FIG. 2, i.e., the region in which the rich spike control is performed. Since an opportunity of determining the air-fuel ratio value KG(i) is forcibly created at every predetermined period, it becomes possible to precisely determine the air-fuel ratio value KG(i) so that the air-fuel ratio value KG(i) corresponds to a value that reflects the deviation between the actual air-fuel ratio and the proper value. By conducting the determination of the air-fuel ratio value KG(i) in this manner, it becomes possible to control, with high precision, the air-fuel ratio to a proper value, e.g., "12," based on the determined air-fuel ratio value KG(i) during the rich combustion operation caused by the rich spike control. Therefore, it is possible to prevent a situation where, due to a deviation between the actual air-fuel ratio and the proper value during the rich combustion operation, NOx stored in the NOx storage-reduction catalyst 33a is not properly reduced into N_2 or the amount of HCs emitted increases thereby deteriorating exhaust emission.

[0058] Each forced stoichiometric combustion operation is continued until the total time of execution of the stoichiometric combustion operation in the lean combustion region indicated by B in FIG. 2 reaches the time t, for example, 2 or 3 minutes, that is suitable to achieve both determination of the air-fuel ratio value KG(i) and improvement of fuel economy of the engine 11. Therefore, the determined air-fuel ratio value KG(i) is more precisely calculated as a value that corresponds to the deviation between the actual air-fuel ratio and the proper value, so that the precision of the air-fuel ratio control based on the determined air-fuel ratio value KG(i) during the rich spike control can be further improved.

[0059] A second embodiment of the invention will be described with reference to FIGS. 4 and 5. In this embodiment, a plurality of air-fuel ratio determination regions i are set in a lean combustion region. The procedures of starting and discontinuing a forced stoichiometric combustion operation for determining an air-fuel ratio value KG(i) separately for each air-fuel ratio determination region i are different from those of the first embodiment.

[0060] FIGS. 4 and 5 show a flowchart illustrating a stoichiometric combustion commanding routine of this embodiment. This stoichiometric combustion commanding routine is periodically executed via the ECU 92, as is the case with the routine of the first embodiment (FIG. 3).

[0061] In the stoichiometric combustion commanding routine, steps S201 to S204 set a flag F to "1," i.e., commanding the stoichiometric combustion operation. The flag F provides a criterion for determining whether to command execution of a forced stoichiometric combustion operation. If the flag F is set to "1," a forced stoichiometric combustion operation is started based on the processing described below.

[0062] In steps S201 to S204, it is determined whether the flag F is "0", for example, whether a forced stoichiometric combustion operation is not being commanded (S201). If the commanding of a stoichiometric combustion operation ("F=1") is not present, it is then determined whether a forced stoichiometric combustion operation needs to be performed. This determination is performed based on determination, for example, as to:

(a) whether the determined air-fuel ratio values KG (i) i.e., i=1 to 5 in this embodiment, that correspond to the air-fuel ratio determination regions i, i.e., i=1 to 5 in this embodiment, are an initial value, e.g., 1.0, (S202); and

(b) whether the cumulative travel distance of the motor vehicle has increased by the distance d from the value assumed at the time of the previous execution of a forced stoichiometric combustion operation (S203).

[0063] If an affirmative determination is made in either step S202 or step S203, the flag F is set to "1," i.e., commanding the stoichiometric combustion operation (S204). Thus, the forced stoichiometric combustion operation is started, not only based on the cumulative travel distance of the motor vehicle, but also when the determined air-fuel ratio values KG(i), i.e., i=1 to 5, are 1.0 (initial value). For example, this situation would apply in a case where the motor vehicle has not been driven at all, or where the battery has been replaced.

[0064] After the flag F is set to "1" as described above, a counter C is reset to "0" (S205) that indicates the elapsed time following the commanding of execution of a forced stoichiometric combustion operation, for example, the time of execution of the stoichiometric combustion operation. Furthermore, a completion flag X(i) is set to "0" (uncompleted) (S206) for determining whether the determination of an air-fuel ratio value KG(i) that corresponds to the lean combustion region is completed.

[0065] A plurality of completion flags X(i) are provided that correspond to the determined air-fuel ratio values KG(i), i.e., i=1 to 5, of the air-fuel ratio determination regions i, i.e., i=1 to 5, present in the lean combustion region. The completion flags X(i) that correspond to the determined air-fuel ratio values KG(i) are set to "1" (completed), based on convergence of the determined air-fuel ratio values KG(i), i.e., i=1 to 5, to predetermined values.

[0066] It is then determined whether the engine operation state is in the lean combustion region and whether the flag F1 is "1," i.e., commanding the stoichiometric combustion operation, (S207) in FIG. 5. If the determination is affirmative, the determination of the air-fuel ratio values KG(i), i.e., i=1 to 5, that correspond to the lean combustion region is performed (S208). Based on convergence of the determined air-fuel ratio values KG(i) to predetermined values, the completion flags X(i), i.e., i=1 to 5 that correspond to the air-fuel ratio determination regions i are set to "1" (completed).

[0067] A determined air-fuel ratio value KG(i) that corresponds to the present engine operation state, i.e., load rate KL, is used to calculate a final amount of fuel injection Qfin for the rich spike control. Therefore, the air-fuel ratio control during the rich spike control is performed by using a determined air-fuel ratio value KG(i) that is suitable for the present engine operation state.

[0068] In the stoichiometric combustion commanding routine, steps S209 to S212 are performed to set the flag F to "0," i.e., permitting a lean combustion operation, so as to discontinue the forced stoichiometric combustion operation. When the flag F is set to "0," execution of a lean combustion operation is permitted based on the process described below, and thus the forced stoichiometric combustion is discontinued.

