(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 030 043 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
23.08.2000 Bulletin 2000/34

(51) Int. Cl.[7]: **F02D 41/02**

(21) Application number: **00103087.3**

(22) Date of filing: **15.02.2000**

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

(30) Priority: **16.02.1999 JP 3665899**

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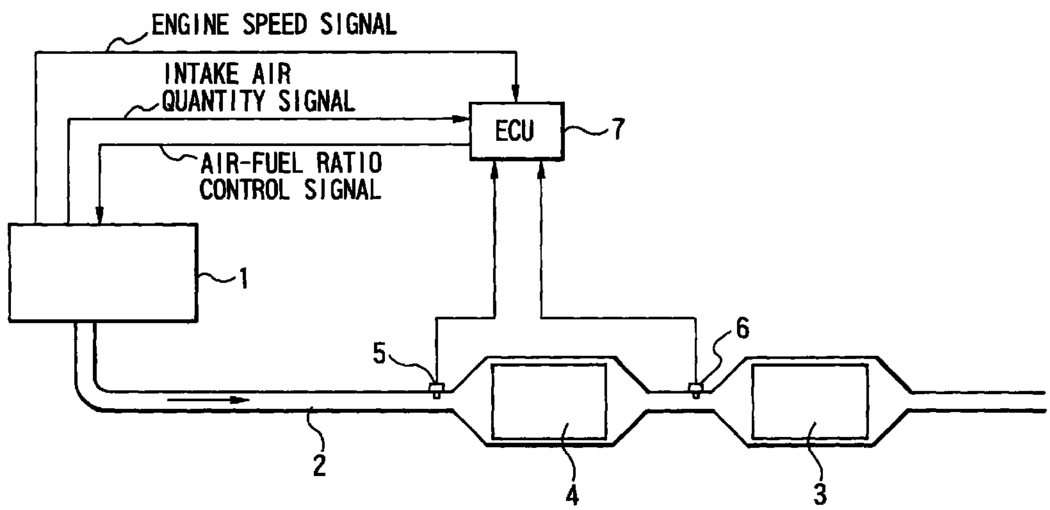
(54) Exhaust gas purification device for engine

(57) In an exhaust system of an internal combustion engine, an SOx reduction catalyst is disposed upstream of an NOx reduction catalyst. A controller calculates an SOx storage quantity in the SOx reduction catalyst, estimates an SOx trap rate of the SOx reduction catalyst from parameters such as the SOx storage quantity and an exhaust temperature, and further estimates an SOx concentration in the exhaust gas mixture flowing into the NOx reduction catalyst. Thus, the controller monitors the SOx concentration during a lean combustion operation of the engine, and switches the engine operating mode to a temporary enrichment mode to reduce the SOx from the SOx reduction catalyst when the SOx concentration exceeds a predetermined threshold.

FIG.1



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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to exhaust gas purifying technique for an internal combustion engine, and specifically to improvements in an exhaust gas purification device for removing nitrogen oxides (NOx) emitted during lean combustion.

[0002] The recent demands for improvement in fuel consumption and reduction of nitrogen oxide emission increase the attractiveness of lean burn engines capable of running at air-fuel ratios higher than the stoichiometric ratio. In such an engine, the treatment of NOx during lean operation is one of the major problems. One exhaust gas purification device employs an NOx reduction catalyst capable of trapping NOx when an inflowing exhaust gas mixture is lean in air-fuel ratio, and of reducing NOx when the inflowing exhaust gas mixture is rich.

[0003] The exhaust gas mixture further contains sulfur oxides (SOx) produced from sulfur in the fuel and lubricating oil. The NOx reduction catalyst traps SOx, and the trapped SOx decreases the catalyst's capability of trapping NOx.

[0004] To avoid this, an exhaust gas purifying system disclosed in a Japanese Patent *Kokai* Publication H06(1994)-229231 employs an SOx reduction catalyst disposed upstream of the NOx reduction catalyst.

SUMMARY OF THE INVENTION

[0005] It is an object of the present invention to provide apparatus and method capable of reducing undesired influence of SOx on NOx reduction efficiently.

