



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
10.02.2010 Bulletin 2010/06

(51) Int Cl.:
F01N 3/08 (2006.01)

(21) Application number: **09166320.3**

(22) Date of filing: **24.07.2009**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK SM TR

(30) Priority: **05.08.2008 JP 2008201476**
26.02.2009 JP 2009043423

(71) Applicant: **Honda Motor Co., Ltd.**
Minato-ku
Tokyo 107-8556 (JP)

(72) Inventors:
• **Iida, Jun**
Saitama 351-0193 (JP)
• **Tsutsumi, Kojiro**
Saitama 351-0193 (JP)
• **Maki, Hidetaka**
Saitama 351-0193 (JP)

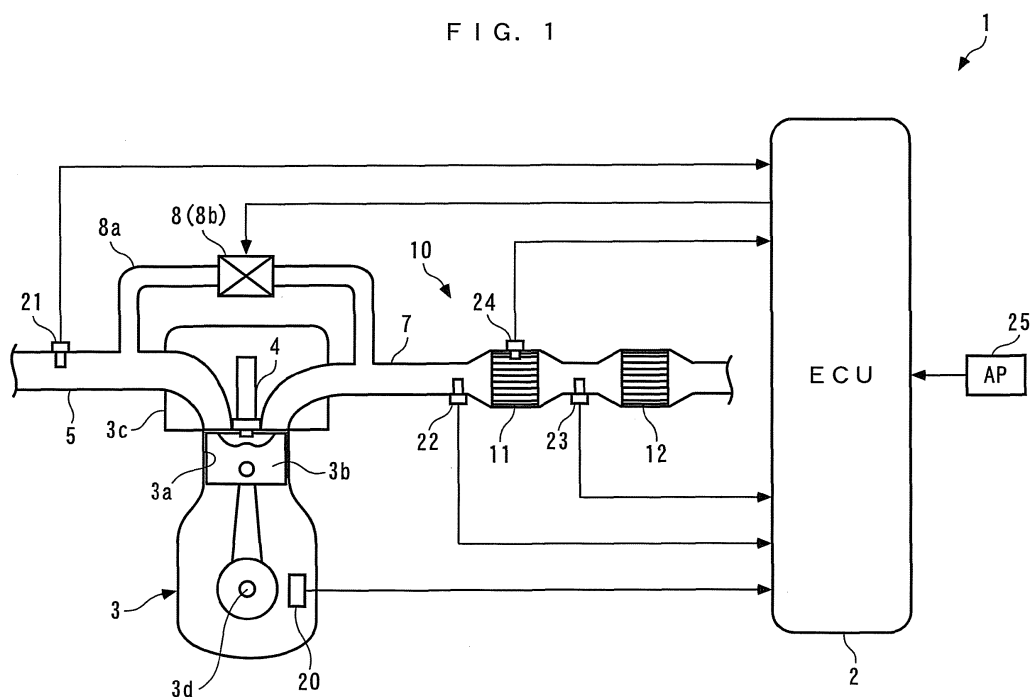
(74) Representative: **Prechtel, Jörg**
Weickmann & Weickmann
Patentanwälte
Postfach 86 08 20
81635 München (DE)

(54) **Deterioration determination device and method for exhaust emission reduction device**

(57) A deterioration determination device for an exhaust emission reduction device which is capable of accurately and rapidly determining deterioration of a NOx purifying catalyst. An ECU executes high NOx concentration control in deterioration determination, calculates a NOx supply (sumPreNOx) amount based on upstream NOx concentration detected during execution of the high

NOx concentration control, calculates a NOx slip (sumPostNOx) amount based on downstream NOx concentration detected during execution of the high NOx concentration control, and determines the NOx purifying catalyst to be deteriorated when the condition of the NOx slip amount exceeds a reference value (NOxJUD) is satisfied, in a case where the NOx supply amount exceeds a predetermined threshold (NOxREF).

F I G . 1



Description**BACKGROUND OF THE INVENTION****Field of the Invention**

[0001] The present invention relates to a deterioration determination device and method for an exhaust emission reduction device including a NOx purifying catalyst for purifying NOx in exhaust gases, which is configured to determine deterioration of the NOx purifying catalyst.

Description of the Related Art

[0002] Conventionally, there has been proposed a deterioration determination device for an exhaust emission reduction device e.g. in Japanese Laid-Open Patent Publication (Kokai) No. H07-180535 is known. This exhaust emission reduction device includes a NOx purifying catalyst disposed in an exhaust passage of a lean-burn engine, and the NOx purifying catalyst is of a type which purifies NOx in exhaust gases by reduction reaction in the presence of HC. Further, the deterioration determination device determines deterioration of the NOx purifying catalyst, and includes a NOx concentration sensor. This NOx concentration sensor is disposed in the exhaust passage at a location downstream of the NOx purifying catalyst, for detecting NOx concentration NOxconc in the exhaust gases that have flowed through the NOx purifying catalyst.

[0003] In this deterioration determination device, a standard concentration SNOxconc of NOx is calculated by searching a map according to the engine speed and the amount of intake air, and a standard amount Sg of NOx is calculated based on the calculated standard concentration SNOxconc, the intake air amount, and the specific gravity of NOx. Then, a standard value SG is calculated by integrating the standard amount Sg (steps 3 to 5). Further, an emission amount g of NOx is calculated based on the NOx concentration NOxconc detected by the NOx concentration sensor, the intake air amount, and the gravity of NOx, and an integrated emission amount G is calculated by integrating the emission amount g (steps 7 to 9). When a predetermined execution time for the above-mentioned integrating operation has elapsed, the integrated emission amount G and the standard value SG are compared with each other, and if $G > SG$ is satisfied, it is determined that the NOx purifying catalyst has been deteriorated (steps 6, 10, and 11).

[0004] According to the above-described conventional deterioration determination device, the emission amount g of NOx is calculated based on the NOx concentration NOxconc in exhaust gases that have flowed through the NOx purifying catalyst and the intake air amount, and by integrating the emission amount g until the predetermined execution time elapses, the integrated emission amount g used for the deterioration determination is calculated. Therefore, if the predetermined execution time is set to be short, when the engine is in an operating condition in which the flow rate of exhaust gases is decreasing or in which the NOx concentration in exhaust gases is decreasing, the computation result of the integrated emission amount g sometimes becomes so small to lower the accuracy of degradation determination. On the other hand, if the predetermined execution time is set to be long, although the determination accuracy can be improved in comparison with the case of the short predetermined execution time, it takes a longer time before obtaining the determination result.

SUMMARY OF THE INVENTION

[0005] It is an object of the present invention to provide a deterioration determination device and method for an exhaust emission reduction device, which are capable of accurately and rapidly determining the deterioration of a NOx purifying catalyst.

[0006] To attain the above object, in a first aspect of the present invention, there is provided a deterioration determination device for an exhaust emission reduction device including a NOx purifying catalyst that is provided in an exhaust passage of an internal combustion engine, for trapping, when exhaust gases forming an oxidation atmosphere flow therein, NOx in the exhaust gases, the deterioration determination device determining deterioration of the NOx purifying catalyst, characterized by upstream NOx concentration parameter-detecting means for detecting a parameter indicative of a NOx concentration in exhaust gases upstream of the NOx purifying catalyst, as an upstream NOx concentration parameter, downstream NOx concentration parameter-detecting means for detecting a parameter indicative of a NOx concentration in exhaust gases downstream of the NOx purifying catalyst, as a downstream NOx concentration parameter, control means for performing oxidation atmosphere control for controlling the exhaust gases flowing into the NOx purifying catalyst to an oxidation atmosphere, NOx supply amount-calculating means for calculating an integrated value of an amount of NOx having flowed into the NOx purifying catalyst, as a NOx supply amount, using the upstream NOx concentration parameter detected during execution of the oxidation atmosphere control, NOx slip amount-calculating means for calculating an integrated value of an amount of NOx having flowed through the NOx purifying catalyst, as a NOx slip

amount, using the downstream NOx concentration parameter detected during execution of the oxidation atmosphere control, and deterioration determination means for determining deterioration of the NOx purifying catalyst by comparing the calculated NOx slip amount with a predetermined reference value when the calculated NOx supply amount exceeds a predetermined threshold.

[0007] With the configuration of the deterioration determination device for the exhaust emission reduction device, according to the first aspect of the present invention, the oxidation atmosphere control for controlling exhaust gases flowing into the NOx purifying catalyst to the oxidation atmosphere is executed, and the integrated value of the amount of NOx flowing into the NOx purifying catalyst is calculated as the NOx supply amount, using the upstream NOx concentration parameter detected during the execution of the oxidation atmosphere control. In this case, since the upstream NOx concentration parameter is a parameter indicative of NOx concentration in exhaust gases on the upstream side of the NOx purifying catalyst, the NOx supply amount is calculated such that it accurately represents the amount of NOx having actually flowed into the NOx purifying catalyst. Further, using the downstream NOx concentration parameter detected during execution of the oxidation atmosphere control, the integrated value of the amount of NOx having flowed through the NOx purifying catalyst is calculated as the NOx slip amount. In this case, since the downstream NOx concentration parameter is a parameter indicative of NOx concentration in exhaust gases on the downstream side of the NOx purifying catalyst, the NOx slip amount is calculated such that it accurately represents the total amount of NOx having actually flowed through the NOx purifying catalyst. Therefore, when the calculated NOx supply amount exceeds the predetermined threshold, the deterioration of the NOx purifying catalyst is determined by comparing the calculated NOx slip amount with the predetermined reference value, and hence by properly setting these predetermined threshold and predetermined reference value, when the amount of NOx having actually flowed into the NOx purifying catalyst reaches a sufficiently large value, it is possible to determine the deterioration of the NOx purifying catalyst depending on whether the total amount of NOx having actually flowed through the NOx purifying catalyst till then is large or small. This makes it possible to accurately determine the deterioration of the NOx purifying catalyst.

[0008] Preferably, the deterioration determination device further comprises execution condition-determining means for determining whether or not conditions for executing the deterioration determination of the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control, and zero point-correcting means for correcting a zero point of the downstream NOx concentration parameter detected after satisfaction of the conditions for executing the deterioration determination, and the NOx slip amount-calculating means calculates the NOx slip amount, using the downstream NOx concentration parameter of which the zero point has been corrected.

In general, the detecting means, such as the downstream NOx concentration parameter-detecting means, for detecting a parameter indicative of NOx concentration in the exhaust gases on the downstream side of the NOx purifying catalyst, has characteristics that the output thereof is liable to an aging-caused change, such as zero point drift, and hence the output characteristics thereof are prone to change, and if the exhaust gas composition is changed due to the activated state or the like of the NOx purifying catalyst, this causes an output fluctuation. For this reason, when the deterioration of the NOx purifying catalyst is determined using the downstream NOx concentration parameter-detecting means, there is a fear that the accuracy of the deterioration determination is lowered due to the aforementioned change in the output characteristics or the output fluctuation. According to this deterioration determination device, however, the zero point-correcting means corrects the zero point of the downstream NOx concentration parameter, and using the corrected downstream NOx concentration parameter, the NOx slip amount is calculated. Therefore, even when the downstream NOx concentration parameter-detecting means is suffering from the above-mentioned change in the output characteristics or the output fluctuation, it is possible to determine the deterioration of the NOx purifying catalyst while preventing the determination from being adversely affected by the change in the output characteristics or the output fluctuation, thereby making it possible to improve the accuracy of the deterioration determination.

[0009] More preferably, the zero point-correcting means corrects the zero point of the downstream NOx concentration parameter based on an average value of a plurality of values of the downstream NOx concentration parameter detected during a predetermined time period after satisfaction of the conditions for executing the deterioration determination.

[0010] With the configuration of this preferred embodiment, the zero point of the downstream NOx concentration parameter is corrected based on the average value of a plurality of values of the downstream NOx concentration parameter detected during the predetermined time period after satisfaction of the conditions for executing the deterioration determination. Therefore, even if the detection result from the downstream NOx concentration parameter-detecting means suffers from a temporary fluctuation or a relatively large temporary error during the predetermined time period, it is possible to correct the zero point of the downstream NOx concentration parameter while preventing the correction from being adversely affected by the temporary fluctuation or error, thereby making it possible to further improve the accuracy of the deterioration determination.

[0011] Preferably, the deterioration determination device further comprises execution condition-determining means for determining whether or not the conditions for executing the deterioration determination for the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control, and reference value-calculating means for calculating the predetermined reference value based on the downstream NOx concentration parameter detected after satisfaction

of the conditions for executing the deterioration determination.

[0012] As described hereinabove, the detecting means, such as the downstream NOx concentration parameter-detecting means, for detecting a parameter indicative of the NOx concentration in the exhaust gases on the downstream side of the NOx purifying catalyst has characteristics that it is liable to a change in the output characteristics or output fluctuation, if the determination of the deterioration of the NOx purifying catalyst is carried out using the above-mentioned downstream NOx concentration parameter-detecting means, there is a fear that the accuracy of the deterioration determination is lowered. According to this deterioration determination device for the exhaust emission reduction device, however, the predetermined reference value is calculated by the reference value-calculating means based on the downstream NOx concentration parameter detected after satisfaction of the conditions for executing the deterioration determination, and hence even when the downstream NOx concentration parameter-detecting means is suffering from the above-mentioned change in the output characteristics or output fluctuation, it is possible to calculate the predetermined reference value while causing the change in the output characteristics or output fluctuation to be reflected thereon, and determine the deterioration of the NOx purifying catalyst using the reference value calculated as above. This makes it possible to improve the accuracy of the deterioration determination.

[0013] More preferably, the reference value-calculating means calculates the predetermined reference value based on an average value of a plurality of values of the downstream NOx concentration parameter detected during a predetermined time period after satisfaction of the conditions for executing the deterioration determination.

[0014] With the configuration of this preferred embodiment, the predetermined reference value is calculated based on the average value of the plurality of values of the downstream NOx concentration parameter detected during the predetermined time period after satisfaction of the conditions for executing the deterioration determination, and hence even when the fluctuation or relatively-large error temporarily occurs in the detection result from the downstream NOx concentration parameter-detecting means during the predetermined time period, it is possible to calculate the predetermined reference value while preventing the calculation from being adversely affected by the temporary fluctuation or errors, thereby making it possible to further improve the accuracy of the deterioration determination.

[0015] Preferably, the deterioration determination device further comprises execution condition-determining means for determining whether or not the conditions for executing the deterioration determination for the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control, and the control means controls, during execution of the oxidation atmosphere control, the NOx concentration in the exhaust gases to a higher value when the conditions for executing the deterioration determination are satisfied than when the conditions for executing the deterioration determination are not satisfied.

[0016] With the configuration of this preferred embodiment, during the execution of the oxidation atmosphere, when the conditions for executing the deterioration determination are satisfied, the NOx concentration in the exhaust gases is controlled to be higher than when the conditions for executing the deterioration determination are not satisfied, and hence it is possible to reduce a time period required for the NOx supply amount to exceed the predetermined threshold, thereby making it possible to rapidly carry out the deterioration determination.

[0017] More preferably, the NOx purifying catalyst has characteristics of reducing the trapped NOx when the exhaust gases flow therein form a reduction atmosphere, the deterioration determination device further comprising NOx trapping amount-calculating means for calculating an amount of NOx trapped by the NOx purifying catalyst during execution of the oxidation atmosphere control, as a NOx trapping amount, and the control means terminates the oxidation atmosphere control when the NOx trapping amount calculated during execution of the oxidation atmosphere control exceeds a predetermined trapping reference value, and controls the exhaust gases flowing into the NOx purifying catalyst to the reduction atmosphere, the deterioration determination device further comprising trapping reference value-setting means for setting the predetermined trapping reference value to a larger value when the conditions for executing the deterioration determination are satisfied during execution of the oxidation atmosphere control than when the conditions for executing the deterioration determination are not satisfied.