[0069] In steps S209 to S212, the flag F is switched from "1," i.e., commanding the stoichiometric combustion operation to "0," i.e., permitting the lean combustion operation in a situation as in the following conditions:

(1) the determination of all the air-fuel ratio values KG(i), i.e., i=1 to 5, is completed; or
(2) the execution time of the forced stoichiometric combustion reaches or exceeds a predetermined time, and the stoichiometric combustion operation was not started with the determined air-fuel ratio values KG(i), i.e., i=1 to 5, being an initial value "1.0".

[0070] It is determined whether the present condition is (1) or (2), based on determination, for example, as to:

(a) whether all the completion flags X(i), i.e., i=1 to 5 are "1" (completed) (S209);
(b) whether the counter C1 is at least a predetermined value x1 (S210); and
(c) whether the forced stoichiometric combustion operation was started in a state in which the determined air-fuel ratio value KG(i), i.e., i=1 to 5, were the initial value equals 1.0 (S211).

[0071] That is, after affirmative determination is made in step S209, thus determining that the condition (1) is present, or after affirmative determination is made in step S210 and negative determination is made in step S211, thus determining that the condition (2) is present, the flag F is set to "0" in step S212.

[0072] Therefore, if the forced stoichiometric combustion operation is started based on the determined air-fuel ratio values KG(i), i.e., i=1 to 5, being 1.0 (initial value), the flag F is switched from "1" to "0" only after the determination of all the air-fuel ratio values KG(i), i.e., i=1 to 5, is completed, regardless of the execution time of the stoichiometric combustion operation.

[0073] If the stoichiometric combustion operation is started based on the cumulative travel distance of the motor vehicle increasing by the distance d following the previous execution of the forced stoichiometric combustion operation, the flag F is switched from "1" to "0" after determining all the air-fuel ratio values KG(i) ("i=1 to 5") is completed, or after the execution time of the forced stoichiometric combustion operation reaches or exceeds a predetermined time.

[0074] The execution time of the forced stoichiometric combustion operation is restricted by the predetermined value x1, corresponding to the aforementioned predetermined time, used in step S210. The predetermined value x1 is preferably a value corresponding to an upper limit value of the execution time such that the fuel economy deterioration caused by the forced stoichiometric combustion operation is acceptable.

[0075] In the stoichiometric combustion commanding routine, the steps S213 to S216 command execution of the stoichiometric combustion operation or permit the lean combustion operation based on the flag F, and periodically increase the value of the counter C1 by "1". First, it is determined whether the flag F is "1," i.e., commanding the stoichiometric combustion operation (S213). If the determination is affirmative, execution of a forced stoichiometric combustion operation is commanded, and the value of the counter C1 indicating the execution time of the stoichiometric combustion operation is increased by "1" (S214, S215). If negative determination is made in step S213, the forced stoichiometric combustion operation for conducting the determination of the air-fuel ratio values KG(i) is discontinued by permitting execution of a lean combustion operation (S216).

[0076] Next, in step S208 within the stoichiometric combustion commanding routine, for example, the determination of the air-fuel ratio values KG(i), i.e., i=1 to 5 that correspond to the lean combustion region, will be described with reference to FIG. 6. FIG. 6 is a flowchart illustrating a determination routine for determining each air-fuel ratio value KG(i). This determination routine is executed via the ECU 92 every time the step S208 in the stoichiometric combustion commanding routine (FIG. 5) is reached.

[0077] In the determination routine, it is determined whether conditions mentioned below are all met (S301).

(a) a warm-up is not being performed;
(b) the state of operation of the engine 11 is stable; and
(c) the air-fuel ratio feedback control is being executed.

[0078] If it is determined that all these conditions are met, it is determined which one of the air-fuel ratio determination regions i, i.e., "i=1 to 5," corresponds to the present engine operation state (S302). The determined air-fuel ratio value KG(i) of the air-fuel ratio determining region i is increased or decreased (updated), with 1.0 being a center value, based on the average value FAFAV of the feedback correction factor FAF so that the feedback correction factor FAF converges into a predetermined range that contains 1.0, which is a reference value of the average value FAFAV (S303).

[0079] It is determined whether the determination of the air-fuel ratio value KG(i), i.e., i=1 to 5 is completed, based on a determination as to whether the average value FAFAV of the feedback correction factor FAF has converged into the predetermined range containing 1.0. This determination is made based on determination, for example, as to:

(a) whether the average value FAFAV has continued to be within a predetermined range of 0.95 to 1.05 for at least a predetermined time t1 (S304); or
(b) whether the cumulative time during which the average value FAFAV is within the predetermined range has reached or exceeded a predetermined time t2 (>t1) (S305).

[0080] The predetermined time t2 is set to a time that is needed before it is determined that the average value FAFAV has converged into the predetermined range in a case where the determination of the air-fuel ratio values KG(i) is intermittently performed, for example, a case where the air-fuel ratio determination region i for the determining frequently changes from one to another, or the like.

[0081] If affirmative determination is made in either step S304 or step S305, the completion flag X(i) corresponding to the determined air-fuel ratio value KG(i) of the air-fuel ratio determination region i calculated in step S302 is set to "1" (completed) (S306).

[0082] In this manner, the determination of the air-fuel ratio values KG(i) correspond to the air-fuel ratio determining regions i, i.e., i=1 to 5. It is determined whether the determination of an air-fuel ratio value KG(i) has been completed, by checking whether the completion flag X(i) that corresponds to that air-fuel ratio value KG (i), i.e., i=1 to 5, is "1" (completed). When all the completion flags X(i) ("i=1 to 5") have been set to "1" (completed), the flag F is set to "0," i.e., permitting the lean combustion operation, thus discontinuing the forced stoichiometric combustion operation.

[0083] The above-described embodiment achieves the aforementioned advantage of the first embodiment, and also achieves the following advantages.