[0006] According to the present invention, an exhaust gas purification device for an engine, comprises:

a first catalyst disposed in an exhaust passage of the engine, the first catalyst trapping and storing NOx when an exhaust gas mixture flowing into the first catalyst is leaner than a stoichiometric air-fuel ratio;

a second catalyst disposed in the exhaust passage, the second catalyst being located upstream of the first catalyst, the second catalyst trapping and storing SOx when an exhaust gas mixture flowing into the second catalyst is leaner than the stoichiometric air-fuel ratio, and the second catalyst reducing SOx stored in the second catalyst when the exhaust gas mixture flowing into the second catalyst is richer than the stoichiometric air-fuel ratio; and

a controller programmed to estimate an SOx concentration of SOx in the exhaust gas mixture flowing into the first catalyst, and to control the air-fuel ratio of the exhaust gas mixture flowing into the second catalyst to a rich air-fuel ratio richer than the stoichiometric air-fuel ratio when the SOx concentration reaches a threshold concentration.

[0007] According to another aspect of the present invention, an exhaust gas purification device comprises means for estimating an SOx concentration of SOx on an entrance side of the first catalyst; and means for forcibly reducing SOx from the second catalyst when the SOx concentration reaches a predetermined threshold concentration.

[0008] According to still another aspect of the invention, an engine system comprises: an engine; a downstream catalyst for NOx reduction; an upstream catalyst for SOx reduction, upstream of the downstream catalyst; and a controller. The controller is a component for determining a quantity representing an SOx concentration of an exhaust gas mixture on a downstream side of the upstream catalyst, and switching an operating mode of the engine from a lean mode to a temporary enrich mode to reduce SOx from the upstream catalyst when the quantity becomes greater than a predetermined threshold.

[0009] According to the present invention, an exhaust gas purifying process comprises: estimating an SOx concentration of SOx on an entrance side of an NOx reduction catalyst disposed in an exhaust passage of the engine; comparing the SOx concentration with a predetermined threshold concentration, and performing an SOx reducing operation to reduce SOx from an SOx reduction catalyst upstream of the first catalyst when the SOx concentration becomes greater than a predetermined threshold concentration.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Fig. 1 is a schematic view showing an engine equipped with an exhaust gas purification device according to one embodiment of the present invention.

Fig. 2 is a flowchart showing an SOx reduction process in the exhaust purification device of Fig. 1.

DETAILED DESCRIPTION OF THE INVENTION

[0011] Fig. 1 shows a system of an engine equipped with an exhaust gas purification device according to one embodiment of the present invention.

[0012] Downstream and upstream (or first and second) catalysts 3 and 4 are disposed in an exhaust passage 2 for an internal combustion engine 1 which, in this example, is a spark ignition gasoline engine. The upstream catalyst 4 is located upstream of the downstream catalyst 3. The downstream catalyst 3 traps and stores NOx when the air-fuel ratio of the exhaust gas mixture flowing into the downstream catalyst 3 is lean.

Under the rich condition of the inflowing exhaust gas mixture, the downstream catalyst 3 reduces the stored NOx and performs a reducing and purifying operation with a reducing agent in the exhaust gas mixture. The upstream catalyst 4 is capable of trapping SOx in the exhaust gas mixture.

[0013] As the downstream catalyst 3 for trapping NOx, it is possible to employ a structure of a honeycomb monolithic support coated with a layer comprising a composite oxide represented as [(Ln1-αAα)1-βBOδ] and at least one selected from the group of platinum, palladium and rhodium. In the above expression, $0 \leq \alpha \leq 1$, $0 < \beta < 1$, δ is an oxygen quantity satisfying the valence of each element, Ln is at least one element selected from the group of La, Ce, Nd and Sm, A is at least one element selected from the group of Mg, Ca, Sr, Ba, Na, K and Cs, and B is at least one element selected from the group of ion, cobalt, nickel and manganese.

[0014] As the upstream catalyst 4 for trapping SOx, it is possible to employ a structure having a honeycomb monolithic support coated with a layer comprising at least one selected from the group of alkaline metals, alkaline earth metals, rare earth elements and transition metals, and at least one selected from the group of platinum, palladium and rhodium.