[0018] With the configuration of this preferred embodiment, when the NOx-trapping amount calculated during the execution of the oxidation atmosphere control exceeds the predetermined trapping reference value, the oxidation atmosphere control is terminated, and the exhaust gases flowing into the NOx purifying catalyst is controlled to the reduction atmosphere.. This causes the NOx trapped by the NOx purifying catalyst to be reduced since the NOx purifying catalyst has a characteristic that it reduces the trapped NOx when the exhaust gases forming the reduction atmosphere flow into the NOx purifying catalyst. In this case, as described above, during the execution of the oxidation atmosphere control, when the conditions for executing the deterioration determination are satisfied, the NOx concentration in the exhaust gases is controlled to be higher than when the conditions for executing the deterioration determination are not satisfied. Therefore, if the conditions for executing the deterioration determination are satisfied, the increasing degree of the NOx trapped by the NOx purifying catalyst becomes larger than when the conditions for executing the deterioration determination are not satisfied. Therefore, the NOx trapping amount more readily exceeds the predetermined trapping reference value, causing interruption of the oxidation atmosphere control, and hence there is a fear that it is impossible to properly determine the deterioration of the NOx purifying catalyst. According to this deterioration determination device,

however, when the conditions for executing the deterioration determination are satisfied, the predetermined NOx trapping reference value is set to a larger value than when the conditions for executing the deterioration determination are not satisfied, and hence it is possible to properly carry out the deterioration determination for the NOx purifying catalyst, while continuing the oxidation atmosphere control of the exhaust gases.

[0019] Preferably, the deterioration determination means executes determining the deterioration of the NOx purifying catalyst when the NOx slip amount exceeds a predetermined value in a case where the NOx supply amount is not more than the predetermined threshold.

[0020] With the configuration of this preferred embodiment, in the case where the NOx supply amount is not more than the predetermined threshold, when the NOx slip amount exceeds the predetermined value, the determination of the deterioration of the NOx purifying catalyst is carried out, even when the amount of NOx having actually flowed into the NOx purifying catalyst does not reach a sufficiently large value, if the total amount of NOx having actually flowed through the NOx purifying catalyst is large, it is possible to carry out the determination of the deterioration of the NOx purifying catalyst by properly setting the predetermined value. This makes it possible to rapidly carry out the determination of the deterioration of the NOx purifying catalyst. In addition, with the configuration of this deterioration determination device for the exhaust emission reduction device according to claim 4 or 5, it is possible to reduce the time required to control the NOx in the exhaust gases to the state of high NOx concentration, thereby making it possible to suppress degradation of the exhaust emission characteristics.

[0021] Preferably, a downstream NOx purifying catalyst is provided downstream of the NOx purifying catalyst in the exhaust passage of the engine, for trapping, when exhaust gases forming the oxidation atmosphere flow therein, NOx in the exhaust gases.

[0022] With the configuration of this preferred embodiment, the downstream NOx purifying catalyst is provided in the exhaust passage at a location downstream of the NOx purifying catalyst, and hence it is possible to purify the NOx having flowed through the NOx purifying catalyst by the downstream NOx purifying catalyst during the determination of the deterioration of the NOx purifying catalyst. This makes it possible to positively prevent the degradation of the exhaust emission characteristics during the determination of the deterioration of the NOx purifying catalyst.

[0023] To attain the above object, in a second aspect of the present invention, there is provided a deterioration determination method for an exhaust emission reduction device including a NOx purifying catalyst that is provided in an exhaust passage of an internal combustion engine, for trapping, when exhaust gases forming an oxidation atmosphere flow therein, NOx in the exhaust gases, the deterioration determination method determining deterioration of the NOx purifying catalyst, characterized by detecting a parameter indicative of a NOx concentration in exhaust gases upstream of the NOx purifying catalyst, as an upstream NOx concentration parameter, detecting a parameter indicative of a NOx concentration in exhaust gases downstream of the NOx purifying catalyst, as a downstream NOx concentration parameter, performing oxidation atmosphere control for controlling the exhaust gases flowing into the NOx purifying catalyst to an oxidation atmosphere, calculating an integrated value of an amount of NOx having flowed into the NOx purifying catalyst, as a NOx supply amount, using the upstream NOx concentration parameter detected during execution of the oxidation atmosphere control, calculating an integrated value of an amount of NOx having flowed through the NOx purifying catalyst, as a NOx slip amount, using the downstream NOx concentration parameter detected during execution of the oxidation atmosphere control, and determining deterioration of the NOx purifying catalyst by comparing the calculated NOx slip amount with a predetermined reference value when the calculated NOx supply amount exceeds a predetermined threshold.

[0024] With the configuration of the deterioration determination method according to the second aspect of the present invention, it is possible to obtain the same advantageous effects as provided by the first aspect of the present invention.

[0025] Preferably, the deterioration determination method further comprises determining whether or not conditions for executing the deterioration determination of the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control, and correcting a zero point of the downstream NOx concentration parameter detected after satisfaction of the conditions for executing the deterioration determination, wherein the calculating the NOx slip amount includes calculating the NOx slip amount, using the downstream NOx concentration parameter of which the zero point has been corrected.

[0026] More preferably, the correcting a zero point includes correcting the zero point of the downstream NOx concentration parameter based on an average value of a plurality of values of the downstream NOx concentration parameter detected during a predetermined time period after satisfaction of the conditions for executing the deterioration determination.

[0027] Preferably, the deterioration determination method further comprises determining whether or not the conditions for executing the deterioration determination for the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control, and calculating the predetermined reference value based on the downstream NOx concentration parameter detected after satisfaction of the conditions for executing the deterioration determination.

[0028] More preferably, the calculating the predetermined reference value includes calculating the predetermined reference value based on an average value of a plurality of values of the downstream NOx concentration parameter

detected during a predetermined time period after satisfaction of the conditions for executing the deterioration determination.

[0029] Preferably, the deterioration determination method further comprises determining whether or not the conditions for executing the deterioration determination for the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control, and wherein the performing oxidation atmosphere control includes controlling, during execution of the oxidation atmosphere control, the NOx concentration in the exhaust gases to a higher value when the conditions for executing the deterioration determination are satisfied than when the conditions for executing the deterioration determination are not satisfied.

[0030] More preferably, the NOx purifying catalyst has characteristics of reducing the trapped NOx when the exhaust gases flow therein form a reduction atmosphere, the deterioration determination method further comprising calculating an amount of NOx trapped by the NOx purifying catalyst during execution of the oxidation atmosphere control, as a NOx trapping amount, wherein the performing oxidation atmosphere control includes terminating the oxidation atmosphere control when the NOx trapping amount calculated during execution of the oxidation atmosphere control exceeds a predetermined trapping reference value, and controls the exhaust gases flowing into the NOx purifying catalyst to the reduction atmosphere, the deterioration determination method further comprising trapping reference value-setting means for setting the predetermined trapping reference value to a larger value when the conditions for executing the deterioration determination are satisfied during execution of the oxidation atmosphere control than when the conditions for executing the deterioration determination are not satisfied.

[0031] Preferably, the determining deterioration includes executing determining the deterioration of the NOx purifying catalyst when the NOx slip amount exceeds a predetermined value in a case where the NOx supply amount is not more than the predetermined threshold.

[0032] Preferably, a downstream NOx purifying catalyst is provided downstream of the NOx purifying catalyst in the exhaust passage of the engine, for trapping, when exhaust gases forming the oxidation atmosphere flow therein, NOx in the exhaust gases.

[0033] With the configurations of these preferred embodiments, it is possible to obtain the same advantageous effects as provided by the respective corresponding preferred embodiments of the first aspect of the present invention. The above and other objects, features, and advantages of the present invention will become more apparent from the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034]

FIG. 1 is a schematic diagram of a deterioration determination device according to a first embodiment of the present invention, and an internal combustion engine including an exhaust emission reduction device to which the deterioration determination device is applied;

FIG. 2 is a flowchart of an air-fuel ratio control process;

FIG. 3 is a flowchart of a high NOx concentration control process;

FIG. 4 is a flowchart of a deterioration determination process executed for a NOx purifying catalyst;

FIG. 5 is a flowchart of a process for setting a judgment condition satisfaction flag F_JUD;

FIG. 6 is an example of a map for the calculation of a NOx trapping capability NOxS;

FIG. 7 is an example of a map for the calculation of a catalyst temperature-dependent correction coefficient CorTCAT;

FIG. 8 is an example of a map for the calculation of an exhaust gas flow rate-dependent correction coefficient CorQGAS;

FIG. 9 is a flowchart of a process for setting a catalyst deterioration flag F_CATNG;

FIG. 10 is a flowchart of a process for setting a rich condition flag F_RICH;

FIG. 11 is a timing diagram showing an example of control results when the high NOx concentration control process and the deterioration determination process are executed by the deterioration determination device according to the first embodiment;

FIG. 12 is flowchart of a variation of the high NOx concentration control process;

FIG. 13 is a flowchart of a deterioration determination process executed for a downstream catalyst of a deterioration determination device according to a second embodiment of the present invention; and

FIG. 14 is a flowchart of a process for setting a catalyst deterioration flag F_CATNG of the deterioration determination device according to the second embodiment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0035] A deterioration determination device for an exhaust emission reduction device, according to a first embodiment

of the present invention will now be described in detail with reference to drawings showing the embodiment. As shown in FIG. 1, the deterioration determination device 1 according to the present embodiment includes an ECU 2, and the ECU 2 performs various control processes, including an air-fuel ratio control process for an internal combustion engine (hereinafter simply referred to as "the engine") 3, and performs a deterioration determination process for an exhaust emission reduction device 10.

[0036] The engine 3 is a diesel engine that is installed on a vehicle, not shown, and includes a plurality of pairs (only one pair is shown) of cylinders 3a and pistons 3b. The engine 3 has a cylinder head 3c having fuel injection valves 4 inserted into the cylinders 3a thereof in a manner facing respective associated combustion chambers.

[0037] The fuel injection valves 4 are connected to a high-pressure pump and a fuel tank via a common rail, none of which are shown. Fuel pressurized by the high-pressure pump is supplied to each fuel injection valves 4 via the common rail to be injected therefrom into the cylinders 3a. The ECU 2 controls a valve opening time period and valve opening timing of each fuel injection valve 4, thereby executing fuel injection control.

[0038] The engine 3 is provided with a crank angle sensor 20. The crank angle sensor 20 is formed by a magnet rotor and an MRE pickup, and delivers a CRK signal and a TDC signal, which are both pulse signals, to the ECU 2 in accordance with rotation of a crankshaft 3d. One pulse of the CRK signal is delivered whenever the crankshaft 3d rotates through a predetermined angle (e.g. 10 °). The ECU 2 calculates the rotational speed NE of the engine 3 (hereinafter referred to as "the engine speed NE") based on the CRK signal. Further, the TDC signal indicates that each piston 3b in an associated one of the cylinders 3a is in a predetermined crank angle position slightly before the TDC position at the start of the intake stroke thereof, and one pulse thereof is delivered whenever the crankshaft 3d rotates through a predetermined crank angle.

[0039] The engine 3 has an intake passage 5 having an air flow sensor 21 inserted therein, which detects an amount (intake air amount) GAIR of air sucked into the cylinders 3a, to deliver a signal indicative of the sensed intake air amount GAIR to the ECU 2.

[0040] On the other hand, the engine 3 has an exhaust passage 7 provided with the exhaust emission reduction device 10 which includes a NOx purifying catalyst 11, a downstream NOx purifying catalyst 12 and so forth. The NOx purifying catalyst 11 has a capability of trapping (storing) NOx in exhaust gases flowing therein, provided that the exhaust gases form an oxidation atmosphere. The NOx trapped by the NOx purifying catalyst 11 is reduced by reacting with a reducing agent when exhaust gases forming a reduction atmosphere flow into the NOx purifying catalyst 11.

[0041] Further, similarly to the NOx purifying catalyst 11, the downstream NOx purifying catalyst 12 also has a capability of trapping NOx in exhaust gases flowing therein when the exhaust gases forming the oxidation atmosphere flow therein. The NOx trapped by the downstream NOx purifying catalyst 12 is reduced by reacting with the reducing agent when the exhaust gases forming the reduction atmosphere flow into the downstream NOx purifying catalyst 12.

[0042] Further, the exhaust passage 7 has an upstream NOx sensor 22 disposed upstream of the NOx purifying catalyst 11, and a downstream NOx sensor 23 disposed downstream of the NOx purifying catalyst 11. The upstream NOx sensor 22 detects NOx concentration in the exhaust gases flowing in the exhaust passage 7 to deliver a signal indicative of the detected NOx concentration to the ECU 2. The ECU 2 calculates NOx concentration (hereinafter referred to as "the upstream NOx concentration") CNOx_Pre in exhaust gases on the upstream side of the NOx purifying catalyst 11, based on the detection signal from the upstream NOx sensor 22. It should be noted that in the present embodiment, the upstream NOx sensor 22 corresponds to upstream NOx concentration parameter-detecting means, and the upstream NOx concentration CNOx_Pre corresponds to a upstream NOx concentration parameter.

[0043] Further, similarly to the upstream NOx sensor 22, the downstream NOx sensor 23 also detects NOx concentration in exhaust gases that flowing in the exhaust passage 7 to deliver a signal indicative of the detected NOx concentration to the ECU 2. The ECU 2 calculates NOx concentration (hereinafter referred to as "the downstream NOx concentration") CNOx_Post in the exhaust gases that have flowed through the NOx purifying catalyst 11, based on the detection signal from the downstream NOx sensor 23. It should be noted that in the present embodiment, the downstream NOx sensor 23 corresponds to downstream NOx concentration parameter-detecting means, and the downstream NOx concentration CNOx_Post corresponds to a downstream NOx concentration parameter.

[0044] Further, the NOx purifying catalyst 11 has a catalyst temperature sensor 24 mounted thereon, for detecting temperature (hereinafter referred to as "the catalyst temperature") TCAT of the NOx purifying catalyst 11 to deliver a signal indicative of the detected catalyst temperature to the ECU 2.

[0045] Further, the engine 3 is provided with an exhaust recirculation mechanism 8. This exhaust recirculation mechanism 8 recirculates part of exhaust gases in the exhaust passage 7 to the intake passage 5, and is comprised of an EGR passage 8a connecting between the intake passage 5 and the exhaust passage 7, and an EGR control valve 8b which opens and closes the EGR passage 8a. One end of the EGR passage 8a opens into a portion of the exhaust passage 7 upstream of the NOx purifying catalyst 11, and the other end of EGR passage 8a opens into a portion of the intake passage 5 downstream of the air flow sensor 21.

[0046] The EGR control valve 8b is formed by a linear solenoid valve of which the opening is linearly changed between a maximum value and a minimum value, and is electrically connected to the ECU 2. The ECU 2 controls a recirculation

amount of exhaust gases, i.e. an EGR amount by changing the opening of the EGR passage 8a via the EGR control valve 8b. The ECU 2 controls the air-fuel ratio, as described hereinafter, by performing the EGR amount control and the above-mentioned fuel injection control. As a result, the engine 3 is normally operated in a lean combustion state in which a mixture leaner than the stoichiometric air-fuel ratio is burned, and during rich spike control, referred to hereinafter, it is operated in a rich combustion state in which a mixture richer than the stoichiometric air-fuel ratio is burned.

[0047] Further, the ECU 2 has an accelerator opening sensor 25 electrically connected thereto. The accelerator opening sensor 25 detects a stepped-on amount (hereinafter referred to as "accelerator opening") AP of an accelerator pedal, not shown, and delivers a detection signal indicative of the detected accelerator opening AP to the ECU 2.