[0084] A plurality of air-fuel ratio determination regions i, i.e., i=1 to 5, are set in the lean combustion region, and air-fuel ratio values KG(i), i.e., i=1 to 5, are determined separately for the individual air-fuel ratio determination regions i. Therefore, the air-fuel ratio values KG(i) corresponding to the air-fuel ratio determination regions i can be precisely calculated to reflect deviations between the actual air-fuel ratio and the proper value. Of the air-fuel ratio values KG(i), i.e., i=1 to 5, a value KG(i) suitable for the engine operation state is used for the air-fuel ratio control during the rich spike control, so that the precision of the determination of an air-fuel ratio can be further improved.

[0085] Furthermore, the forced stoichiometric combustion operation started based on the cumulative travel distance is discontinued not only when the determination of the air-fuel ratio values KG(i) is completed, but also when the execution time of the stoichiometric combustion operation reaches or exceeds a predetermined time, for example, when the counter C1 has reached or exceeded the predetermined value x1. Therefore, the embodiment substantially prevents a situation where the execution time of the forced stoichiometric combustion operation is excessively long and the deterioration of fuel economy, for example, when a determined air-fuel ratio value KG(i) does not readily converge.

[0086] In addition, if a forced stoichiometric combustion operation is started in a state in which the air-fuel ratio values KG(i), i.e., i=1 to 5, are the initial values, i. e., 1.0, for example, in a case where the motor vehicle has not been driven at all, or where the battery has been replaced, etc., the stoichiometric combustion operation is continued until the determined air-fuel ratio values KG (i), i.e., i=1 to 5, converge, regardless of the execution time of the stoichiometric combustion operation. Therefore, if the determined air-fuel ratio values KG(i), i.e., i=1 to 5, are the initial values, it is possible to converge the determined air-fuel ratio values KG(i) as soon as possible and determine the values KG(i) to reflect deviations between the air-fuel ratio and the proper value. Hence, it is possible to substantially prevent a situation where the rich spike control is executed with the determined air-fuel ratio values KG(i), i.e., i=1 to 5, being the initial values, therefore deteriorating the precision of the air-fuel ratio control during the rich spike control.

[0087] The foregoing embodiments may be modified, for example, in the following manners.

[0088] In the first embodiment, the forced stoichiometric combustion operation is continued until the total execution time of the forced stoichiometric combustion operation in the lean combustion regions indicated by B in FIG. 2 becomes equal to a predetermined time t, e. g., 2 or 3 minutes, that is suitable to achieve both convergence of the determined air-fuel ratio value KG(i) to the predetermined value and improvement in the fuel economy of the engine 11. However, the value of the time t may be suitably changed. For example, the time may be set to a value that is longer than 2 or 3 minutes so that the determined air-fuel ratio value KG(i) is converged to a predetermined value without fail during the execution of the forced stoichiometric combustion operation. Furthermore, the time t may be set to a value that is shorter than 2 or 3 minutes, so as to further improve the fuel economy of the engine 11.

[0089] In the first embodiment, the forced stoichiometric combustion operation is ended provided that the total execution time of the stoichiometric combustion operation in the lean combustion region indicated by B in FIG. 2 reaches or exceeds the time t. However, it is also possible to adopt a construction in which it is determined whether the determined air-fuel ratio value KG(i) has converged to a predetermined value by monitoring the amount of fluctuation of the determined air-fuel ratio value KG(i) or the like, and in which the forced stoichiometric combustion operation is ended when it is determined that the value KG(i) has converged.

[0090] Although in the first embodiment, the air-fuel ratio determination regions i are set so that one air-fuel ratio determination region i exists in the lean combustion region indicated by B in FIG. 2, air-fuel ratio determination regions i may also be set so that a plurality of air-fuel ratio determination regions i exist in the lean combustion region.

[0091] In the first embodiment, it is also possible to always execute a forced stoichiometric combustion operation if the cumulative travel distance is "0." In this case, even if the cumulative travel distance is reset to "0," for example, at the time of replacement of the battery or the like, a forced stoichiometric combustion operation is executed so as to conduct the determination of air-fuel ratio values KG(i) in the lean combustion region indicated by B in FIG. 2.

[0092] In the second embodiment, the number of air-fuel ratio determination regions i in the lean combustion region may be suitably changed.

[0093] In the second embodiment, the execution time of a forced stoichiometric combustion operation may also be limited to at most a predetermined time if the forced stoichiometric combustion operation is started with the determined air-fuel ratio values KG(i) corresponding to the lean combustion region being an initial value, as well.

[0094] In the second embodiment, it is not essential to limit the execution time of a forced stoichiometric combustion operation to at most a predetermined time.

[0095] Although in the foregoing embodiments, the forced stoichiometric combustion operation is executed every time the cumulative travel distance of the motor vehicle increases by the distance d, e.g., 1000 km, following the previous execution of the forced stoichiometric combustion operation, the value of the distance d may be suitably changed.

[0096] In the foregoing embodiments, it is also possible to execute the forced stoichiometric combustion operation based on the cumulative operation time of the engine 11 instead of executing the forced stoichiometric combustion operation based on the cumulative travel distance of the motor vehicle. In this case, the forced stoichiometric combustion operation is executed every time the cumulative operation time of the engine 11 increases by a predetermined time from the value occurring at the time of the previous execution of the forced stoichiometric combustion operation. Furthermore, it is also possible to execute the forced stoichiometric combustion operation at every predetermined period, for example, once a month, a week, or a day, etc., regardless of the cumulative operation time of the engine 11.