[0015] Upstream and downstream exhaust temperature sensors 5 and 6 are disposed, respectively, at the entrances of the upstream and downstream catalysts 4 and 3. The upstream exhaust temperature sensor 5 senses an exhaust gas temperature TexS at the entrance of the upstream catalyst 4 for SOx. The downstream exhaust gas temperature sensor 6 senses an exhaust gas temperature TexN at the entrance of the downstream catalyst 3 for NOx.

[0016] An engine control unit (ECU) 7 serving as a controller of this control system receives exhaust temperature signals from the exhaust temperature sensors 5 and 6. The engine control unit 7 further receives signals on other engine operating conditions, such as a signal on an intake air quantity from an air flowmeter, and a signal on an engine speed from a crank angle sensor. In accordance with the thus-collected input information, the engine control unit 7 controls the fuel injection quantity of fuel injectors (hence the air-fuel ratio), the fuel injection timing, and the ignition timing.

[0017] Fig. 2 shows a control process performed periodically by the engine control unit 7, for controlling the SOx reduction. This process is repeated at regular time intervals.

[0018] At a step S1, the control unit 7 reads the engine operating conditions such as the engine speed and the engine load.

[0019] Then, the control unit 7 reads the exhaust temperature TexS sensed by the upstream temperature sensor 5 at a step S2. Instead of sensing the exhaust temperature at the entrance of the catalyst 4, it is optional to sense the temperature of the catalyst 4 itself with a temperature sensor, or to estimate the temperature from the history of engine operation of the engine 1 without using a temperature sensor.

[0020] At a step S3, the control unit 7 further reads the exhaust temperature TexN sensed by the downstream temperature sensor 5. Instead of sensing the exhaust temperature at the entrance of the catalyst 3, it is optional to sense the temperature of the catalyst 3 itself with a temperature sensor, or to estimate the temperature from the history of engine operation of the engine 1 without using a temperature sensor.

[0021] At a step S4, the control unit 7 determines whether the engine 1 is operated in a lean air-fuel ratio region, or not. In the case of lean operation, SOx in the exhaust gas mixture is trapped by the upstream catalyst 4. Conversely, the SOx is reduced from the upstream catalyst 4 when the engine 1 is operated in a rich region. Normally, the engine 1 is operated in the learn region, and accordingly, the control unit 7 proceeds from the step S4 to a step S5.

[0022] At the step S5, the control unit 7 calculates an SOx discharge quantity (or rate) SOXex which is a quantity of SOx discharged from the engine 1 into the exhaust passage 2 per unit time (an execution cycle time of this routine, for example), in accordance with the air-fuel ratio and other engine operating conditions. Since the proportion of sulfur in the fuel is approximately constant, the SOx discharge quantity SOXex increases as the fuel supply quantity per unit time increases.

[0023] Then, at a step S6 following the step S5, the control unit 7 calculates an SOx trap rate (or SOx absorption rate) Sal of the upstream catalyst 4. This SOx trap rate Sal is calculated by using, as parameters, an SOx storage amount (or SOx absorption quantity) SOX which is a quantity of SOx remaining in the upstream catalyst 4, the upstream exhaust temperature TexS at the entrance of the upstream catalyst 4, and the air-fuel ratio. In this example, the SOx trap rate Sa1 is a value within the range of 0 ~ 1. The SOx trap rate has the following characteristic with respect to each parameter. The SOx trap rate Sa1 increases as the SOx storage quantity SOX is decreased. The SOx trap rate Sa1 reaches a maximum when the SOx storage quantity SOX is zero. The SOx trap rate Sa1 reaches a maximum when the exhaust temperature TexS at the entrance of the upstream catalyst 4 is equal to a predetermined temperature. The SOx trap rate Sa1 decreases as the upstream exhaust temperature TexS decreases from the predetermined temperature. The SOx trap rate Sa1 is zero at temperatures lower than an activation temperature of the upstream catalyst 4. The SOx trap rate Sa1 decreases as the upstream exhaust temperature TexS increases from the predetermined temperature. The SOx trap rate Sa1 is zero at temperatures higher than an SOx reduction temperature. The SOx trap rate Sa1 decreases as the degree of leanness becomes smaller. The SOx trap rate Sa1 is zero on the rich side of the stoichiometric air-fuel ratio.