[0048] On the other hand, the ECU 2 is implemented by a microcomputer comprised of a CPU, a RAM, a ROM, and an I/O interface (none of which is shown). The ECU 2 determines operating conditions of the engine 3 according to the detection signals from the aforementioned sensors 20 to 25 and carries out various control processes. Specifically, as described hereinafter, the ECU 2 carries out an air-fuel ratio control process, and a deterioration determination process for determining deterioration of the NOx purifying catalyst 11 of the exhaust emission reduction device 10.

[0049] It should be noted that in the present embodiment, the ECU 2 corresponds to the upstream NOx concentration parameter-detecting means, the downstream NOx concentration parameter-detecting means, control means, NOx supply amount-calculating means, NOx slip amount-calculating means, deterioration determination means, execution condition-determining means, zero point-correcting means, NOx trapping amount-calculating means, and trapping reference value-setting means, in the present invention.

[0050] Hereafter, a description will be given of the air-fuel ratio control process executed by the ECU 2, with reference to FIG. 2. This process calculates a fuel injection amount QINJ indicative of the amount of fuel injected by each fuel injection valve 4 and fuel injection timing ϕ INJ, and controls the EGR amount through the EGR control valve 8b. The process is executed at a control period synchronized with occurrence of the TDC signal pulse.

[0051] In this process, first, in a step 1 (shown as S1 in abbreviated form in FIG. 2; the following steps are also shown in abbreviated form), it is determined whether or not a rich condition flag F_RICH is equal to 1. The rich condition flag F_RICH is set in a process for setting the rich condition flag F_RICH, as described hereinafter.

[0052] If the answer to the question of the step 1 is negative (NO), the process proceeds to a step 2, wherein it is determined whether or not a high NOx condition flag F_NOxUP is equal to 1. The value of the high NOx condition flag F_NOxUP is set in the deterioration determination process, referred to hereinafter.

[0053] If the answer to the question of the step 2 is negative (NO), it is determined that lean control of the air-fuel ratio should be executed, so that the process proceeds to a step 3, wherein a lean control process is executed. In the lean control process, demanded torque PMCMD for lean control is calculated by searching a map, not shown, according to the accelerator pedal opening AP and the engine speed NE, and a map, not shown, is searched according to the demanded torque PMCMD for lean control and the engine speed NE, to thereby calculate a fuel injection amount QINJ for lean control. Further, a map, not shown, is searched according to the fuel injection amount QINJ for lean control and the engine speed NE, to thereby calculate fuel injection timing ϕ INJ for lean control.

[0054] In addition, a map, not shown, is searched according to the demanded torque PMCMD for lean control and the engine speed NE, to thereby calculate a target intake air amount GAIR_CMD for lean control, and the EGR control valve 8b is feedback-controlled such that the intake air amount GAIR converges to the target intake air amount GAIR_CMD.

[0055] After executing the lean control process in the step 3 as described above, the present process is terminated. This controls the air-fuel ratio of the engine 3 to a value leaner than the stoichiometric air-fuel ratio. As a result, the exhaust gases forming the oxidation atmosphere are exhausted from the engine 3 into the exhaust passage 7.

[0056] On the other hand, if the answer to the question of the step 1 is affirmative (YES), it is determined that rich spike control should be executed, so that the process proceeds to a step 4, wherein a rich spike control process is executed. In the rich spike control process, demanded torque PMCMD for rich spike control is calculated by searching a map, not shown, according to the accelerator pedal opening AP and the engine speed NE, and a map, not shown, is searched according to the demanded torque PMCMD for rich spike control and the engine speed NE, to thereby calculate the fuel injection amount QINJ for rich spike control. Further, a map, not shown, is searched according to the fuel injection amount QINJ for rich spike control and the engine speed NE, to thereby calculate fuel injection timing ϕ INJ for rich spike control.

[0057] In addition, a map, not shown, is searched according to the demanded torque PMCMD for rich spike control and the engine speed NE, to thereby calculate a target intake air amount GAIR_CMD for rich spike control, and the EGR control valve 8b is feedback-controlled such that the intake air amount GAIR converges to the target intake air amount GAIR_CMD.

[0058] After executing the rich spike control process in the step 4 as described above, the present process is terminated. This controls the air-fuel ratio of the engine 3 to a value richer than the stoichiometric air-fuel ratio. As a result, the exhaust gases forming the reduction atmosphere are exhausted from the engine 3 into the exhaust passage 7, whereby the NOx trapped by the NOx purifying catalyst 11 is reduced.

[0059] On the other hand, if the answer to the question of the step 2 is affirmative (YES), it is determined that the high

NOx concentration control should be executed, so that the process proceeds to a step 5, wherein the high NOx concentration control process is executed. Specifically, the high NOx concentration control process is executed as shown in FIG. 3.

[0060] First, in a step 10, the fuel injection amount QINJ and the fuel injection timing ϕ INJ for high NOx concentration control are calculated in a manner similar to the above-described lean control process and the rich spike control process. That is, demanded torque PMCMD for high NOx concentration control is calculated by searching a map, not shown, according to the accelerator pedal opening AP and the engine speed NE, and a map, not shown, is searched according to the demanded torque PMCMD for high NOx concentration control and the engine speed NE, to thereby calculate the fuel injection amount QINJ and the fuel injection timing ϕ INJ for high NOx concentration control.

[0061] Next, in a step 11, a map, not shown, is searched according to the demanded torque PMCMD for high NOx concentration control and the engine speed NE, to thereby calculate the target intake air amount GAIR_CMD for high NOx concentration control.

[0062] Then, the process proceeds to a step 12, wherein the EGR control process is executed, followed by terminating the present process. In this EGR control process, the EGR control valve 8b is feedback-controlled such that the intake air amount GAIR converges to the target intake air amount GAIR_CMD, to thereby control the EGR amount to be less than that during the lean control. From the above, the exhaust gases exhausted from the engine 3 into the exhaust passage 7 are controlled to the same oxidation atmosphere as during the lean control, and the NOx concentration is controlled to a higher value than that during the lean control. Specifically, the upstream NOx concentration CNOx_Pre is controlled to a predetermined upper limit CNOx_H, referred to hereafter.

[0063] Referring again to FIG. 2, after performing the high NOx concentration control in the step 5 as above, the air-fuel ratio control process is terminated.

[0064] Next, a description will be given of the deterioration determination process executed by the ECU 2, with reference to FIG. 4. This process determines deterioration of the NOx purifying catalyst 11 based on the upstream NOx concentration CNOx_Pre and the downstream NOx concentration CNOx_Post, and is executed at a predetermined control period ΔT (e.g. 10 msec).

[0065] In this process, first, in a step 20, it is determined whether or not a judgment condition satisfaction flag F_JUD is equal to 1. Specifically, the judgment condition satisfaction flag F_JUD is set in a setting process shown in FIG. 5. In this process, in a step 40, it is determined whether or not there are satisfied all of the following conditions (f1) to (f11):

(f1) A predetermined time period has elapsed after terminating the rich spike control (this predetermined time period includes a value of 0).

(f2) The deterioration determination process has not been executed during the present vehicle-driving cycle (i.e. from the start of the engine to the stop of the engine).

(f3) The engine speed NE is in a range from a predetermined upper limit NE_H (e.g. 2500 rpm) to a predetermined lower limit NE_L (e.g. 1500 rpm).

(f4) The demanded torque PMCMD is in a range from a predetermined upper limit PM_H (e.g. 100 Nm) to a predetermined lower limit PM_L (e.g. 80 Nm).

(f5) The catalyst temperature TCAT is in a range from a predetermined upper limit TCAT_H (e.g. 450 °C) to a predetermined lower limit TCAT_L (e.g. 350 °C).

(f6) Exhaust gas temperature TEX is in a range from a predetermined upper limit TEX_H (e.g. 500 °C) to a predetermined lower limit TEX_L (e.g. 350 °C). It should be noted that the exhaust gas temperature TEX is the temperature of exhaust gases flowing into the NOx purifying catalyst 11, and is detected using an exhaust gas temperature sensor, not shown.

(f7) The upstream NOx concentration CNOx_Pre is in a range from a predetermined upper limit CNOx_H (e.g. 300 ppm) to a predetermined lower limit CNOx_L (e.g. 100 ppm).

(f8) A NOx flow rate GNOx is in a range from a predetermined upper limit GNOx_H (e.g. 6 g/hr) to a predetermined lower limit GNOx_L (e.g. 3 g/hr). It should be noted that the NOx flow rate GNOx is calculated by calculating the exhaust gas flow rate QGAS based on the engine speed NE, the intake air amount GAIR, etc., and multiplying the calculated exhaust gas flow rate QGAS by the upstream NOx concentration CNOx_Pre.

(f9) A NOx trapping amount S_QNOx in the NOx purifying catalyst 11 is in a range from a predetermined upper limit S_QNOx_H (e.g. 0.2 g) to a predetermined lower limit S_QNOx_L (e.g. 0.1 g). It should be noted that the NOx trapping amount S_QNOx is an integrated value of the amount of NOx estimated to have been trapped by the NOx purifying catalyst 11, and is calculated in a manner similar to a NOx supply amount sumPreNOx, referred to hereinafter.

(f10) An EGR rate REGR is in a range more than a predetermined upper limit REGR_H (e.g. 50 %). It should be noted that the EGR rate REGR is calculated based on the engine speed NE, the intake air amount QAIR, etc.

(f11) Opening θ EGR of the EGR control valve 8b is in a range more than a predetermined upper limit θ EGR_H (e.g. 60°). It should be noted that the opening θ EGR of the EGR control valve 8b is detected using an opening sensor,

not shown.

In the above conditions (f1) to (f11), the conditions (f5) and (f6) indicate that the NOx purifying catalyst 11 is in an appropriate activated state, and the conditions (f7) to (f11) indicate that exhaust gases supplied to the NOx purifying catalyst 11 are in a state most suitable for the deterioration determination.

Then, if it is determined that these conditions (f1) to (f11) are all satisfied, it is determined that conditions for the deterioration determination of the NOx purifying catalyst 11 are satisfied, so that the judgment condition satisfaction flag F_JUD is set to 1, whereas if not, the judgment condition satisfaction flag F_JUD is set to 0. In the step 40, the judgment condition satisfaction flag F_JUD is set as above, followed by terminating the present process.

Referring again to FIG. 4, if the answer to the question of the step 20 is negative (NO), i.e. the conditions for the deterioration determination of the NOx purifying catalyst 11 are not satisfied, it is determined that the deterioration determination of the NOx purifying catalyst 11 should not be executed, so that the process proceeds to a step 21, wherein both of two flags F_ZERO and F_CAL, referred to hereinafter, are set to 0, followed by terminating the present process. On the other hand, if the answer to the question of the step 20 is affirmative (YES), i.e. the conditions for the deterioration determination of the NOx purifying catalyst 11 are satisfied, the process proceeds to a step 22, wherein it is determined whether or not the zero point correction completion flag F_ZERO is equal to 1. If the answer to the question of the step 22 is negative (NO), the zero point correction of the downstream NOx concentration CNOx_Post should be executed, so that the process proceeds to a step 23, wherein the zero point correction process is executed as described hereinafter, followed by terminating the present process.

In the zero point correction process in the step 23, first, the downstream NOx concentration CNOx_Post calculated based on the detection signals from the downstream NOx sensor 23 is sampled at each control period ΔT , and when a predetermined number of (e.g. 100) calculated values of the downstream NOx concentration CNOx_Post have been sampled, the predetermined number of the sampled values of the downstream NOx concentration CNOx_Post are averaged (the arithmetic mean thereof is calculated) to thereby calculate an average value. Then, after calculating the average value, the average value is subtracted from an actual value of the downstream NOx concentration CNOx_Post calculated based on the detection signal from the downstream NOx sensor 23 to thereby calculate the zero point-corrected downstream NOx concentration CNOx_Post.

Further, in the zero point correction process in the step 23, when the above-mentioned correction term is calculated, to indicate that the zero point correction process has been executed, the zero point correction completion flag F_ZERO is set to 1. It should be noted that in the present embodiment, a time period required for the predetermined number of calculated values of the downstream NOx concentration CNOx_Post to be sampled corresponds to the predetermined time period.

As described above, if the zero point correction completion flag F_ZERO is set to 1 in the step 23, the answer to the question of the step 22 becomes affirmative (YES), and in this case, the process proceeds to a step 24, wherein it is determined whether or not the reference value calculation completion flag F_CAL is equal to 1.

If the answer to the question of the step 24 is negative (NO), it is determined that a NOx supply amount reference value NOxREF, referred to hereinafter, should be calculated, so that the process proceeds to a step 25, wherein a NOx trapping capability NOxS is calculated by searching a map in FIG. 6 according to the NOx trapping amount S_QNOx. The NOx trapping amount S_QNOx is the amount of NOx estimated to have been trapped by the NOx purifying catalyst 11, and is calculated in a rich condition flag F_RICH setting process, as described hereinafter.

Further, the NOx trapping capability NOxS indicates the amount of NOx which can be trapped by the NOx purifying catalyst 11, and in the map in FIG. 6, as the NOx trapping amount S_QNOx is larger, the NOx trapping capability NOxS is set to a smaller value. This is because the NOx trapping amount S_QNOx is the amount of NOx estimated to have been trapped by the NOx purifying catalyst 11, and hence as the NOx trapping amount S_QNOx is larger, the amount of NOx which can be trapped by the NOx purifying catalyst 11 becomes smaller.

Then, the process proceeds to a step 26, wherein a catalyst temperature-dependent correction coefficient CorTCAT is calculated by searching a map in FIG. 7 according to the catalyst temperature TCAT. In FIG. 7, TREFa to TREFd are predetermined values of the catalyst temperature TCAT set such that $TREFa < TREFb < TREFc < TREFd$ holds. In this map, in a range of $TREFa \leq TCAT < TREFb$, the catalyst temperature-dependent correction coefficient CorTCAT is set to a smaller value as the catalyst temperature TCAT is lower. This is because when the catalyst temperature TCAT is in the range of $TREFa \leq TCAT < TREFb$, as the catalyst temperature TCAT is lower, the activity of the NOx purifying catalyst 11 becomes lower, so that the NOx trapping capability becomes lower, and hence the map is configured to cope with this tendency.

Further, in a range of $TREFb \leq TCAT \leq TREFc$, the catalyst temperature-dependent correction coefficient CorTCAT is set to a fixed value. This is because when the catalyst temperature TCAT is in the range of $TREFb \leq TCAT \leq TREFc$, the activity of the NOx purifying catalyst 11 does not change. Further, in a range of $TREFc < TCAT \leq TREFd$, the catalyst temperature-dependent correction coefficient CorTCAT is set to a smaller value as the catalyst temperature TCAT is higher. This is because when the catalyst temperature TCAT is in the range of $TREFc < TCAT \leq TREFd$, as the catalyst

temperature TCAT is higher, the NOx trapping capability of the NOx purifying catalyst 11 becomes lower, and hence the map is configured to cope with this tendency. In a step 27 following the step 26, an exhaust gas flow rate-dependent correction coefficient CorQGAS is calculated by searching a map shown in FIG. 8 according to the exhaust gas flow rate QGAS. In this map, the exhaust gas flow rate-dependent correction coefficient CorQGAS is set to a smaller value as the exhaust gas flow rate QGAS is larger. This is because if the exhaust gas flow rate QGAS is larger, exhaust gases become difficult to react with the NOx purifying catalyst 11 when flowing through NOx purifying catalyst 11, so that the activity of the exhaust gases flowing through the NOx purifying catalyst 11 becomes lower, resulting in a state where the NOx purifying catalyst 11 indicates a lower NOx trapping capability than the actual capability, or the reaction time (contact time) of the NOx purifying catalyst 11 itself with the exhaust gases becomes shorter and NOx in exhaust gases become difficult to be trapped by the NOx purifying catalyst 11, resulting in a state where the amount of NOx actually trapped by the NOx purifying catalyst 11 becomes lower, and hence the map is configured to cope with these tendencies. [0066] Next, the process proceeds to a step 28, wherein the NOx supply amount reference value NOxREF (pre-determined threshold) is calculated by the following equation (1):

$$\text{NOxREF} = \text{NOxS} \cdot \text{CorTCAT} \cdot \text{CorQGAS} \quad \dots\dots (1)$$

[0067] Then, to indicate the fact that the NOx supply amount reference value NOxREF has been calculated, the process proceeds to a step 29, wherein the reference value calculation completion flag F_CAL is set to 1, followed by terminating the present process.