[0097] In the illustrated embodiment, the controllers are implemented with general purpose processors. It will be appreciated by those skilled in the art that the controllers can be implemented using a single special purpose integrated circuit (e.g., ASIC) having a main or central processor section for overall, system-level control, and separate sections dedicated to performing various different specific computations, functions and other processes under control of the central processor section. The controllers can be a plurality of separate dedicated or programmable integrated or other electronic circuits or devices (e.g., hardwired electronic or logic circuits such as discrete element circuits, or programmable logic devices such as PLDs, PLAs, PALs or the like). The controllers can be suitably programmed for use with a general purpose computer, e.g., a microprocessor, microcontroller or other processor device (CPU or MPU), either alone or in conjunction with one or more peripheral (e.g., integrated circuit) data and signal processing devices. In general, any device or assembly of devices on which a finite state machine capable of implementing the procedures described herein can be used as the controllers. A distributed processing architecture can be used for maximum data/signal processing capability and speed.

[0098] While the invention has been described with reference to what are presently considered to be preferred embodiments thereof, it is to be understood that the invention is not limited to the disclosed embodiments or constructions. On the contrary, the invention is intended to cover various modifications and equivalent arrangements.

[0099] A forced stoichiometric combustion is executed every time a cumulative travel distance of a vehicle increases by a distance, thereby creating an opportunity to determine an air-fuel ratio value in a region in which a rich spike control is performed. Therefore, the determination of an air-fuel ratio value can be precisely calculated so that the air-fuel ratio value corresponds to a value that reflects a deviation of the actual air-fuel ratio and a proper value. Accordingly, it becomes possible to control, with high precision, correlation between the air-fuel ratio and a proper value based on the determined air-fuel ratio value during a fuel-rich combustion that is caused by the rich spike control.

Claims

1. A control apparatus of an internal combustion engine, having a NOx storage-reduction catalyst (33a) provided in an exhaust system, and a controller (92) that executes a rich spike control that temporarily shifts an air-fuel ratio to a fuel-rich air-fuel ratio when a condition for reducing NOx stored in the NOx storage-reduction catalyst (33a) is met, and that, during the rich spike control, controls the air-fuel ratio based on an air-fuel ratio value that is determined through an air-fuel ratio feedback control during execution of a stoichiometric combustion, the apparatus **characterized in**

   that the controller (92) forcibly executes the stoichiometric combustion regardless of a state of operation of the engine, every time the internal combustion engine is operated for a predetermined period.

2. A control apparatus according to claim 1, **charac-**

terized in that the controller (92) forcibly executes the stoichiometric combustion regardless of the state of operation of the engine, every time a cumulative travel distance of a vehicle in which the internal combustion engine is installed increases by a predetermined distance.

3. A control apparatus according to claim 1, **characterized in that** the controller (92) forcibly executes the stoichiometric combustion regardless of the state of operation of the engine, every time a cumulative operation time of the internal combustion engine increases by a predetermined time.

4. A control apparatus according to any one of claims 1 to 3, **characterized in that** the controller (92) discontinues a forced stoichiometric combustion on a condition that the air-fuel ratio value converges with a predetermined value due to the determination performed through the feedback control.

5. A control apparatus according to claim 4, **characterized in:**

that the air-fuel ratio value is determined separately for each one of a plurality of air-fuel ratio determination regions that are set in an operation region in which a lean combustion is executed; and
that the controller (92) discontinues the forced stoichiometric combustion on a condition that all the air-fuel ratio values corresponding to the plurality of air-fuel ratio determination regions converge.

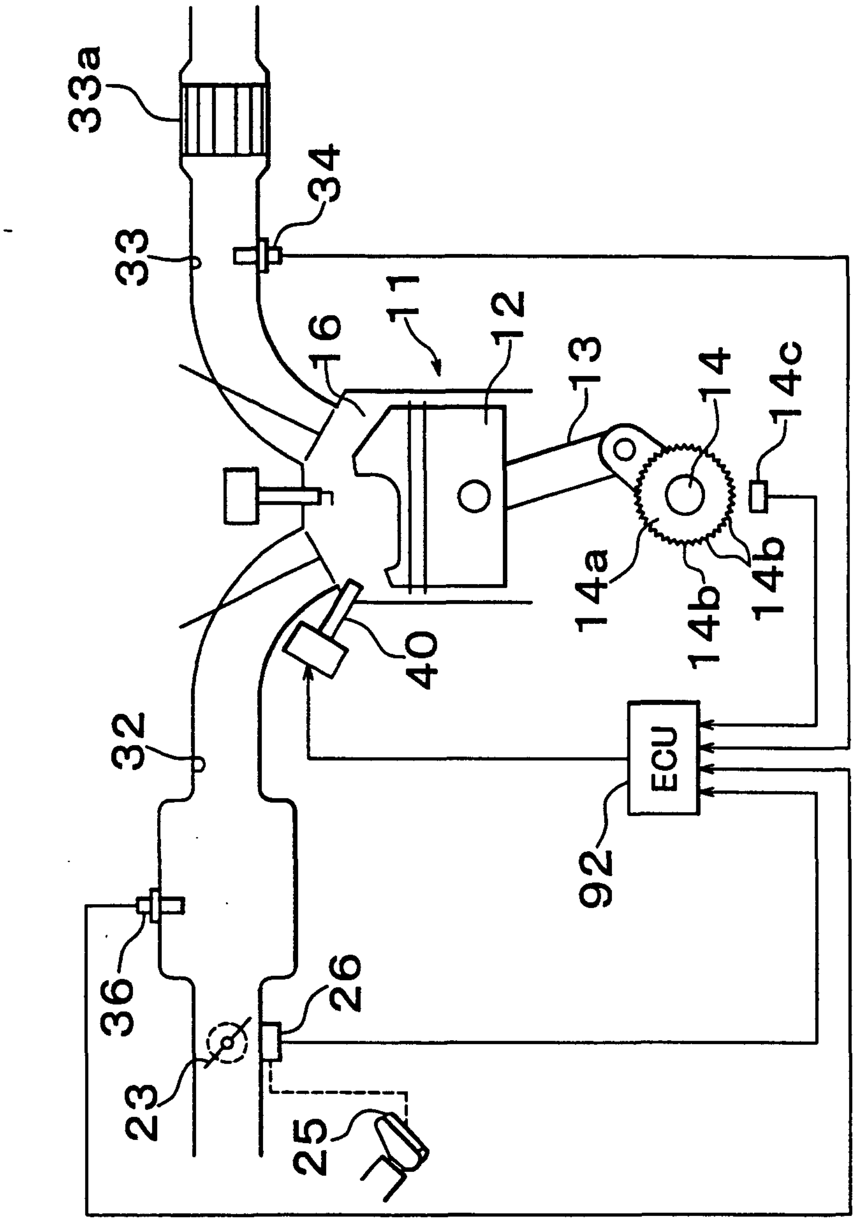
6. A control apparatus according to claim 4 or 5, **characterized in that** the controller (92) discontinues the forced stoichiometric combustion regardless of convergence of the air-fuel ratio value, if an execution time of the forced stoichiometric combustion is at least a predetermined time.