[0024] Then, at a step S7 following the step S6, the control unit 7 calculates the SOx storage quantity of the SOx remaining in the upstream catalyst 4 by; SOX = SOXz + SOXex*Sa1 . In this equation, SOXz is a previous value (or the last value) of SOX, and the term (SOXex*Sa1) corresponds to the quantity of SOx newly trapped in the upstream catalyst 4 during a period from the last calculation to the current calculation.

[0025] At a step S8, the control unit 7 calculates an SOx concentration (or concentration of SOx) Sni of the exhaust gas mixture flowing into the downstream catalyst 3 for trapping NOx by Sni = SOXex*K1*(1-Sa1) . In this equation, the quantity {SOXex*(1-Sa1)} corresponds to the quantity of SOx flowing, out of the engine 1, through the upstream catalyst 4, and into the downstream catalyst 3, and the factor K1 is a constant for converting the quantity of SOx into the concentration of SOx.

[0026] At a step S9, the control unit 7 determines a permissible SOx concentration to the exhaust gas mixture flowing into the downstream catalyst 3, in accordance with the downstream exhaust temperature TexN at the entrance of the downstream catalyst 3 for NOx. The permissible SOx concentration is increased as the downstream exhaust temperature TexN increases.

[0027] At a step S10, the control unit 7 determines whether the SOx concentration Sni estimated at the step S8 is greater than the permissible SOx concentration set at the step S9. When Sni is greater than the permissible SOx concentration, the control unit 7 proceeds from the step S10 to a step S11 to meet the need of an SOx reducing operation in the upstream catalyst 4 for trapping SOx, and sets a SOx reduction flag Fsox to one. When Sni is equal to or smaller than the permissible SOx concentration, then the control unit 7 proceeds directly to a step S16.

[0028] At the step S16, the control unit 7 stores the then-existing value of the SOx storage quantity SOX, to use as the previous value SOXz in the next execution cycle of the routine.

[0029] When the SOx reduction flag Fsox is one, the control unit 7 modifies the air-fuel ratio to the rich side according to an air-fuel ratio control routine. As a result, SOx is reduced from the upstream catalyst 4.

[0030] When the SOx reduction flag Fsox is set to one, and the air-fuel ratio becomes rich, then the control unit 7 proceeds from the step S4 to a step S12. At the step S12, the control unit 7 calculates an SOx reduction (or release) rate Sr1 representing the rate of SOx reduced from the upstream catalyst 4 by this enrichment. This SOx reduction rate Sr1 is calculated by using, as parameters, the SOx storage quantity (or SOx absorption quantity) SOX which is a quantity of SOx remaining in the upstream catalyst 4, the upstream exhaust temperature TexS at the entrance of the upstream catalyst 4, and the air-fuel ratio. In this example, the SOx reduction rate Sr1 is a value within the range of 0 ~ 1. The SOx reduction rate has the following characteristic with respect to each parameter. The SOx reduction rate Sr1 decreases as the SOx storage quantity SOX is decreased. The SOx reduction rate Sr1 is zero when the SOx storage quantity SOX is zero. The SOx reduction rate Sr1 decreases as the exhaust temperature TexS at the entrance of the upstream catalyst 4 becomes lower. The SOx reduction rate Sr1 is zero at temperatures lower than an SOx reduction temperature of the upstream catalyst 4. The SOx reduction rate Sr1 decreases as the degree of leanness becomes smaller. The SOx reduction rate Sr1 is zero on the lean side of the stoichiometric air-fuel ratio.