If the reference value calculation completion F_CAL is set to 1 in the step 29 as described above, the answer to the question of the step 24 becomes affirmative (YES). In this case, the process proceeds to a step 30, wherein it is determined whether or not the high NOx condition flag F_NOxUP is equal to 1. If the answer to the question of the step 30 is negative (NO), the process proceeds to a step 31, wherein, to indicate the fact that the high NOx concentration control should be executed, the high NOx condition flag F_NOxUP is set to 1, followed by terminating the present process.

If the high NOx condition flag F_NOxUP is set to 1 in the step 31 as described above, the answer to the question of the step 30 becomes affirmative (YES), in this case, the process proceeds to a step 32, wherein the NOx supply amount sumPreNOx is calculated by the following equation (2):

$$\text{sumPreNOx} = \text{sumPreNOxZ} + \text{CNOx_Pre} \cdot \text{QGAS} \cdot \Delta T \quad \dots\dots (2)$$

[0068] In this equation (2), sumPreNOxZ represents the immediately preceding value of the NOx supply amount. Further, the second term of the right side of the equation (2) is the product CNOx_Pre · QGAS · ΔT of the upstream NOx concentration, the flow rate of exhaust gases, and the control period, and hence represents the amount of NOx supplied to the NOx purifying catalyst 11 during the time period between the immediately preceding control timing and the present control timing. Therefore, the NOx supply amount sumPreNOx is calculated by integrating the above-mentioned value CNOx_Pre · QGAS · ΔT, and hence represents the total amount of NOx which is estimated to have been supplied to the NOx purifying catalyst 11 during the time period between the start timing of the high NOx concentration control process and the present control timing. Then, the process proceeds to a step 33, wherein a NOx slip amount sumPostNOx is calculated by the following equation (3):

$$\text{sumPostNOx} = \text{sumPostNOxZ} + \text{CNOx_Post} \cdot \text{QGAS} \cdot \Delta T \quad \dots\dots (3)$$

[0069] In this equation (3), sumPostNOxZ represents the immediately preceding value of the NOx slip amount. Further, the second term of the right side of the equation (3) is the product CNOx_Post · GAS · ΔT of the downstream NOx concentration, the flow rate of exhaust gases, and the control period, and hence represents the amount of NOx having flowed through the NOx purifying catalyst 11 without being trapped by the NOx purifying catalyst 11 during the time period between the start timing of the high NOx concentration control process and the present control timing. Therefore, since the NOx slip amount sumPostNOx is calculated by integrating the above-mentioned value CNOx_Post · QGAS · ΔT, the NOx slip amount sumPostNOx represents the total amount of NOx which is estimated to have flowed through

the NOx purifying catalyst 11 during the time period between the start timing of the high NOx concentration control process and the present control timing.

Next, in a step 34, it is determined whether or not $\text{sumPreNOx} > \text{NOxREF}$ holds. If the answer to the question of the step 34 is affirmative (YES), i.e. $\text{sumPreNOx} > \text{NOxREF}$ holds, it is determined that the amount of NOx enough to carry out the deterioration determination of the NOx purifying catalyst 11 has been supplied to the NOx purifying catalyst 11, so that the process proceeds to a step 36, referred to hereinafter.

On the other hand, if the answer to the question of the step 34 is negative (NO), i.e. $\text{sumPreNOx} \leq \text{NOxREF}$ holds, the process proceeds to a step 35, wherein it is determined whether or not $\text{sumPostNOx} > \text{NOxREF2}$ holds. The NOxREF2 is a predetermined reference value (predetermined value) of the NOx slip amount sumPostNOx , and is set to a fixed value.

If the answer to the question of the step 35 is negative (NO), the process is immediately terminated. On the other hand, if the answer to the question of the step 35 is affirmative (YES), i.e. $\text{sumPostNOx} > \text{NOxREF2}$ holds, the amount of NOx having flowed through the NOx purifying catalyst 11 is large, and hence it is determined that the deterioration determination of the NOx purifying catalyst 11 should be carried out, so that the process proceeds to the step 36.

In the step 36 following the above-mentioned step 34 or 35, a catalyst deterioration flag F_CATNG setting process is executed. Specifically, the catalyst deterioration flag F_CATNG setting process is executed as shown in FIG. 9.

In this process, first, in a step 50, it is determined whether or not the NOx slip amount sumPostNOx is larger than a predetermined reference value NOxJUD. The reference value NOxJUD is set to a fixed value. If the answer to the question of the step 50 is negative (NO), i.e. $\text{sumPostNOx} \leq \text{NOxJUD}$ holds, it is determined that the NOx purifying catalyst 11 has not been deteriorated, so that the process proceeds to a step 51, wherein to indicate this fact, the catalyst deterioration flag F_CATNG is set to 0.

On the other hand, if the answer to the question of the step 50 is affirmative (YES), i.e. $\text{sumPostNOx} > \text{NOxJUD}$ holds, it is determined that the NOx purifying catalyst 11 has been deteriorated, so that the process proceeds to a step 52, wherein to indicate this fact, the catalyst deterioration flag F_CATNG is set to 1.

In a step 53 following the above-mentioned step 51 or 52, to indicate that the high NOx concentration control process should be terminated, the high NOx condition flag F_NOxUP is set to 0. Next, the process proceeds to a step 54, wherein both of the NOx supply amount sumPreNOx and the NOx slip amount sumPostNOx are set to 0, followed by terminating the present process.

Referring again to FIG. 4, in the step 36, the catalyst deterioration flag F_CATNG setting process is executed as described above, followed by terminating the present deterioration determination process.

It should be noted that in the above-mentioned step 35, the process may be configured to compare the NOx slip amount sumPostNOx with the reference value NOxJUD used in the above-mentioned step 50 in place of the reference value NOxREF2.

Next, a description will be given of the above-mentioned rich condition flag F_RICH setting process with reference to FIG. 10. As shown in FIG. 10, in this setting process, first, in a step 60, it is determined whether or not the rich condition flag F_RICH is equal to 1. If the answer to the question of the step 60 is negative (NO), the process proceeds to a step 61, wherein the NOx trapping amount S_QNOx is calculated.

The NOx trapping amount S_QNOx is the amount of NOx estimated to have been trapped by the NOx purifying catalyst 11, as mentioned hereinabove, and is specifically calculated as follows: A NOx exhaust amount QNOx exhausted from the combustion chamber of the engine 3 into the exhaust passage 7 is calculated by searching a map, now shown, according to parameters, such as the demanded torque PMCMD, the engine speed NE, the intake air amount GAIR, and the opening of the EGR control valve 8b (i.e. EGR amount), and the NOx trapping amount S_QNOx is calculated by integrating the calculated NOx exhaust amount QNOx.

Then, the process proceeds to a step 62, wherein it is determined whether or not the above-mentioned high NOx condition flag F_NOxUP is equal to 1. If the answer to the question of the step 62 is negative (NO), i.e. if the lean control is being executed, the process proceeds to a step 63, wherein a trapping reference value SREF is set to a first predetermined value SREF1.

On the other hand, if the answer to the question of the step 62 is affirmative (YES), i.e. if the high NOx concentration control is being executed, the process proceeds to a step 64, wherein the trapping reference value SREF is set to a second predetermined value SREF2. Here, the first and second predetermined values SREF1 and SREF2 are set to fixed values such that $\text{SREF1} < \text{SREF2}$ holds. This is because during execution of the high NOx concentration control, the operation of the engine 3 is controlled such that the NOx concentration in exhaust gases becomes higher than that during the lean control, so that the increasing degree of the NOx trapping amount S_QNOx becomes larger than that during the lean control.

In a step 65 following the step 63 or 64, it is determined whether or not the NOx trapping amount S_QNOx is larger than the trapping reference value SREF. If the answer to the question of the step 65 is negative (NO), it is determined that the lean control or the high NOx concentration control should be continued, and hence the process is immediately terminated, whereas if the answer to the question of the step 65 is affirmative (YES), it is determined that the rich spike control should be executed, so that the process proceeds to a step 66, wherein to indicate this fact, the rich condition

flag F_RICH is set to 1, followed by terminating the present process.

On the other hand, if the answer to the question of the step 60 is affirmative (YES), i.e. the rich spike control is being executed, the process proceeds to a step 67, wherein a subtraction value DEC is calculated. The subtraction value DEC is an amount of NOx estimated to have been reduced by the NOx purifying catalyst 11 during a time period between the immediately preceding control timing and the present control timing by execution of the rich spike control. Specifically, the subtraction value DEC is calculated by searching a map, not shown, according to the parameters indicative of the operating conditions (e.g. the demanded torque PMCMD, the engine speed NE, the intake air amount GAIR, and the opening of the EGR control valve 8b).

Then, the process proceeds to a step 68, wherein the NOx trapping amount S_QNOx is set to a value (S_QNOxZ - DEC) obtained by subtracting the subtraction value DEC from the immediately preceding value S_QNOxZ of the NOx trapping amount S_QNOx. Next, in a step 69, it is determined whether or not the NOx trapping amount S_QNOx is not more than a predetermined termination reference value SDEC. If the answer to the question of the step 69 is negative (NO), it is determined that the rich spike control should be continued, so that the present process is immediately terminated. On the other hand, if the answer to the question of the step 69 is affirmative (YES), it is determined that the rich spike control should be terminated, so that the process proceeds to a step 70, wherein to indicate this fact, the rich condition flag F_RICH is set to 0, followed by terminating the present process. Next, a description will be given of an example of control results in a case where the high NOx concentration process and the deterioration determination process are executed as described above, with reference to FIG. 11. It should be noted that for each of the downstream NOx concentration CNOx_Post and the NOx slip amount sumPostNOx shown in FIG. 11, a curve indicated by a solid line shows a case where the NOx purifying catalyst 11 has been deteriorated, and a curve indicated by a dashed line shows a case where the NOx purifying catalyst 11 has not been deteriorated.

As shown in FIG. 11, if the conditions for the deterioration determination of the NOx purifying catalyst 11 are satisfied, i.e. if F_JUD = 1 holds, at a time point t1, the condition of F_NOxUP = 1 is satisfied at a time point (time point t2) at which the NOx supply amount reference value NOxREF is calculated, so that the high NOx concentration control process is started, and the exhaust gases of high NOx concentration reach the upstream NOx sensor 22 in timing (at a time point t3) at which a desired time period has elapsed from the time point at which the high NOx concentration control process is started, so that the NOx supply amount sumPreNOx starts to rise. If the NOx purifying catalyst 11 has been deteriorated, the downstream NOx concentration CNOx_Post also rises with the lapse of time after the NOx supply amount sumPreNOx starts to rise, and the NOx slip amount sumPostNOx also rises with the lapse of time. Then, when the condition of sumPreNOx > NOxREF is satisfied (at a time point t4), the condition of sumPostNOx > NOxJUD is satisfied, whereby it is determined that the NOx purifying catalyst 11 has been deteriorated.

On the other hand, when the NOx purifying catalyst 11 has not been deteriorated, the downstream NOx concentration CNOx_Post and the NOx slip amount sumPostNOx hardly change. Thus, also when sumPreNOx > NOxREF is satisfied (time point t4), sumPostNOx ≤ NOxJUD is satisfied. Therefore, it is determined that the NOx purifying catalyst 11 has not been deteriorated.

As described above, according to the deterioration determination device 1 in the first embodiment, in the deterioration determination process in FIG. 4, the zero point-corrected downstream NOx concentration CNOx_Post is calculated based on the detection signal values from the downstream NOx sensor 23, and the NOx slip amount sumPostNOx is calculated based on the calculated zero point-corrected downstream NOx concentration CNOx_Post. Further, the upstream NOx concentration CNOx_Pre is calculated based on the detection signal values from the upstream NOx sensor 22, and the NOx supply amount sumPreNOx is calculated based on the calculated upstream NOx concentration CNOx_Pre.

Then, when the condition of sumPreNOx > NOxREF is satisfied, the deterioration determination of the NOx purifying catalyst 11 is carried out by comparing the NOx slip amount sumPostNOx with the predetermined reference value NOxJUD. That is, the deterioration of the NOx purifying catalyst 11 is determined depending on whether the total amount of NOx estimated to have flowed through the NOx purifying catalyst 11 is large or small at the time point at which the amount of NOx having actually flowed into the NOx purifying catalyst 11 has reached a sufficiently large value.

In general, a sensor, such as the downstream NOx sensor 23, which detects a parameter indicative of NOx concentration in exhaust gases downstream of the NOx purifying catalyst 11 has characteristics that the output thereof is liable to an aging-caused change, such as zero point drift, and hence the output characteristics thereof are prone to change, and if the exhaust gas composition is changed due to the activated state of the NOx purifying catalyst 11, this causes an output fluctuation. For this reason, when the deterioration of the NOx purifying catalyst 11 is determined using the downstream NOx sensor 23, there is a fear that the accuracy of calculation of the downstream NOx concentration CNOx_Post is lowered, and hence the accuracy of the deterioration determination is lowered. According to the deterioration determination device 1, however, in the deterioration determination process, the zero point-corrected downstream NOx concentration CNOx_Post is used, and hence even if the downstream NOx sensor 23 is suffering from the above-mentioned change in the output characteristics or the output fluctuation immediately before starting the deterioration determination, it is possible to determine the deterioration of the NOx purifying catalyst 11 while preventing the determination from

being adversely affected by the change in the output characteristics or the output fluctuation, thereby making it possible to improve the accuracy of the deterioration determination.

Further, in the zero point correction process of the step 23 in FIG. 4, the predetermined number of the downstream NOx concentration CNOx_Post calculated based on the detection signal from the downstream NOx sensor 23 after the conditions for the deterioration determination of the NOx purifying catalyst 11 are satisfied are sampled, and by using the average value of these sampled values as the correction term, the zero point-corrected downstream NOx concentration CNOx_Post is calculated. Therefore, even if the detection signal value from the downstream NOx sensor 23 temporarily varies, or a relatively-large error temporarily occurs during sampling, it is possible to accurately calculate the zero point-corrected downstream NOx concentration CNOx_Post, while preventing the calculation from being adversely affected by the temporary variation or the temporary errors, thereby making it possible to improve the accuracy of the deterioration determination.

Further, in the step 31 in FIG. 4, if the high NOx condition flag F_NOxUP is set to 1, the high NOx concentration control process of the step 5 is executed in the air-fuel ratio control process in FIG. 2. This controls the exhaust gases exhausted from the engine 3 into the exhaust passage 7 to the same oxidation atmosphere as during in the lean control, and controls the NOx concentration in the exhaust gases to be higher than that during the lean control, whereby it is possible to reduce a time period required for the answer to the question of the step 34 or 35 in FIG. 4 to become affirmative (YES). As a result, it is possible to rapidly execute the deterioration determination of the NOx purifying catalyst 11.