7. A control apparatus in according to claim 6, **characterized in that** if the forced stoichiometric combustion is started with the air-fuel ratio value being an initial value, the controller (92) continues the stoichiometric combustion regardless of the execution time of the stoichiometric combustion until the air-fuel ratio value converges.

8. A method of controlling an internal combustion engine having a NOx storage-reduction catalyst (33a) in an exhaust system, **characterized by** comprising the steps of:

executing a rich spike control that temporarily shifts an air-fuel ratio to a fuel-rich air-fuel ratio when a condition for reducing NOx stored in the NOx storage-reduction catalyst (33a) is met; and
controlling the air-fuel ratio, during the rich spike control, based on an air-fuel ratio value that is determined through an air-fuel ratio feedback control during execution of a stoichiometric combustion, wherein the stoichiometric combustion is forcibly executed regardless of a state of operation of the engine, every time the internal combustion engine is operated for a predetermined period.

FIG. 1



F I G. 2

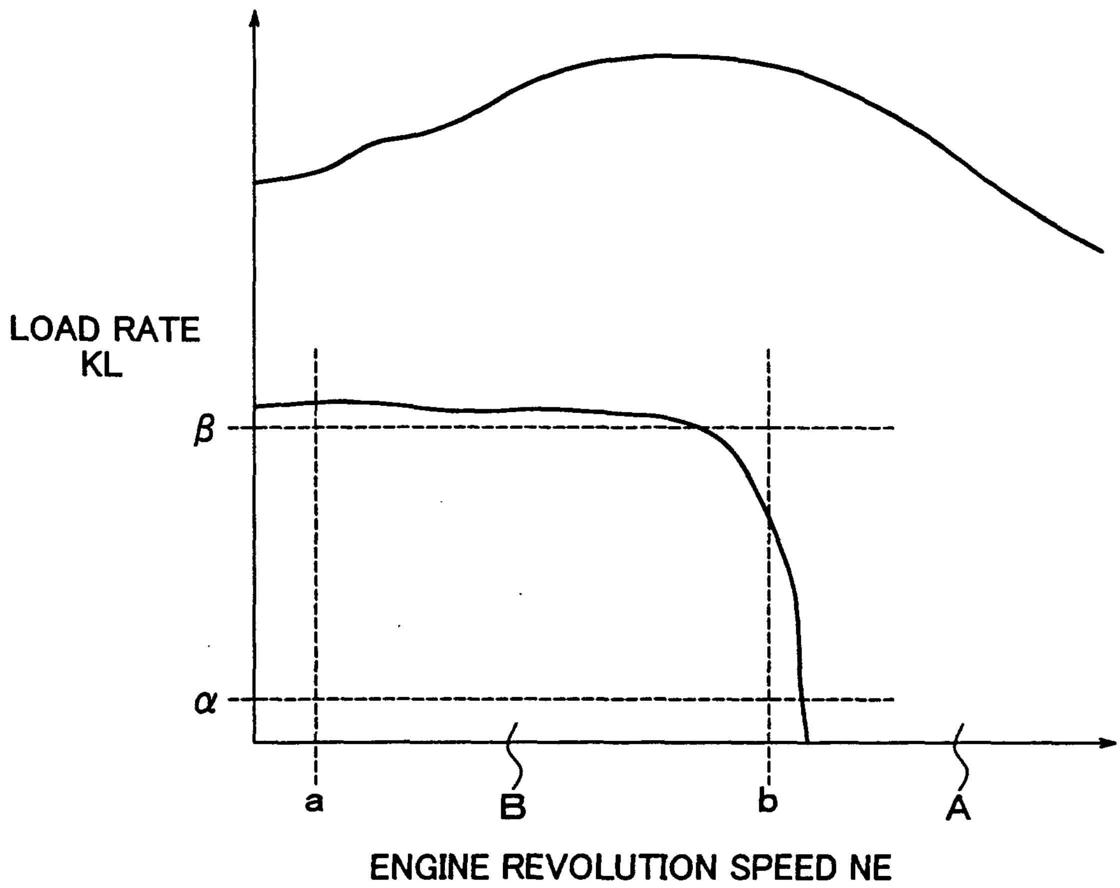


FIG. 3

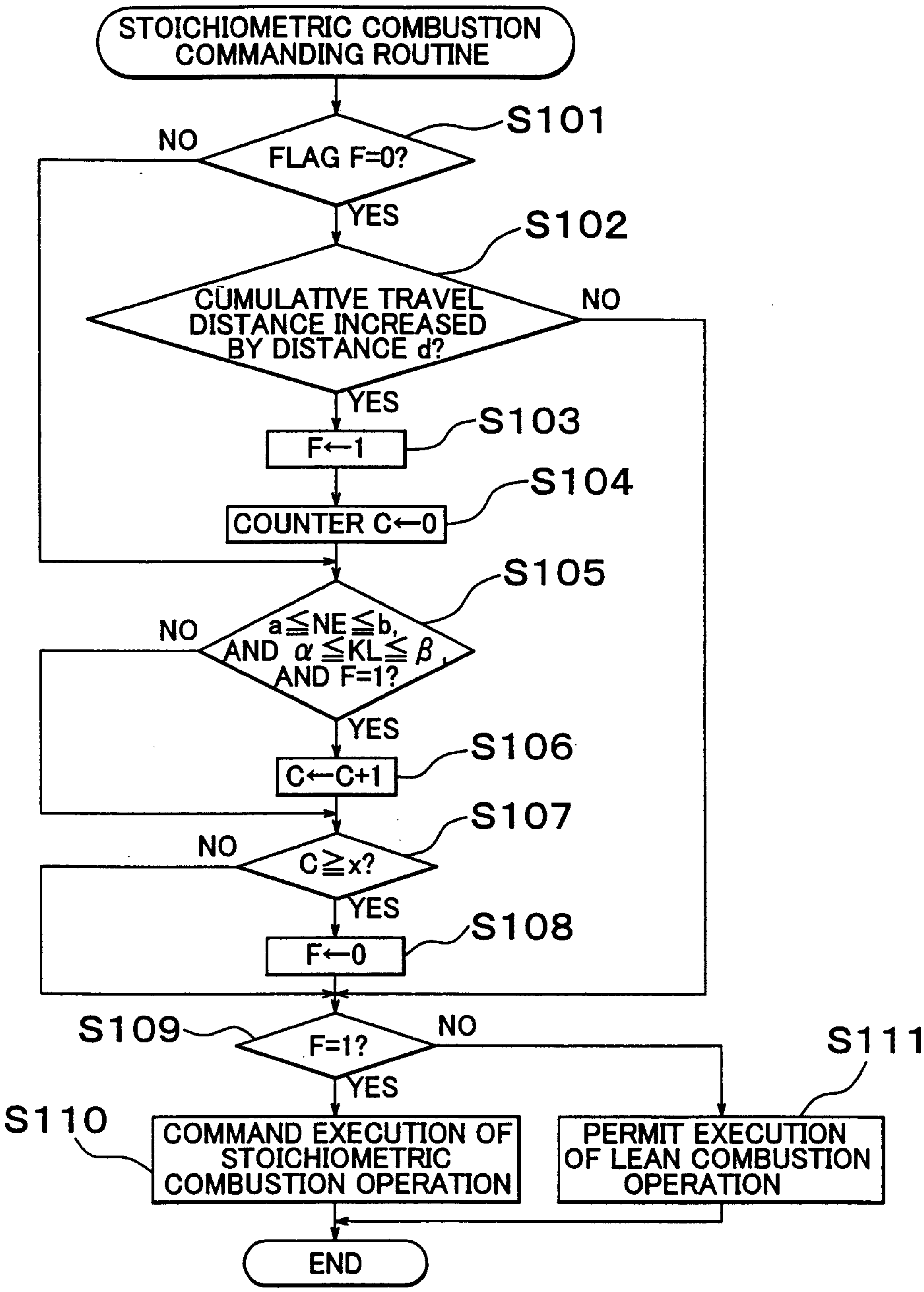

STOICHIOMETRIC COMBUSTION COMMANDING ROUTINE
S101
FLAG F=0?
NO
YES
S102
CUMULATIVE TRAVEL DISTANCE INCREASED BY DISTANCE d?
NO
YES
S103
F←1
S104
COUNTER C←0
S105
a≦NE≦b, AND α≦KL≦β, AND F=1?
NO
YES
S106
C←C+1
S107
C≧x?
NO
YES
S108
F←0
S109
F=1?
NO
YES
S110
COMMAND EXECUTION OF STOICHIOMETRIC COMBUSTION OPERATION
S111
PERMIT EXECUTION OF LEAN COMBUSTION OPERATION
END