[0031] Then, at a step S13 following the step S12, the control unit 7 calculates the SOx storage quantity ofthe SOx remaining in the upstream catalyst 4 by; SOX = SOXz - SOXz*Sr1 . In this equation, SOXz is the previous value (or the last value) of SOX, and the term (SOXz*Sr1) corresponds to the quantity of SOx reduced from the upstream catalyst 4 during a period from the last calculation to the current calculation. Thus, the SOx storage quantity SOX gradually decreases by the reduction of SOx.

[0032] At a step S14, the control unit 7 determines whether the SOx storage quantity SOX determined at the step S13 is smaller than or equal to a predetermined (minimum) value SOXmin which is set equal to a relatively small value close to zero. When SOX is greater than SOXmin, the control unit 7 proceeds from the step S14 to the step S16 to store the value of SOX, and then repeats this routine. When SOX becomes smaller than or equal to SOXmin, the control unit 7 resets the SOx reduction flag Fsox to zero at a step S15, and terminates the enrichment. The control unit 7 retains the value of the SOx storage quantity SOX stored at the step S16 while the engine 1 is off, and continues the estimation of the SOx storage quantity SOX by using the retained value when the engine 1 is restarted.

[0033] The thus-constructed control system according to this embodiment of the present invention performs a forcible SOx reducing operation based on the SOx concentration Sni of the exhaust gas mixture flowing through the upstream catalyst 4 into the downstream catalyst 3. Therefore, even though the SOx storage quantity SOX increases, this system does not start the enrichment as long as the actual SOx concentration Sni is low. This system can avoid an unnecessary enrichment in such a situation and thereby minimize the deterioration of the fuel consumption. Once the SOx concentration Sni exceeds the permissible SOx concentration, this control system continues the SOx reducing operation until the SOx storage quantity SOX is reduced to a value approximately equal to zero. Therefore, this system can avoid undesirable frequent repetition of the SOx reduction operation.

[0034] This system can estimate the SOx concentration accurately from the SOx trap rate which is determined in accordance with the SOx storage quantity of the SOx reduction catalyst, the temperature condition of the SOx reduction catalyst, and the air-fuel ratio of the exhaust gas mixture flowing into the SOx reduction catalyst.

[0035] It is optional to employ a sensor for sensing the air-fuel ratio of the exhaust gas mixture flowing into the SOx reduction catalyst 4.

[0036] This application is based on a prior Japanese Patent Application. The entire contents of the prior Japanese Patent Application No. 11-36658 with a filing date of February 16, 1999 are hereby incorporated by reference.

[0037] Although the invention has been described above by reference to certain embodiments of the invention, the invention is not limited to the embodiments described above. Modifications and variations of the embodiments described above will occur to those skilled in the art in light of the above teachings. The scope of the invention is defined with reference to the following claims.

Claims

1. An exhaust gas purification device for an engine, comprising:

   a first catalyst disposed in an exhaust passage of the engine, the first catalyst trapping and storing NOx when an exhaust gas mixture flowing into the first catalyst is leaner than a stoichiometric air-fuel ratio;
   a second catalyst disposed in the exhaust passage, the second catalyst being located upstream of the first catalyst, the second catalyst trapping and storing SOx when an exhaust gas mixture flowing into the second catalyst is leaner than the stoichiometric air-fuel ratio, and the second catalyst reducing SOx stored in the second catalyst when the exhaust gas mixture flowing into the second catalyst is richer than the stoichiometric air-fuel ratio; and
   a controller programmed:

   to estimate an SOx concentration of SOx in the exhaust gas mixture flowing into the first catalyst; and
   to control the air-fuel ratio of the exhaust gas mixture flowing into the second catalyst to a rich air-fuel ratio richer than the stoichiometric air-fuel ratio when the SOx concentration reaches a threshold concentration.

2. An exhaust gas purification device according to Claim 1 wherein the controller is programmed:

   to estimate an SOx storage quantity of SOx remaining in the second catalyst;
   to determine an SOx trap rate of the second catalyst by using, as a parameter, the SOx storage quantity; and
   to estimate the SOx concentration by using the SOx trap rate.

3. An exhaust gas purification device according to Claim 2 wherein the controller is programmed to determine the SOx trap rate by using, as parameters, the SOx storage quantity of SOx remaining in the second catalyst, an exhaust temperature on an entrance side of the second catalyst, and an air-fuel ratio.