Further, even when $\text{sumPreNOx} \leq \text{NOxREF}$ holds, if the condition of $\text{sumPostNOx} > \text{NOxREF2}$ is satisfied, the deterioration determination of the NOx purifying catalyst 11 is executed by comparing the NOx slip amount sumPostNOx with the predetermined reference value NOxJUD in the steps 50 to 52. That is, even when the amount of NOx having actually flowed into the NOx purifying catalyst 11 is small, if the total amount of NOx having actually flowed through the NOx purifying catalyst 11 is large, which means that there is a high possibility that the NOx purifying catalyst 11 has been deteriorated, the high NOx concentration control is interrupted by executing the deterioration determination of the NOx purifying catalyst 11. This makes it possible to reduce the execution time of the high NOx concentration control process, thereby making it possible to suppress degradation of the exhaust emission characteristics. Further, during execution of the high NOx concentration control, in the step 64 in FIG. 10, the trapping reference value SREF for comparison with the NOx trapping amount S_QNOx is set to the second predetermined value SREF2 which is larger than the first predetermined value SREF1 during the lean control. Therefore, even when the increasing degree of the NOx trapping amount S_QNOx is larger than that during the lean control due to execution of the high NOx concentration control, the condition of $S_QNOx > SREF$ is made difficult to be satisfied, whereby it is possible to properly execute the deterioration determination of the NOx purifying catalyst 11 while continuing the high NOx concentration control.

In addition, the downstream NOx purifying catalyst 12 is disposed downstream of the NOx purifying catalyst 11 in the exhaust passage 7, and therefore during the deterioration determination of the NOx purifying catalyst 11, it is possible to purify the NOx having flowed through the NOx purifying catalyst 11 by the downstream NOx purifying catalyst 12. This makes it possible to positively prevent the exhaust emission characteristics from being degraded during the deterioration determination of the NOx purifying catalyst 11.

It should be noted that the first embodiment is an example in which the upstream NOx sensor 22 is employed as the upstream NOx concentration parameter-detecting means, this is not limitative, but any suitable upstream NOx concentration parameter-detecting means may be employed insofar as it is capable of detecting a parameter indicative of NOx concentration on the upstream side of the NOx purifying catalyst.

Further, the first embodiment is an example in which the downstream NOx sensor 23 is employed as the downstream NOx concentration parameter-detecting means, this is not limitative, but any suitable downstream NOx concentration parameter-detecting means may be employed insofar as it is capable of detecting a parameter indicative of NOx concentration on the downstream side of the NOx purifying catalyst.

Further, although the first embodiment is an example in which the zero point correction process is executed in the step 23 in FIG. 4 as described above, the zero point correction process may be executed as follows: The detection signal value from the downstream NOx sensor 23 is sampled at each control period ΔT , and when a predetermined number of (e.g. 100) detection signal values have been sampled, the predetermined number of the sampled values are averaged (arithmetic mean thereof is calculated) to thereby calculate the correction term. Then, after the calculation of the correction term, the downstream NOx concentration CNOx_Post is calculated based on a value obtained by subtracting the correction term from the actual detection signal value from the downstream NOx sensor 23. Even when the zero point correction process is executed as above in the step 23 in FIG. 4, it is possible to obtain the same advantageous effects as provided by the first embodiment.

On the other hand, the first embodiment is an example in which the high NOx concentration control process is executed as shown in FIG. 3, this is not limitative, but any suitable high NOx concentration control process may be executed insofar as it controls the exhaust gases flowing into the NOx purifying catalyst 11 to the same oxidation atmosphere as during the lean control, and controls the NOx concentration in the exhaust gases to a higher value than that during the lean control. For example, the high NOx concentration control process may be executed as shown in FIG. 12.

As shown in FIG. 12, in this high NOx concentration control process, first, in a step 71, the fuel injection amount QINJ for high NOx concentration control and the fuel injection timing ϕ INJ for high NOx concentration control are calculated in a manner similar to the step 10.

Then, in a step 72, a target value CNOx_PreCMD of the upstream NOx concentration CNOx_Pre is calculated by searching a map, not shown, according to the demanded torque PMCMD for high NOx concentration control and the engine speed NE. This target value CNOx_PreCMD is set to a higher value than the upstream NOx concentration CNOx_Pre in the lean control.

In a step 73 following the step 72, the EGR control process is executed. Specifically, the EGR control valve 8b is feedback-controlled such that the upstream NOx concentration CNOx_Pre converges to the above-mentioned target value CNOx_PreCMD. Then, the present process is terminated. Thus, the exhaust gases exhausted from the engine 3 into the exhaust passage 7 are controlled to form the same oxidation atmosphere as during the lean control, and the upstream NOx concentration CNOx_Pre is controlled to a higher value than that during the lean control. This makes it possible to accurately and rapidly execute the deterioration determination of the NOx purifying catalyst 11. Next, a description will be given of a deterioration determination device for an exhaust emission reduction device according to a second embodiment of the present invention. This deterioration determination device is different from the deterioration determination device 1 according to the first embodiment only in that a deterioration determination process shown in FIG. 13 is executed by the ECU 2 in place of the deterioration determination process shown in FIG. 4 in the first embodiment, so that only the deterioration determination process shown in FIG. 13 will be explained.

[0070] It should be noted that in the present embodiment, the ECU 2 corresponds to upstream NOx concentration parameter-detecting means, downstream NOx concentration parameter-detecting means, control means, NOx supply amount-calculating means, NOx slip amount-calculating means, deterioration determination means, execution condition-determining means, reference value-calculating means, NOx trapping amount-calculating means, and trapping reference value-setting means.

[0071] Also in the deterioration determination process shown in FIG. 13, similarly to the above-described deterioration determination process shown in FIG. 4, the deterioration determination of the NOx purifying catalyst 11 is carried out based on the upstream NOx concentration CNOx_Pre and the downstream NOx concentration CNOx_Post, and is executed at the predetermined control period ΔT (e.g. 10 msec).

[0072] In this process, first, in a step 80, it is determined whether or not the above-mentioned judgment condition satisfaction flag F_JUD is equal to 1. If the answer to the question of the step 80 is negative (NO), i.e. if the conditions for the deterioration determination of the NOx purifying catalyst 11 are not satisfied, it is determined that the deterioration determination of the NOx purifying catalyst 11 should not be executed, and the process proceeds to a step 81, wherein both of an averaged value calculation completion flag F_AVE, referred to hereinafter and the above-mentioned reference value calculation completion flag F_CAL are set to 0, followed by terminating the present process.

[0073] On the other hand, if the answer to the question of the step 80 is affirmative (YES), i.e. the conditions for the deterioration determination of the NOx purifying catalyst 11 are satisfied, the process proceeds to a step 82, wherein it is determined whether or not the average value calculation completion flag F_AVE is equal to 1. If the answer to the question of the step 82 is negative (NO), it is determined that an average value aveCNOx of the downstream NOx concentration CNOx_Post should be calculated, so that the process proceeds to a step 83, wherein a process of calculating the average value aveCNOx is executed, followed by terminating the present process. It should be noted that in the present embodiment, the average value aveCNOx corresponds to the average value of the downstream NOx concentration parameters.

[0074] In the step 83, the average value aveCNOx is calculated as follows: First, the downstream NOx concentration CNOx_Post is calculated at each control period ΔT based on the detection signal from the downstream NOx sensor 23, and the calculated value is sampled. Then, when a predetermined number of (e.g. 100) calculated values of the downstream NOx concentration CNOx_Post are sampled, the predetermined number of sampled values of the downstream NOx concentration CNOx_Post are averaged (arithmetic mean thereof is calculated) to thereby calculate the average value aveCNOx. It should be noted that in the present embodiment, a time period required for the predetermined number of downstream NOx concentration CNOx_Post to be sampled corresponds to the predetermined time period. Then, when the average value aveCNOx is calculated, to indicate that the average value has been calculated, the averaged value calculation completion flag F_AVE is set to 1.

[0075] If the averaged value calculation completion flag F_AVE is set to 1 in the step 83 as described above, the answer to the question of the step 82 becomes affirmative (YES), and in this case, the process proceeds to a step 84, wherein it is determined whether or not the reference value calculation completion flag F_CAL is equal to 1.

[0076] If the answer to the question of the step 84 is negative (NO), it is determined that the NOx supply amount reference value NOxREF should be calculated, so that steps 85 to 89 are executed similarly to the above described steps 25 to 29, followed by terminating the present process.

[0077] If the step 89 is executed as above, the answer to the question of the step 84 becomes affirmative (YES), and in this case, the process proceeds to a step 90, wherein it is determined whether or not the above-mentioned high NOx

concentration condition flag F_NOxUP is equal to 1. If the answer to the question of the step 90 is negative (NO), it is determined that the high NOx concentration control should be executed, so that the process proceeds to a step 91, wherein to indicate this fact, the high NOx concentration condition flag F_NOxUP is set to 1, followed by terminating the present process.

[0078] If the high NOx concentration condition flag F_NOxUP is set to 1 in the step 91 as described above, the answer to the question of the step 90 becomes affirmative (YES), and in this case, the process proceeds to a step 92, wherein the NOx supply amount sumPreNOx is calculated by the above-mentioned equation (2).

[0079] Then, the process proceeds to a step 93, wherein the NOx slip amount sumPostNOx is calculated by the above-mentioned equation (3).

[0080] Next, in a step 94, an exhaust gas supply amount sumQGAS is calculated by the following equation (4):

$$\text{sumQGAS} = \text{sumQGASZ} + \text{QGAS} \cdot \Delta T \quad \dots\dots (4)$$

[0081] In this equation (4), sumQGAS represents the immediately preceding value of the exhaust supply amount. Further, the second term of the right side of the equation (4) is the product QGAS · ΔT of the exhaust flow rate and the control period, and hence indicates the amount of exhaust gases estimated to have been supplied to the NOx purifying catalyst 11 during the time period between the immediately preceding control timing and the present control timing. The exhaust gas supply amount sumQGAS is calculated by integrating the above-mentioned value GAS · ΔT, and hence represents the total amount of exhaust gases estimated to have been supplied to the NOx purifying catalyst 11 during the time period between the start timing of the high NOx concentration control process and the present control timing. Then, the process proceeds to a step 95, wherein similarly to the above-mentioned step 34, it is determined whether or not the condition of sumPreNOx > NOxREF is satisfied. If the answer to the question of the step 95 is affirmative (YES), i.e. if the condition of sumPreNOx > NOxREF is satisfied, it is determined that the enough amount of NOx for executing the deterioration determination of the NOx purifying catalyst 11 has been supplied to the NOx purifying catalyst 11, so that the process proceeds to a step 97.

On the other hand, if the answer to the question of the step 95 is negative (NO), i.e. if sumPreNOx ≤ NOxREF holds, the process proceeds to a step 96, wherein it is determined whether or not the condition of sumPostNOx > NOxREF2 is satisfied. If the answer to the question of the step 96 is negative (NO), the present process is immediately terminated. On the other hand, if the answer to the question of the step 96 is affirmative (YES), the process proceeds to the step 97. In the step 97 following the step 95 or 96, the catalyst deterioration flag F_CATNG setting process is executed. The catalyst deterioration flag F_CATNG setting process is specifically executed as shown in FIG. 14. In this process, first, in a step 100, a reference value NOxJUD2 is calculated by the following equation (5):

$$\text{NOxJUD2} = C1 + \text{sumQGAS} \cdot \text{aveCNOx} \quad \dots\dots (5)$$

[0082] In this equation (5), C1 represents a predetermined constant. As is apparent from this equation (5), the reference value NOxJUD2 is calculated by adding the product sumQGAS · aveCNOx of the exhaust supply amount and the average value to the constant C1, and hence is calculated such that it represents the total amount of NOx estimated to have been supplied to the NOx purifying catalyst 11 during the time period between the start timing of the high NOx concentration control process and the present control timing.

Then, the process proceeds to a step 101, wherein it is determined whether or not the NOx slip amount sumPostNOx is larger than the reference value NOxJUD2. If the answer to the question of the step 101 is negative (NO), i.e. if sumPostNOx ≤ NOxJUD2 holds, it is determined that the NOx purifying catalyst 11 has not been deteriorated, so that the process proceeds to a step 102, wherein to indicate this fact, the catalyst deterioration flag F_CATNG is set to 0.

On the other hand, if the answer to the question of the step 101 is affirmative (YES), i.e. if sumPostNOx > NOxJUD2 holds, it is determined that the NOx purifying catalyst 11 has been deteriorated, so that the process proceeds to a step 103, wherein to indicate this fact, the catalyst deterioration flag F_CATNG is set to 1.

In a step 104 following the step 102 or 103, to indicate that the high NOx concentration control process should be terminated, the high NOx condition flag F_NOxUP is set to 0.

Then, the process proceeds to a step 105, wherein all of the NOx supply amount sumPreNOx, the NOx slip amount sumPostNOx, and the exhaust gas supply amount sumQGAS are set to 0, followed by terminating the present process. Referring again to FIG. 13, after the catalyst deterioration flag F_CATNG setting process is executed as above in the step 97, the present deterioration determination process is terminated.

It should be noted that in the above-mentioned step 96, the process may be configured to compare the NOx slip amount sumPostNOx with the reference value NOxJUD2 calculated in the above-mentioned step 100 in place of the reference value NOxREF2. As described above, according to the deterioration determination device according to the second embodiment, in the deterioration determination process in FIG. 13, the downstream NOx concentration CNOx_Post is calculated based on the detection signal values from the downstream NOx sensor 23, and the NOx slip amount sumPostNOx is calculated based on the calculated downstream NOx concentration CNOx_Post. Further, the upstream NOx concentration CNOx_Pre is calculated based on the detection signal values from the upstream NOx sensor 22, and the NOx supply amount sumPreNOx is calculated based on the calculated upstream NOx concentration CNOx_Pre. Then, when the condition of sumPreNOx > NOxREF is satisfied, the deterioration determination of the NOx purifying catalyst 11 is executed by comparing the NOx slip amount sumPostNOx with the reference value NOxJUD2. That is, the deterioration of the NOx purifying catalyst 11 is determined depending on whether the total amount of NOx estimated to have flowed through the NOx purifying catalyst 11 is large or small at the time point at which the amount of NOx having actually flowed into the NOx purifying catalyst 11 has reached a sufficiently large value.

As described above, if the deterioration of the NOx purifying catalyst 11 is determined using the downstream NOx sensor 23, there is a fear that the accuracy of the deterioration determination is lowered due to the occurrence of a change in the output characteristics of the downstream NOx sensor 23.

According to this deterioration determination device, however, in the step 83, the average value aveCNOx of the downstream NOx concentration CNOx_Post is calculated, and the reference value NOxJUD2 for comparison with the NOx slip amount sumPostNOx is calculated based on the calculated average value aveCNOx. Therefore, even when the downstream NOx sensor 23 is suffering from the above-mentioned change in the output characteristics, it is possible to calculate the reference value NOxJUD2 while causing the change in the output characteristics to be reflected thereon, and determine the deterioration of the NOx purifying catalyst 11 using the reference value calculated as above, thereby making it possible to improve the accuracy of the deterioration determination.

Further, in the average value aveCNOx calculation process in the step 83, the predetermined number of values of the downstream NOx concentration CNOx_Post are sampled which are calculated based on the detection signal from the downstream NOx sensor 23 detected after the conditions for the deterioration determination of the NOx purifying catalyst 11 are satisfied, and the predetermined number of the sampled values are averaged (arithmetic mean thereof is calculated) to thereby calculate the average value aveCNOx. Therefore, even when the detection signal value from the downstream NOx sensor 23 undergoes a temporary variation, or a relatively large error temporarily occurs during the sampling time period, it is possible to calculate the average value aveCNOx while preventing the calculation from being adversely affected from by the temporary variation or the temporary error, and using the average value aveCNOx thus calculated, it is possible to calculate the downstream NOx concentration CNOx_Post. This makes it possible to further improve the accuracy of the deterioration determination.