FIG. 4

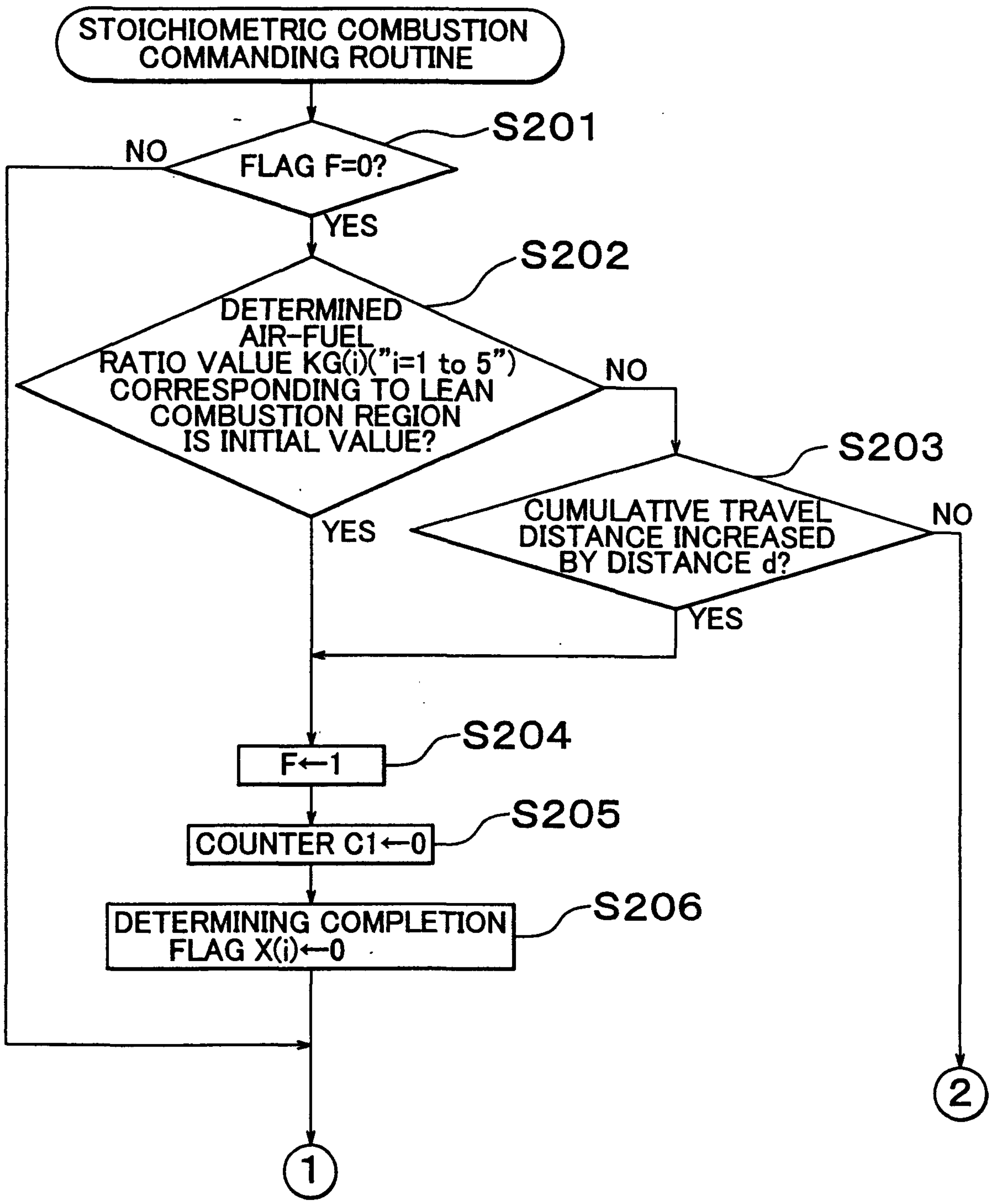

STOICHIOMETRIC COMBUSTION COMMANDING ROUTINE
S201
FLAG F=0?
NO
YES
S202
DETERMINED AIR-FUEL RATIO VALUE KG(i)("i=1 to 5") CORRESPONDING TO LEAN COMBUSTION REGION IS INITIAL VALUE?
NO
YES
S203
CUMULATIVE TRAVEL DISTANCE INCREASED BY DISTANCE d?
NO
YES
S204
F←1
S205
COUNTER C1←0
S206
DETERMINING COMPLETION FLAG X(i)←0
1
2