4. An exhaust gas purification device according to Claim 2 wherein the controller is programmed to enrich the air-fuel ratio of the engine temporarily when the SOx concentration becomes greater than the threshold concentration, and to modify the SOx storage quantity by estimating an SOx reduction quantity from an exhaust temperature at the time of the temporary enrichment, the degree of enrichment and the period of the enrichment.

5. An exhaust gas purification device for an internal combustion engine, comprising:

   a first catalyst disposed in an exhaust passage of the engine, for trapping NOx when an air-fuel ratio of an exhaust gas mixture flowing into the first catalyst is leaner than a stoichiometric air-fuel ratio;
   a second catalyst disposed, upstream of the first catalyst, in the exhaust passage, for trapping SOx in the exhaust gas mixture;
   means for estimating an SOx concentration of SOx on an entrance side of the first catalyst; and
   means for forcibly reducing SOx from the second catalyst when the SOx concentration reaches a predetermined threshold concentration.

6. An engine system comprising:

   an internal combustion engine;
   a downstream catalyst for NOx reduction, disposed in an exhaust passage for the engine;
   an upstream catalyst for SOx reduction, disposed in the exhaust passage at a location upstream of the downstream catalyst; and
   a controller for determining a quantity representing an SOx concentration of an exhaust gas mixture on a downstream side of the upstream catalyst, and switching an operating mode of the engine from a lean mode to a temporary enrich mode to reduce SOx from the upstream catalyst when the quantity becomes

greater than a predetermined threshold.

7. An engine system according to Claim 6 wherein the controller estimates the SO_x concentration in accordance with an SO_x trap rate of the upstream catalyst, and starts the temporary enrich mode when the SO_x concentration becomes greater than a predetermined threshold value.

8. An engine system according to Claim 7 wherein the controller estimates an SO_x storage quantity of SO_x stored in the upstream catalyst, and further estimates the SO_x trap rate in accordance with the SO_x storage quantity and an exhaust temperature in the exhaust passage.

9. An engine system according to Claim 8 wherein the engine system further comprises an exhaust temperature sensor for sensing the exhaust temperature of the exhaust gas mixture flowing in the upstream catalyst.

10. An engine system according to Claim 8 wherein the controller increases the SO_x trap rate as the SO_x storage quantity of the upstream catalyst decreases.

11. An engine system according to Claim 8 wherein the SO_x trap rate decreases with a decrease in the exhaust temperature in a lower temperature range lower than a predetermined temperature, and the SO_x trap rate decreases with an increase in the exhaust temperature in a higher temperature range higher than the predetermined temperature.

12. An engine system according to Claim 8 wherein the controller calculates the SO_x concentration from an SO_x discharge quantity of SO_x discharged form the engine into the exhaust passage, and the SO_x trap rate of the upstream catalyst.

13. An engine system according to Claim 8 wherein the controller calculates the SO_x concentrate when the engine is in the lean mode, and calculates an SO_x reduction quantity when the engine is operated in the temporary enrich mode, to decrease the SO_x storage quantity by the SO_x reduction quantity, and terminates the temporary enrich mode when the SO_x storage quantity is reduced to a predetermined minimum level.

14. An exhaust gas purifying process for an internal combustion engine, comprising:

estimating an SO_x concentration of SO_x on an entrance side of an NO_x reduction catalyst disposed in an exhaust passage of the engine;
comparing the SO_x concentration with a predetermined threshold concentration, and
performing an SO_x reducing operation to reduce SO_x from an SO_x reduction catalyst upstream of the first catalyst when the SO_x concentration becomes greater than a predetermined threshold concentration.