Further, even when sumPreNOx ≤ NOxREF holds, if the condition of sumPostNOx > NOxREF2 is satisfied, the deterioration determination of the NOx purifying catalyst 11 is executed in the steps 101 to 103 by comparing the NOx slip amount sumPostNOx with the reference value NOxJUD2, and hence it is possible to reduce the time required for executing the high NOx concentration control process, thereby making it possible to suppress degradation of the exhaust emission characteristics.

[0083] It is further understood by those skilled in the art that the foregoing are preferred embodiments of the invention, and that various changes and modifications may be made without departing from the spirit and scope thereof.

[0084] A deterioration determination device for an exhaust emission reduction device which is capable of accurately and rapidly determining deterioration of a NOx purifying catalyst. The deterioration determination device for the exhaust emission reduction device for determining deterioration of the NOx purifying catalyst includes an ECU. The ECU executes high NOx concentration control in deterioration determination, calculates a NOx supply amount based on upstream NOx concentration detected during execution of the high NOx concentration control, calculates a NOx slip amount based on downstream NOx concentration detected during execution of the high NOx concentration control, and determines the NOx purifying catalyst to be deteriorated when the condition of the NOx slip amount > a reference value is satisfied, in a case where the NOx supply amount > a reference value holds.

Claims

1. A deterioration determination device for an exhaust emission reduction device including a NOx purifying catalyst that is provided in an exhaust passage of an internal combustion engine, for trapping, when exhaust gases forming an oxidation atmosphere flow therein, NOx in the exhaust gases, the deterioration determination device determining deterioration of the NOx purifying catalyst, characterized by:

upstream NOx concentration parameter-detecting means for detecting a parameter indicative of a NOx concentration in exhaust gases upstream of the NOx purifying catalyst, as an upstream NOx concentration parameter;

downstream NOx concentration parameter-detecting means for detecting a parameter indicative of a NOx concentration in exhaust gases downstream of the NOx purifying catalyst, as a downstream NOx concentration parameter;

control means for performing oxidation atmosphere control for controlling the exhaust gases flowing into the NOx purifying catalyst to an oxidation atmosphere;

NOx supply amount-calculating means for calculating an integrated value of an amount of NOx having flowed into the NOx purifying catalyst, as a NOx supply amount, using the upstream NOx concentration parameter detected during execution of the oxidation atmosphere control;

NOx slip amount-calculating means for calculating an integrated value of an amount of NOx having flowed through the NOx purifying catalyst, as a NOx slip amount, using the downstream NOx concentration parameter detected during execution of the oxidation atmosphere control; and

deterioration determination means for determining deterioration of the NOx purifying catalyst by comparing the calculated NOx slip amount with a predetermined reference value when the calculated NOx supply amount exceeds a predetermined threshold.

2. A deterioration determination device as claimed in claim 1, further comprising:

execution condition-determining means for determining whether or not conditions for executing the deterioration determination of the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control; and
zero point-correcting means for correcting a zero point of the downstream NOx concentration parameter detected after satisfaction of the conditions for executing the deterioration determination, and

wherein said NOx slip amount-calculating means calculates the NOx slip amount, using the downstream NOx concentration parameter of which the zero point has been corrected.

3. A deterioration determination device as claimed in claim 1, further comprising:

execution condition-determining means for determining whether or not the conditions for executing the deterioration determination for the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control; and

reference value-calculating means for calculating the predetermined reference value based on the downstream NOx concentration parameter detected after satisfaction of the conditions for executing the deterioration determination.

4. A deterioration determination device as claimed in claim 1, further comprising execution condition-determining means for determining whether or not the conditions for executing the deterioration determination for the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control, and
wherein said control means controls, during execution of the oxidation atmosphere control, the NOx concentration in the exhaust gases to a higher value when the conditions for executing the deterioration determination are satisfied than when the conditions for executing the deterioration determination are not satisfied.

5. A deterioration determination device as claimed in claim 4, wherein the NOx purifying catalyst has characteristics of reducing the trapped NOx when the exhaust gases flow therein form a reduction atmosphere, the deterioration determination device further comprising NOx trapping amount-calculating means for calculating an amount of NOx trapped by the NOx purifying catalyst during execution of the oxidation atmosphere control, as a NOx trapping amount,
wherein said control means terminates the oxidation atmosphere control when the NOx trapping amount calculated during execution of the oxidation atmosphere control exceeds a predetermined trapping reference value, and controls the exhaust gases flowing into the NOx purifying catalyst to the reduction atmosphere,
the deterioration determination device further comprising trapping reference value-setting means for setting the predetermined trapping reference value to a larger value when the conditions for executing the deterioration determination are satisfied during execution of the oxidation atmosphere control than when the conditions for executing the deterioration determination are not satisfied.

6. A deterioration determination device as claimed in claim 1, wherein said deterioration determination means executes

determining the deterioration of the NOx purifying catalyst when the NOx slip amount exceeds a predetermined value in a case where the NOx supply amount is not more than the predetermined threshold.

7. A deterioration determination device as claimed in claim 1, wherein a downstream NOx purifying catalyst is provided downstream of the NOx purifying catalyst in the exhaust passage of the engine, for trapping, when exhaust gases forming the oxidation atmosphere flow therein, NOx in the exhaust gases.

8. A deterioration determination method for an exhaust emission reduction device including a NOx purifying catalyst that is provided in an exhaust passage of an internal combustion engine, for trapping, when exhaust gases forming an oxidation atmosphere flow therein, NOx in the exhaust gases, the deterioration determination method determining deterioration of the NOx purifying catalyst,
characterized by:

detecting a parameter indicative of a NOx concentration in exhaust gases upstream of the NOx purifying catalyst, as an upstream NOx concentration parameter;
detecting a parameter indicative of a NOx concentration in exhaust gases downstream of the NOx purifying catalyst, as a downstream NOx concentration parameter;
performing oxidation atmosphere control for controlling the exhaust gases flowing into the NOx purifying catalyst to an oxidation atmosphere;
calculating an integrated value of an amount of NOx having flowed into the NOx purifying catalyst, as a NOx supply amount, using the upstream NOx concentration parameter detected during execution of the oxidation atmosphere control;
calculating an integrated value of an amount of NOx having flowed through the NOx purifying catalyst, as a NOx slip amount, using the downstream NOx concentration parameter detected during execution of the oxidation atmosphere control; and
determining deterioration of the NOx purifying catalyst by comparing the calculated NOx slip amount with a predetermined reference value when the calculated NOx supply amount exceeds a predetermined threshold.

9. A deterioration determination method as claimed in claim 8, further comprising:

determining whether or not conditions for executing the deterioration determination of the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control; and
correcting a zero point of the downstream NOx concentration parameter detected after satisfaction of the conditions for executing the deterioration determination,

wherein said calculating the NOx slip amount includes calculating the NOx slip amount, using the downstream NOx concentration parameter of which the zero point has been corrected.

10. A deterioration determination method as claimed in claim 8, further comprising:

determining whether or not the conditions for executing the deterioration determination for the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control; and
calculating the predetermined reference value based on the downstream NOx concentration parameter detected after satisfaction of the conditions for executing the deterioration determination.

11. A deterioration determination method as claimed in claim 8, further comprising determining whether or not the conditions for executing the deterioration determination for the NOx purifying catalyst are satisfied during execution of the oxidation atmosphere control, and
wherein said performing oxidation atmosphere control includes controlling, during execution of the oxidation atmosphere control, the NOx concentration in the exhaust gases to a higher value when the conditions for executing the deterioration determination are satisfied than when the conditions for executing the deterioration determination are not satisfied.

12. A deterioration determination method as claimed in claim 11, wherein the NOx purifying catalyst has characteristics of reducing the trapped NOx when the exhaust gases flow therein form a reduction atmosphere,
the deterioration determination method further comprising calculating an amount of NOx trapped by the NOx purifying catalyst during execution of the oxidation atmosphere control, as a NOx trapping amount,
wherein said performing oxidation atmosphere control includes terminating the oxidation atmosphere control when

the NOx trapping amount calculated during execution of the oxidation atmosphere control exceeds a predetermined trapping reference value, and controls the exhaust gases flowing into the NOx purifying catalyst to the reduction atmosphere,

the deterioration determination method further comprising trapping reference value-setting means for setting the predetermined trapping reference value to a larger value when the conditions for executing the deterioration determination are satisfied during execution of the oxidation atmosphere control than when the conditions for executing the deterioration determination are not satisfied.

13. A deterioration determination method as claimed in claim 8, wherein said determining deterioration includes executing determining the deterioration of the NOx purifying catalyst when the NOx slip amount exceeds a predetermined value in a case where the NOx supply amount is not more than the predetermined threshold.

14. A deterioration determination method as claimed in claim 8, wherein a downstream NOx purifying catalyst is provided downstream of the NOx purifying catalyst in the exhaust passage of the engine, for trapping, when exhaust gases forming the oxidation atmosphere flow therein, NOx in the exhaust gases.