FIG. 5

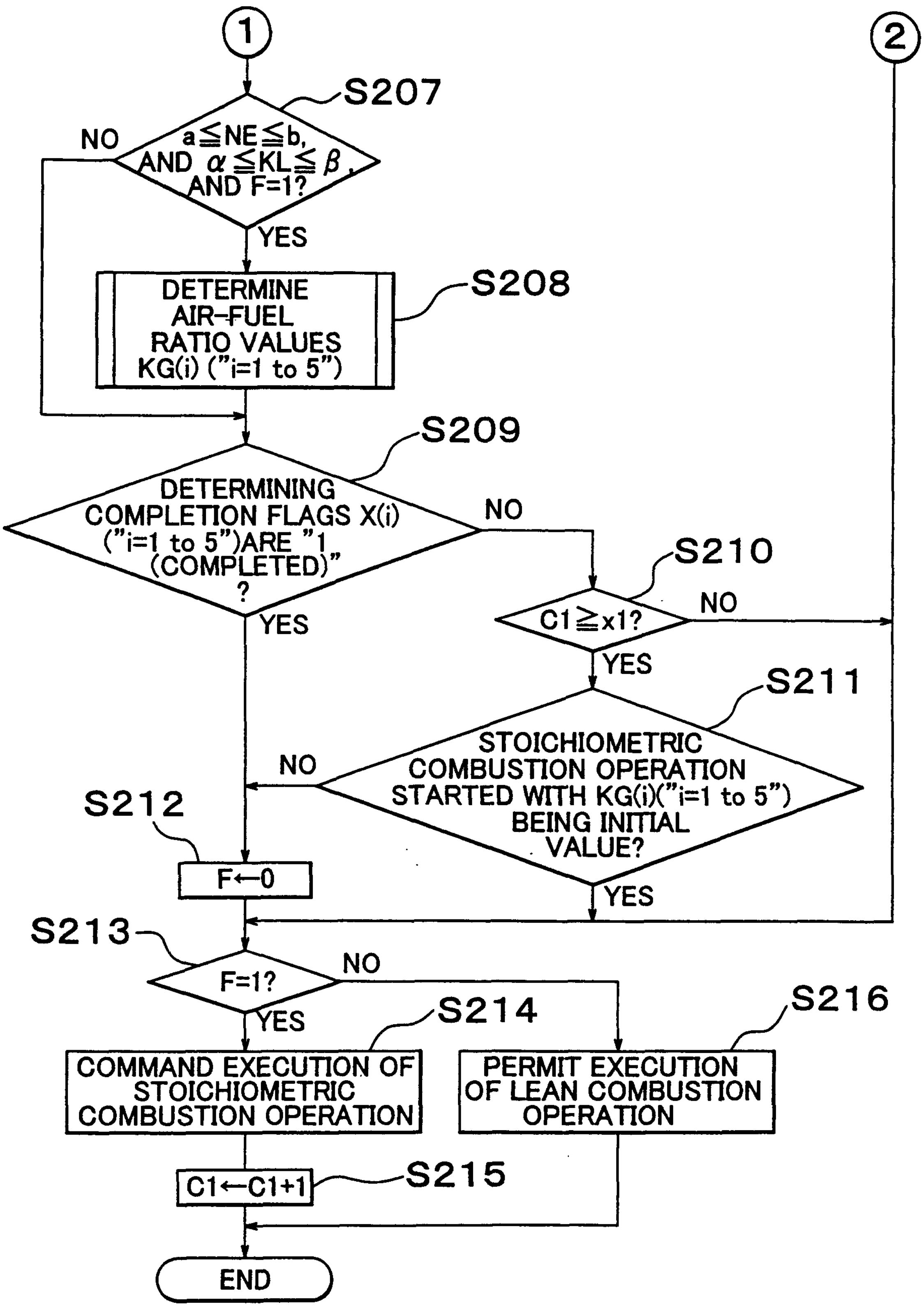
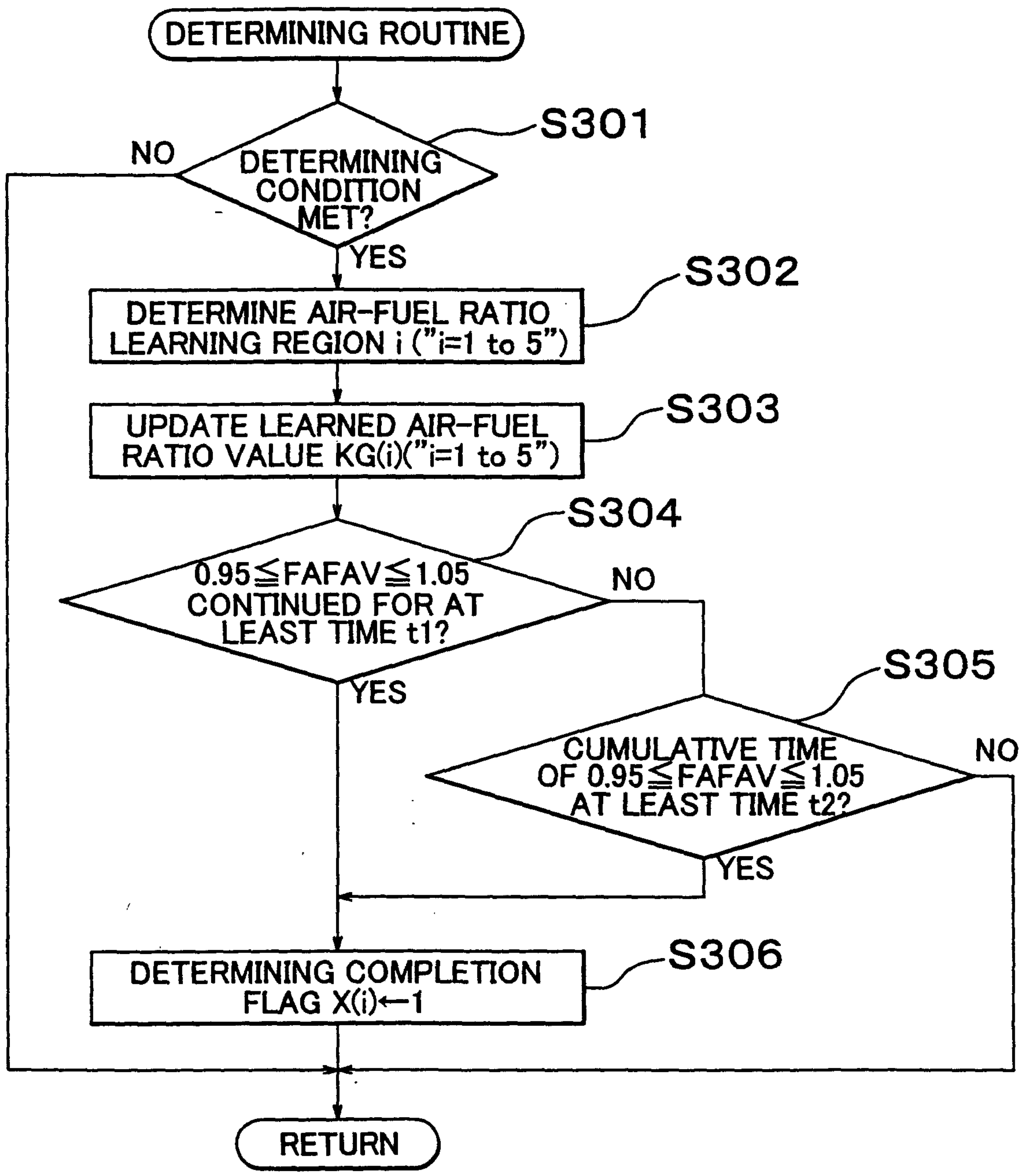

1
2
S207
a≦NE≦b, AND α≦KL≦β, AND F=1?
NO
YES
S208
DETERMINE AIR-FUEL RATIO VALUES KG(i) ("i=1 to 5")
S209
DETERMINING COMPLETION FLAGS X(i) ("i=1 to 5")ARE "1 (COMPLETED)" ?
NO
YES
S210
C1≧x1?
NO
YES
S211
STOICHIOMETRIC COMBUSTION OPERATION STARTED WITH KG(i)("i=1 to 5") BEING INITIAL VALUE?
NO
YES
S212
F←0
S213
F=1?
NO
YES
S214
COMMAND EXECUTION OF STOICHIOMETRIC COMBUSTION OPERATION
S216
PERMIT EXECUTION OF LEAN COMBUSTION OPERATION
S215
C1←C1+1
END

FIG. 6


DETERMINING ROUTINE
S301
DETERMINING CONDITION MET?
NO
YES
S302
DETERMINE AIR-FUEL RATIO LEARNING REGION i ("i=1 to 5")
S303
UPDATE LEARNED AIR-FUEL RATIO VALUE KG(i)("i=1 to 5")
S304
0.95≦FAFAV≦1.05 CONTINUED FOR AT LEAST TIME t1?
NO
YES
S305
CUMULATIVE TIME OF 0.95≦FAFAV≦1.05 AT LEAST TIME t2?
NO
YES
S306
DETERMINING COMPLETION FLAG X(i)←1
RETURN