FIG.1

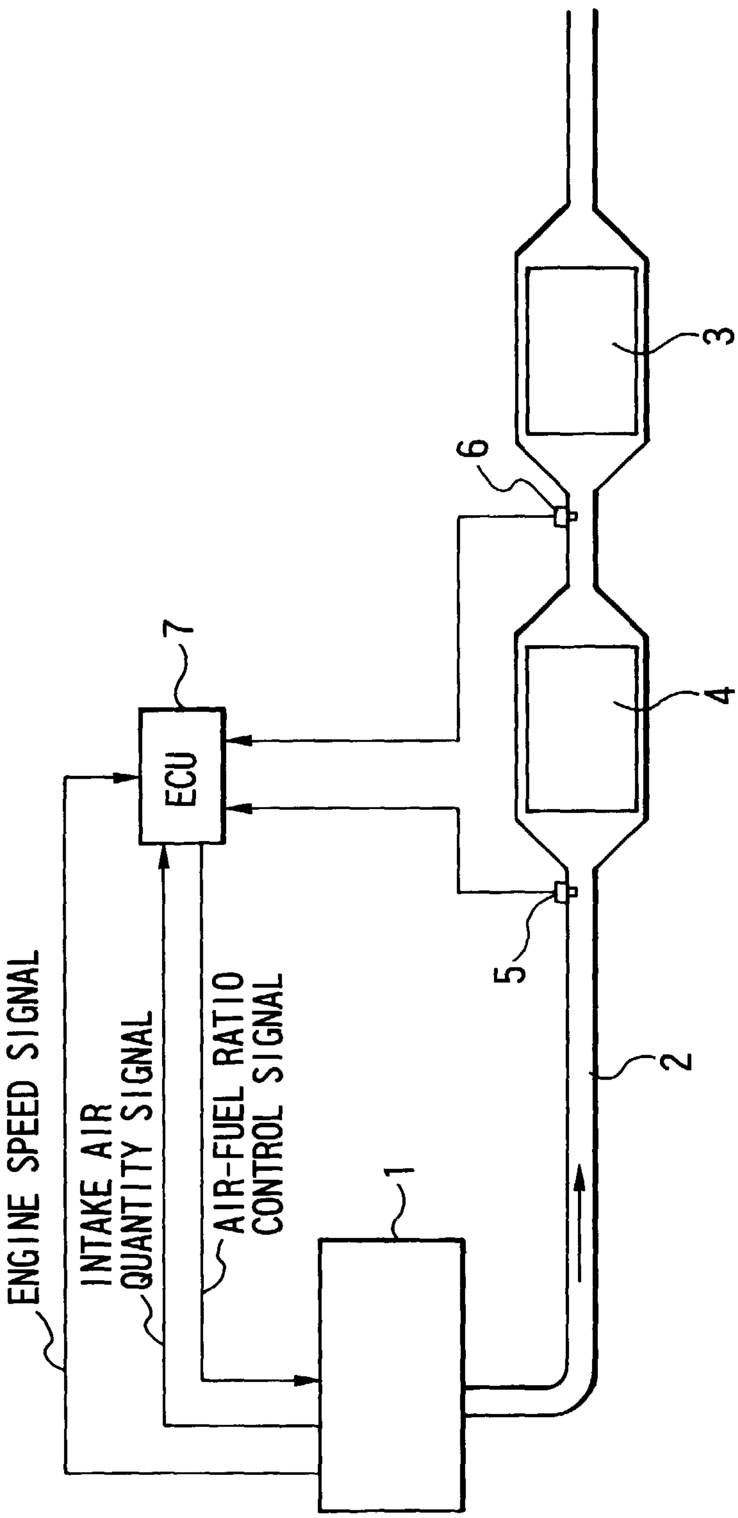
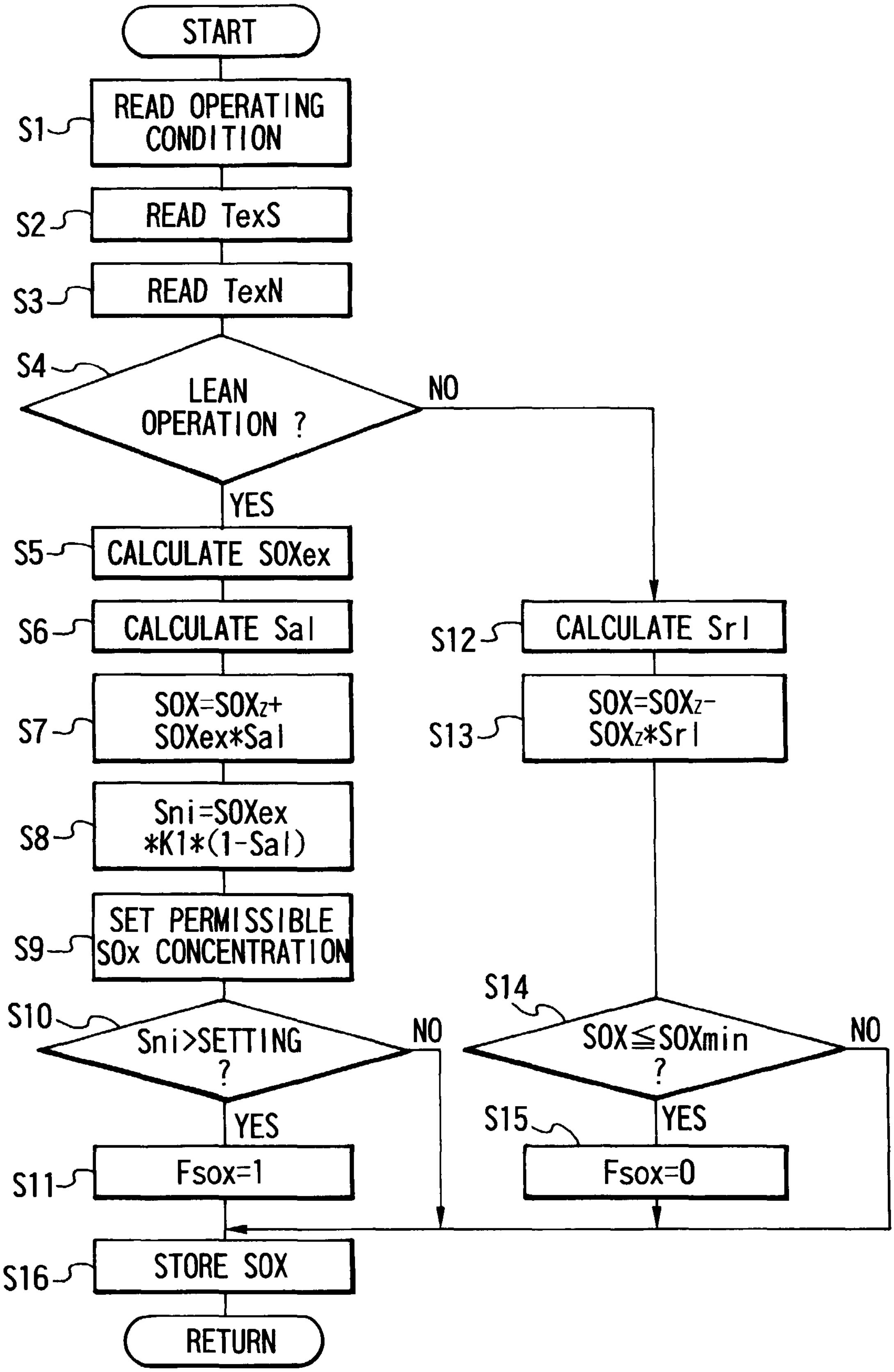

ENGINE SPEED SIGNAL
INTAKE AIR QUANTITY SIGNAL
AIR-FUEL RATIO CONTROL SIGNAL
ECU
7
1
2
3
4
5
6

FIG.2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S2
READ TexS
S3
READ TexN
S4
LEAN OPERATION ?
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YES
S5
CALCULATE SOXex
S6
CALCULATE Sal
S7
SOXz=SOXz+ SOXex*Sal
S8
Sni=SOXex *K1*(1-Sal)
S9
SET PERMISSIBLE SOx CONCENTRATION
S10
Sni>SETTING ?
NO
YES
S11
Fsox=1
S12
CALCULATE Srl
S13
SOX=SOXz- SOXz*Srl
S14
SOX≦SOXmin ?
NO
YES
S15
Fsox=0
S16
STORE SOX
RETURN