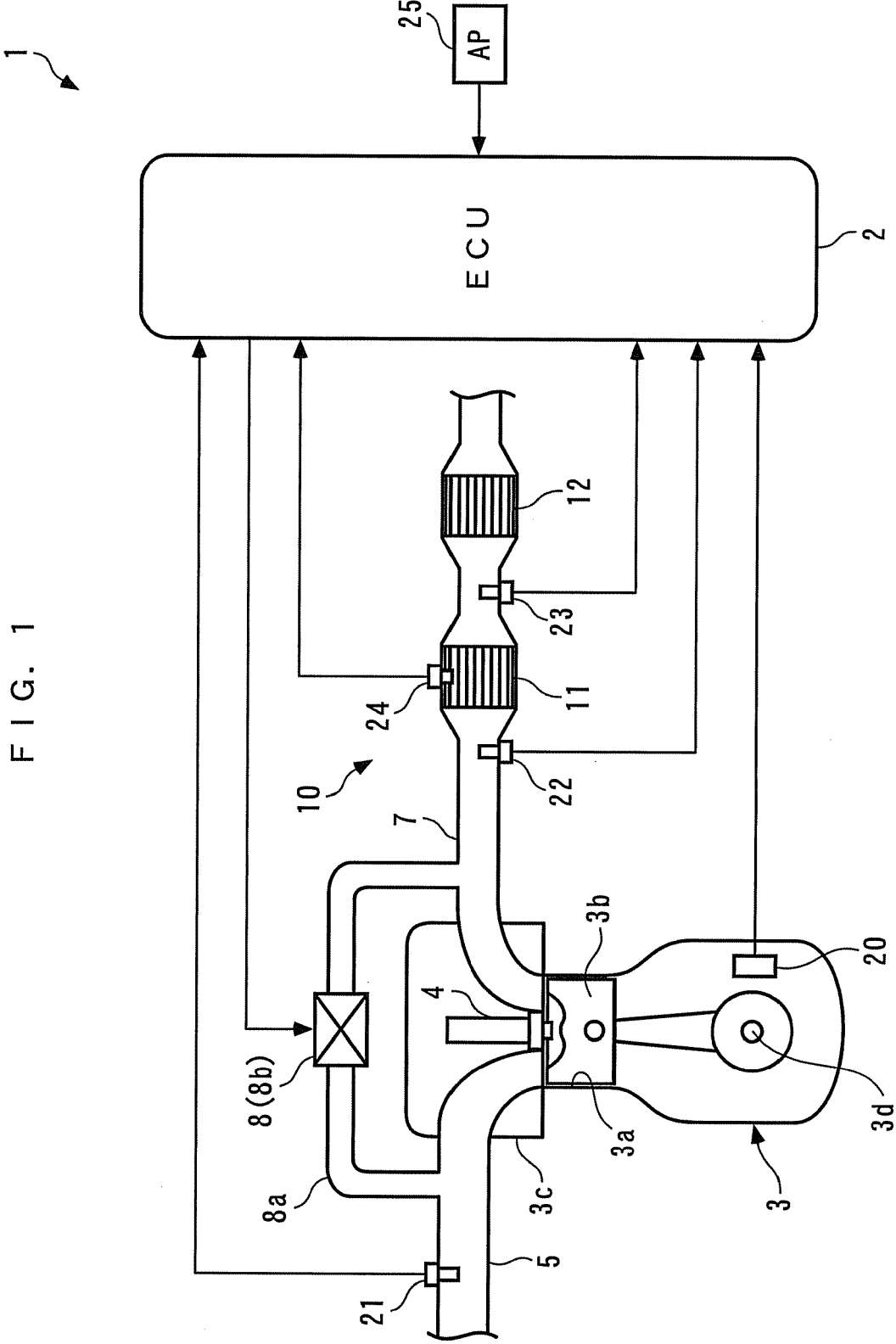


FIG. 2

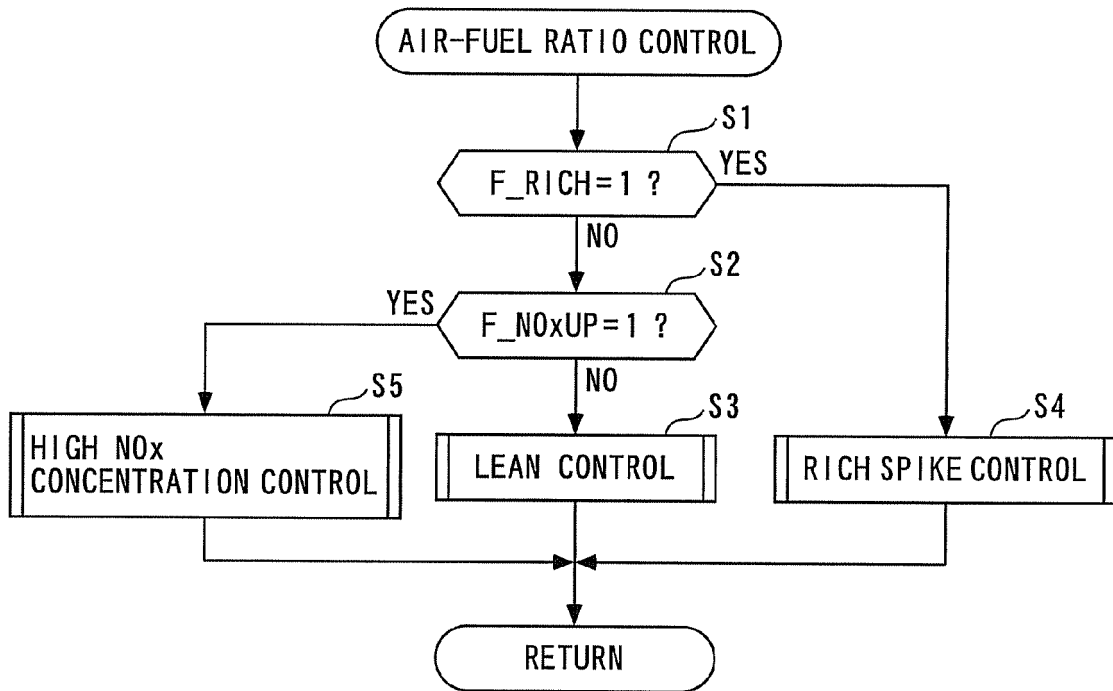


FIG. 3

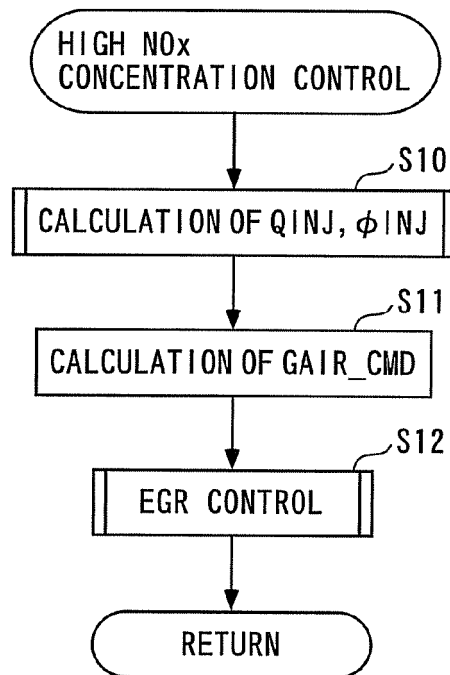


FIG. 4

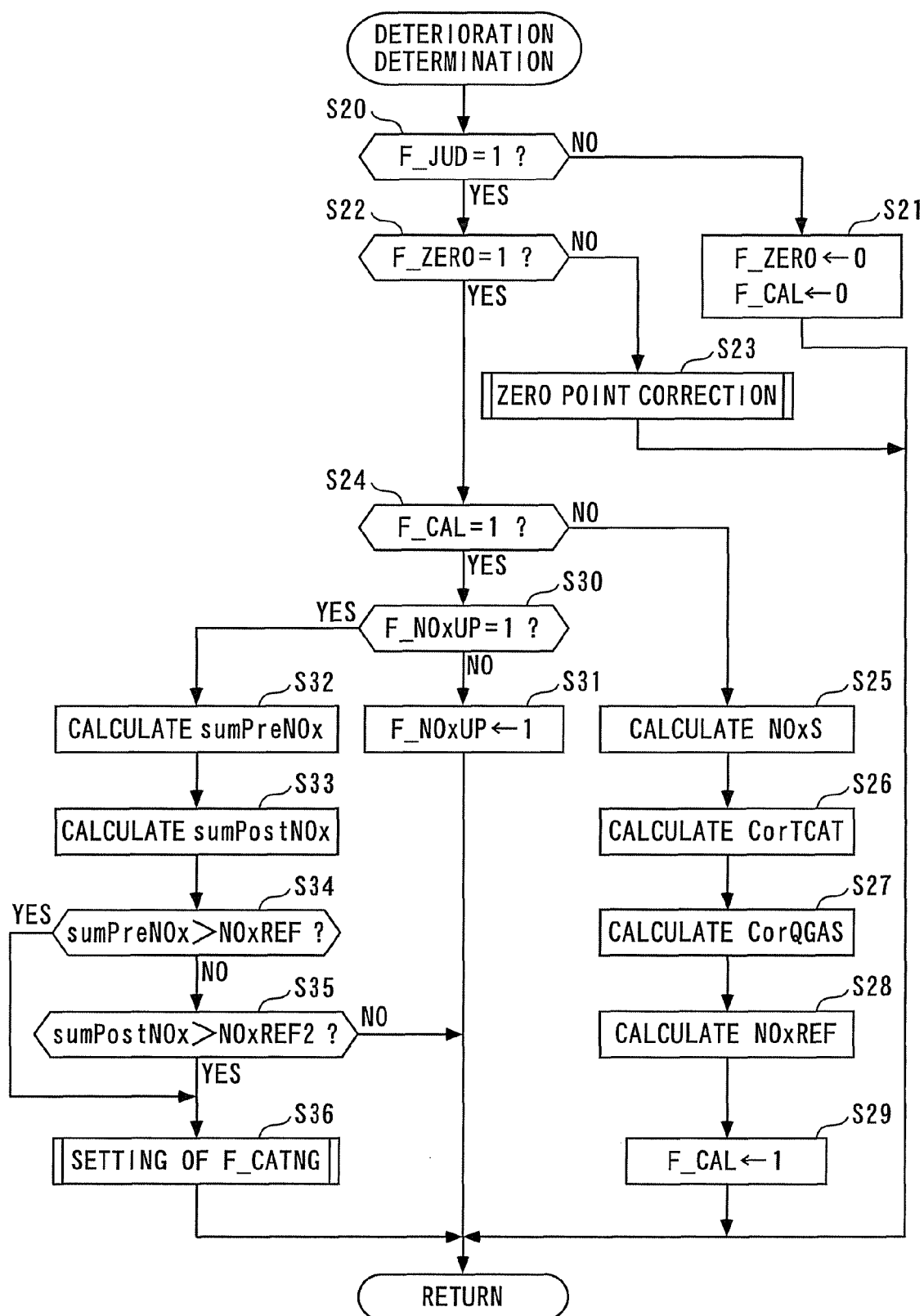


FIG. 5

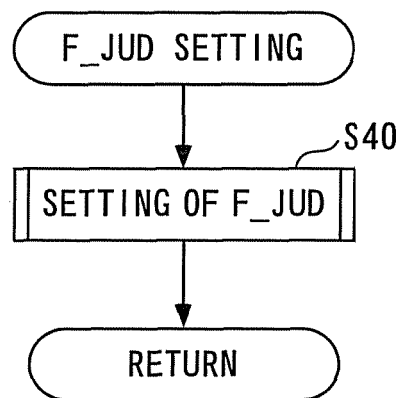


FIG. 6

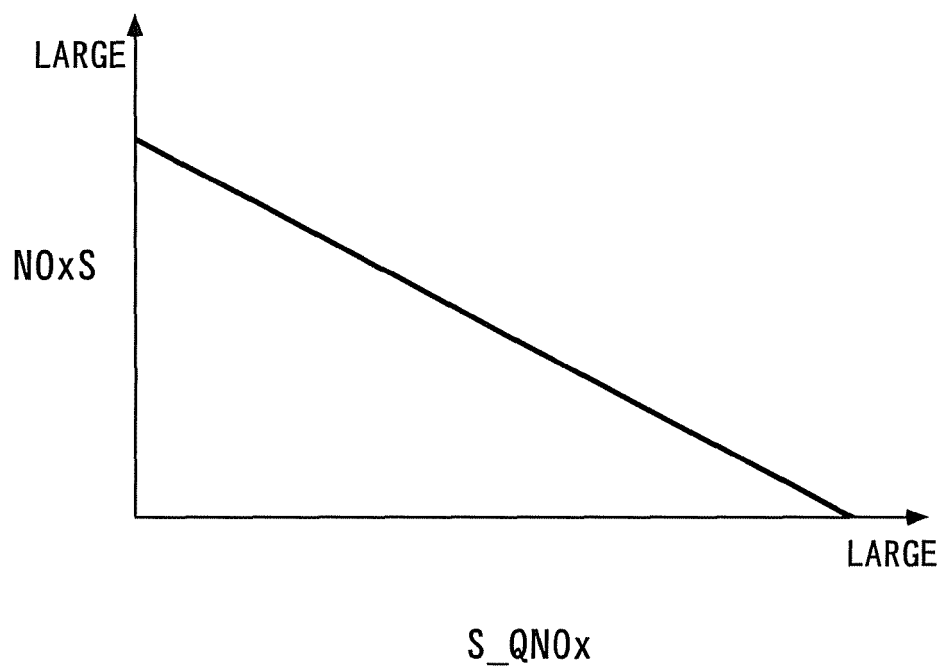


FIG. 7

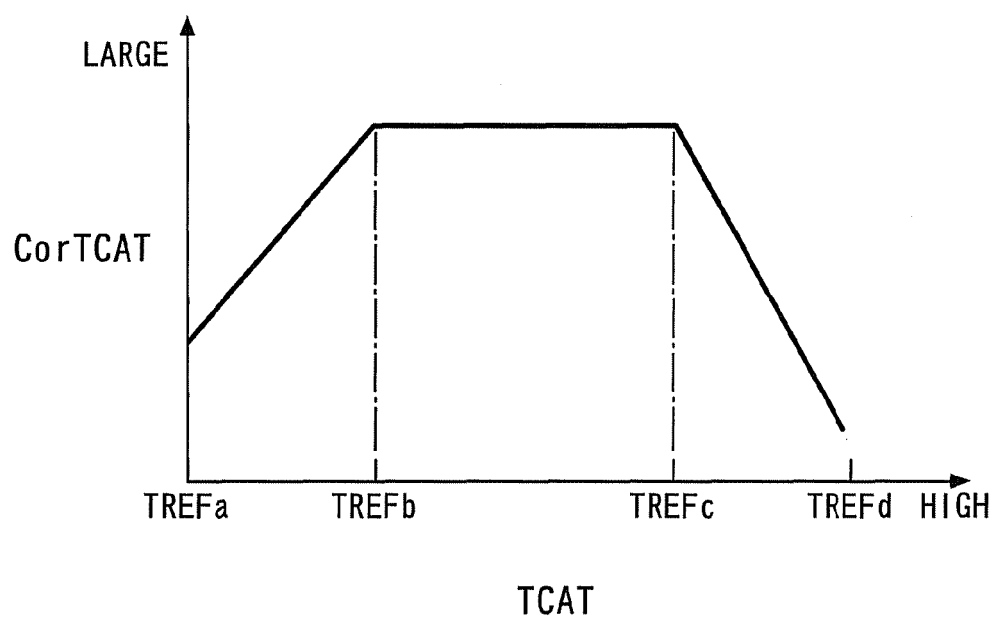


FIG. 8

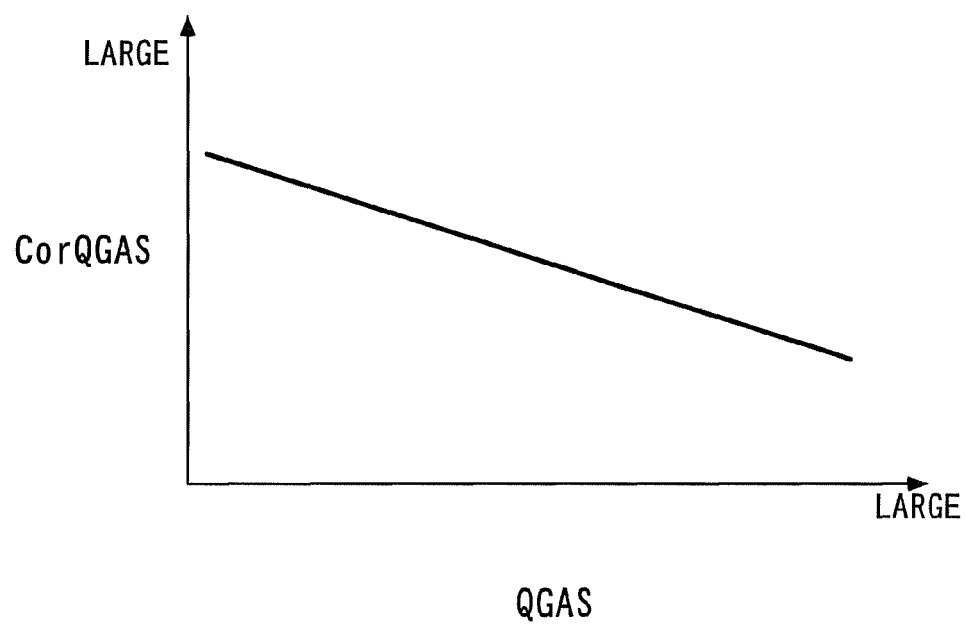


FIG. 9

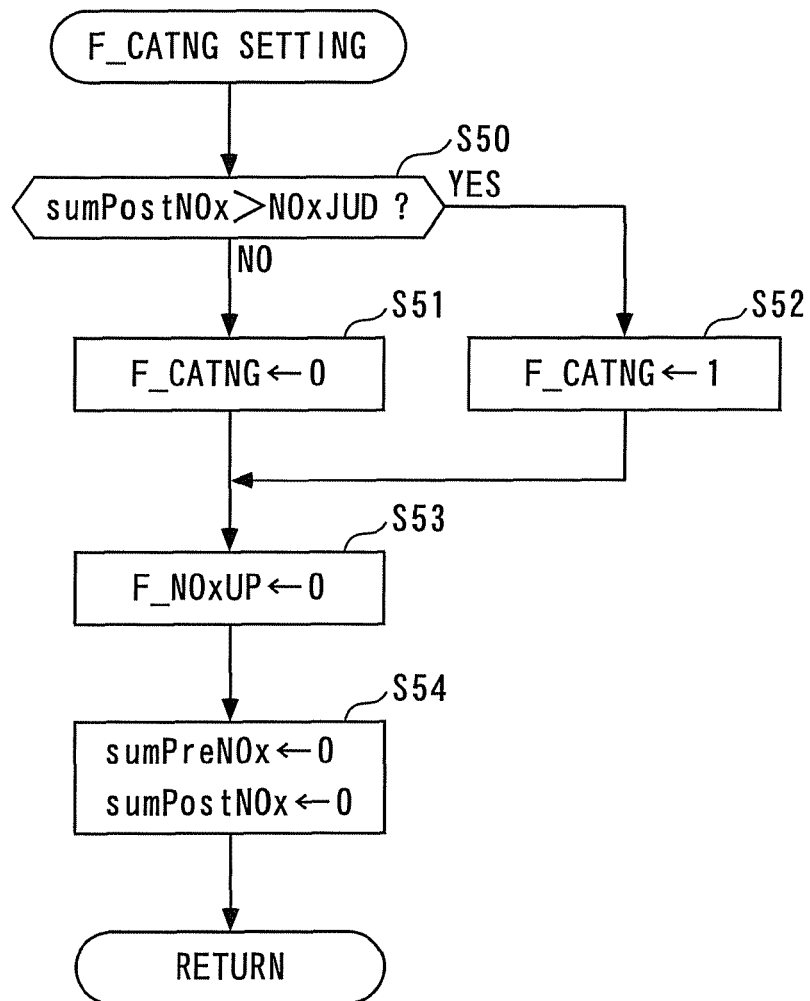


FIG. 10

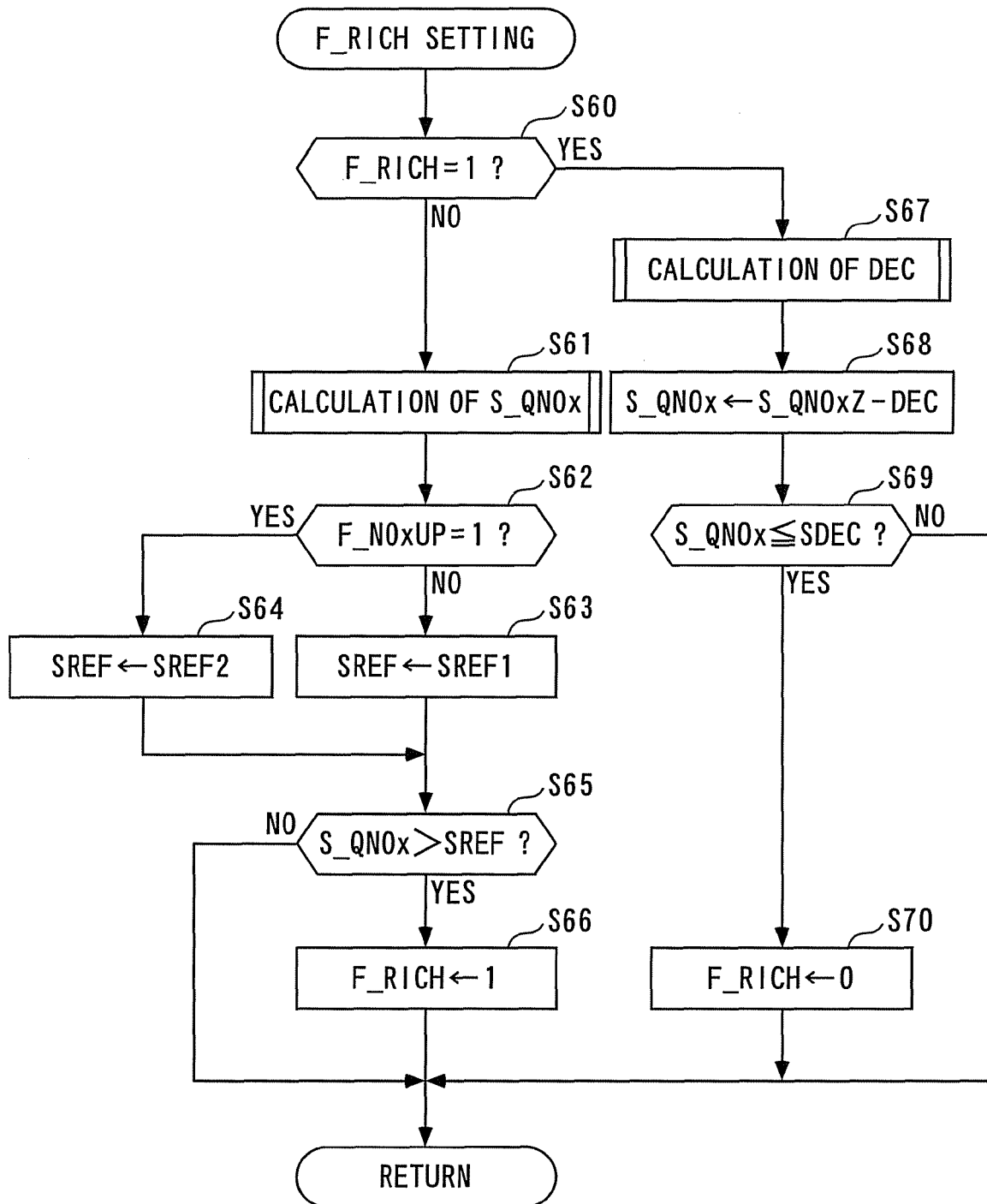


FIG. 11

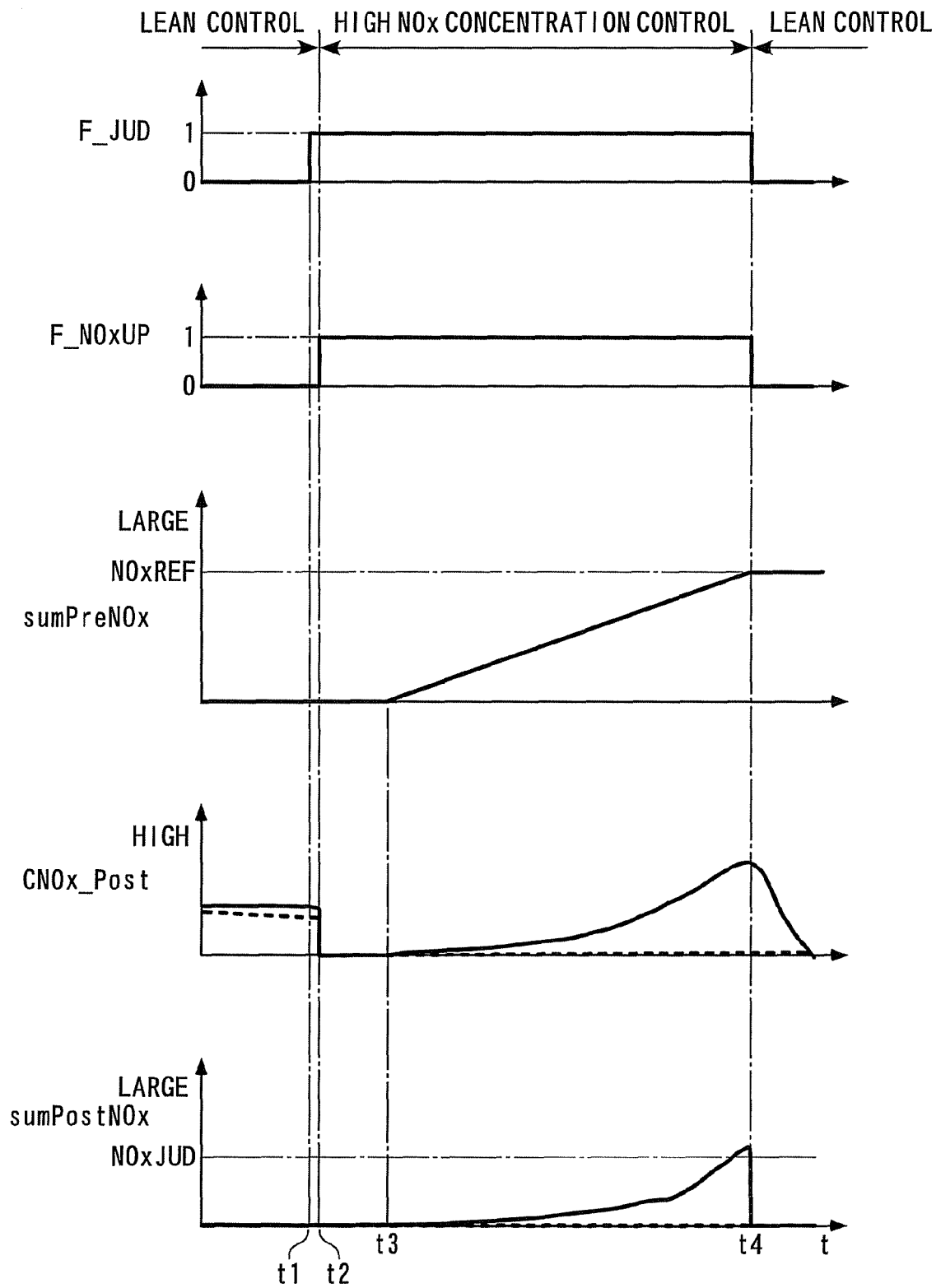


FIG. 12

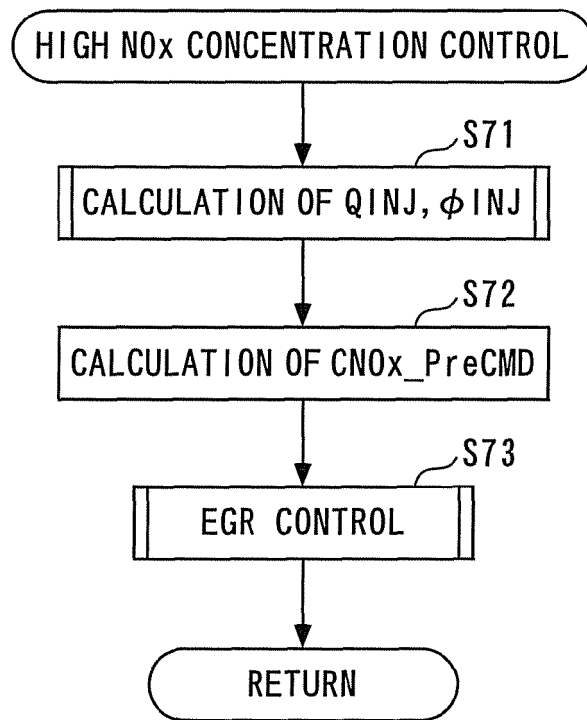


FIG. 13

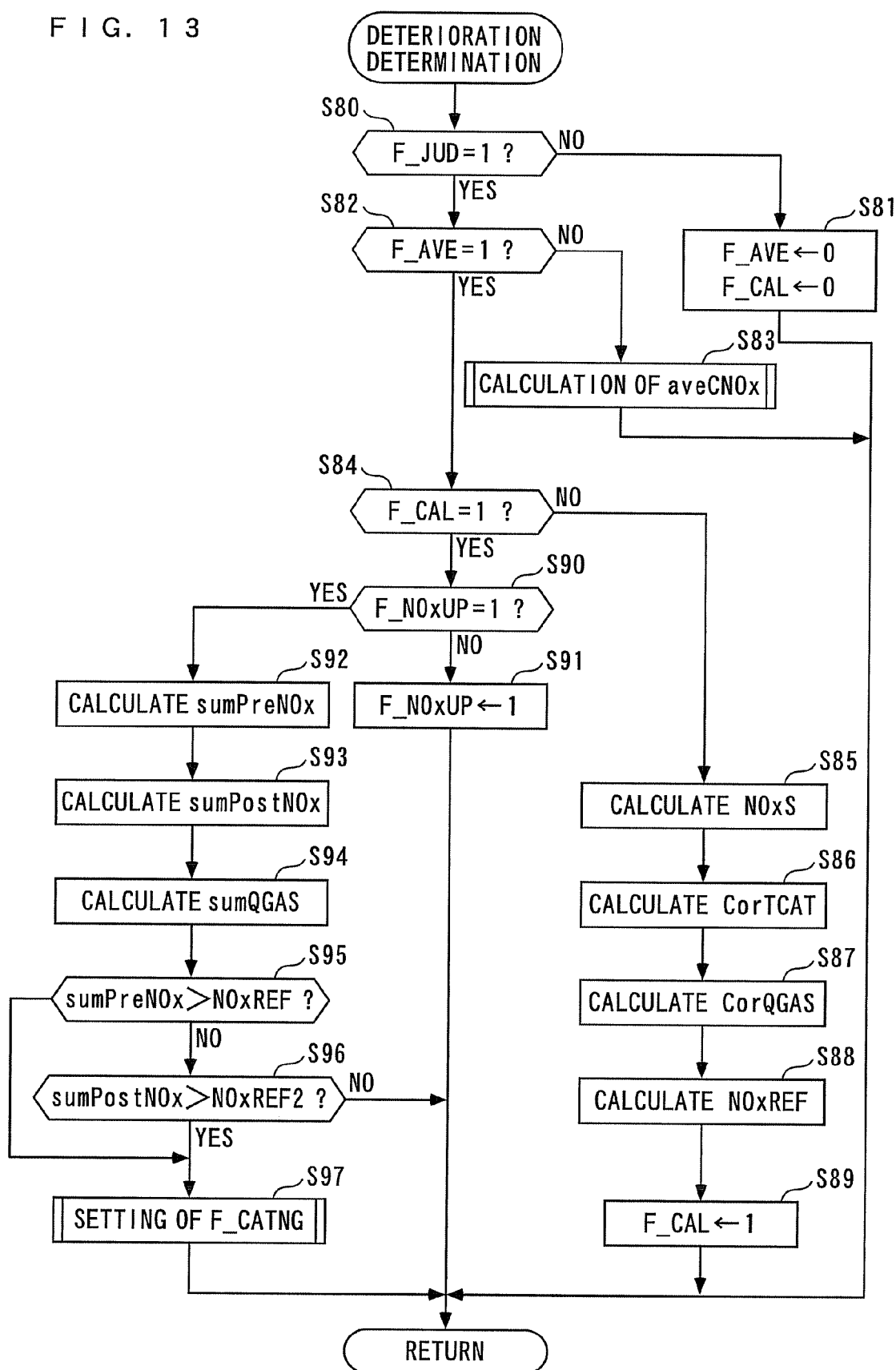
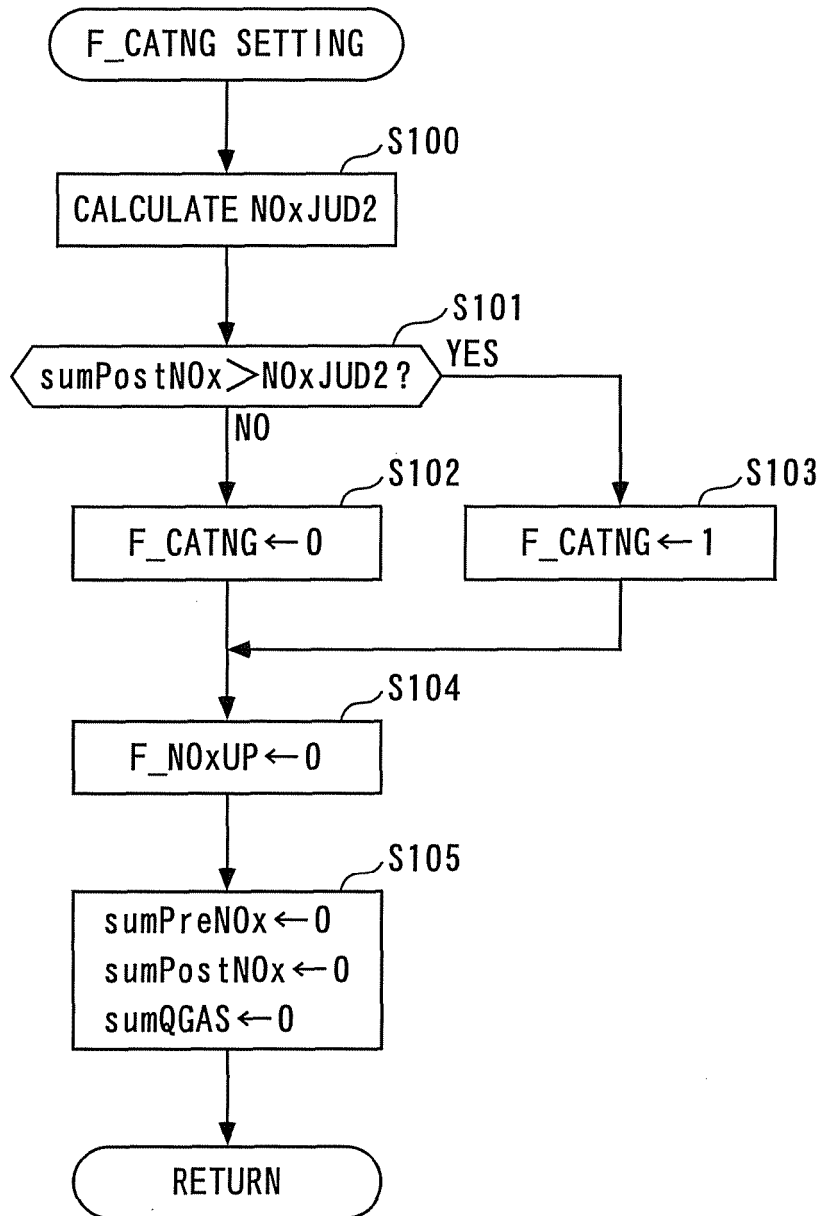


FIG. 14





EUROPEAN SEARCH REPORT

Application Number
EP 09 16 6320

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 2003/140622 A1 (TAYLOR WILLIAM [US] ET AL TAYLOR III WILLIAM [US] ET AL) 31 July 2003 (2003-07-31) * paragraph [0089]; figures 8,9 *	1,8	INV. F01N3/08
D,A	JP 07 180535 A (FUJI HEAVY IND LTD) 18 July 1995 (1995-07-18) * abstract; figures *	1-8	
A	DE 10 2004 051747 A1 (BOSCH GMBH ROBERT [DE]) 27 April 2006 (2006-04-27) * abstract *	1,2,8,9	
A	US 2004/031261 A1 (SUN JING [US] ET AL) 19 February 2004 (2004-02-19) * paragraph [0042] - paragraph [0045]; figures 1,3a *	1,8	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
			F01N
Place of search		Date of completion of the search	Examiner
Munich		28 August 2009	Torle, Erik
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

3
EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 09 16 6320

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

28-08-2009

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
US 2003140622	A1	31-07-2003	EP	1468176	A1	20-10-2004
			JP	2005516154	T	02-06-2005
			WO	03064835	A1	07-08-2003
			US	2006168950	A1	03-08-2006
			US	2005072140	A1	07-04-2005

JP 7180535	A	18-07-1995	JP	3316066	B2	19-08-2002

DE 102004051747	A1	27-04-2006	FR	2877695	A1	12-05-2006
			JP	2006118505	A	11-05-2006

US 2004031261	A1	19-02-2004	DE	10327299	A1	26-02-2004
			GB	2394911	A	12-05-2004

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP H07180535 B [0002]