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**Nakamura**

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(54) **ABNORMALITY DETERMINATION APPARATUS AND METHOD FOR OXYGEN SENSOR**

7,574,905 B2 8/2009 Toya  
8,065,910 B2 \* 11/2011 Nakamura ..... 73/114.75  
8,108,130 B2 \* 1/2012 Scheuerer ..... 701/109

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**FOREIGN PATENT DOCUMENTS**

JP 09170966 6/1997  
JP 2003343339 12/2003  
JP 2008038847 A 2/2008  
JP 2008169776 7/2008

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\* cited by examiner

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**G01M 15/10** (2006.01)

(52) **U.S. Cl.** ..... **73/114.73; 73/114.75**

(58) **Field of Classification Search** ..... **73/114.73, 73/114.75**

See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

5,672,817 A \* 9/1997 Sagisaka et al. .... 73/114.72  
6,439,038 B1 \* 8/2002 Rosel et al. .... 73/114.73  
6,539,784 B1 \* 4/2003 King et al. .... 73/114.73

(57) **ABSTRACT**

An abnormality determination apparatus for an oxygen sensor provided on the downstream side of a catalyst includes: a first determination portion that determines whether a rich-output continuation time during which output value of the oxygen sensor continues being an output value that shows a rich state before a fuel cut is started is longer than a set continuation time; a second determination portion that determines whether degree of change in the output value when the output value changes from a first reference value to a second reference value that shows a leaner state than the first reference value is more gradual than a set degree of change after the fuel cut is started; and a third determination portion that determines whether the oxygen sensor is abnormal based on determinations by the first determination portion the second determination portion.

**16 Claims, 6 Drawing Sheets**

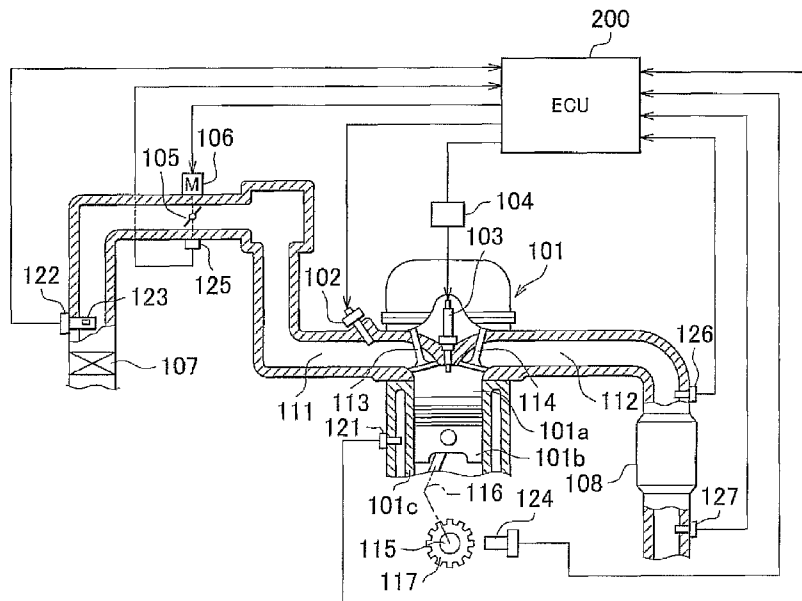
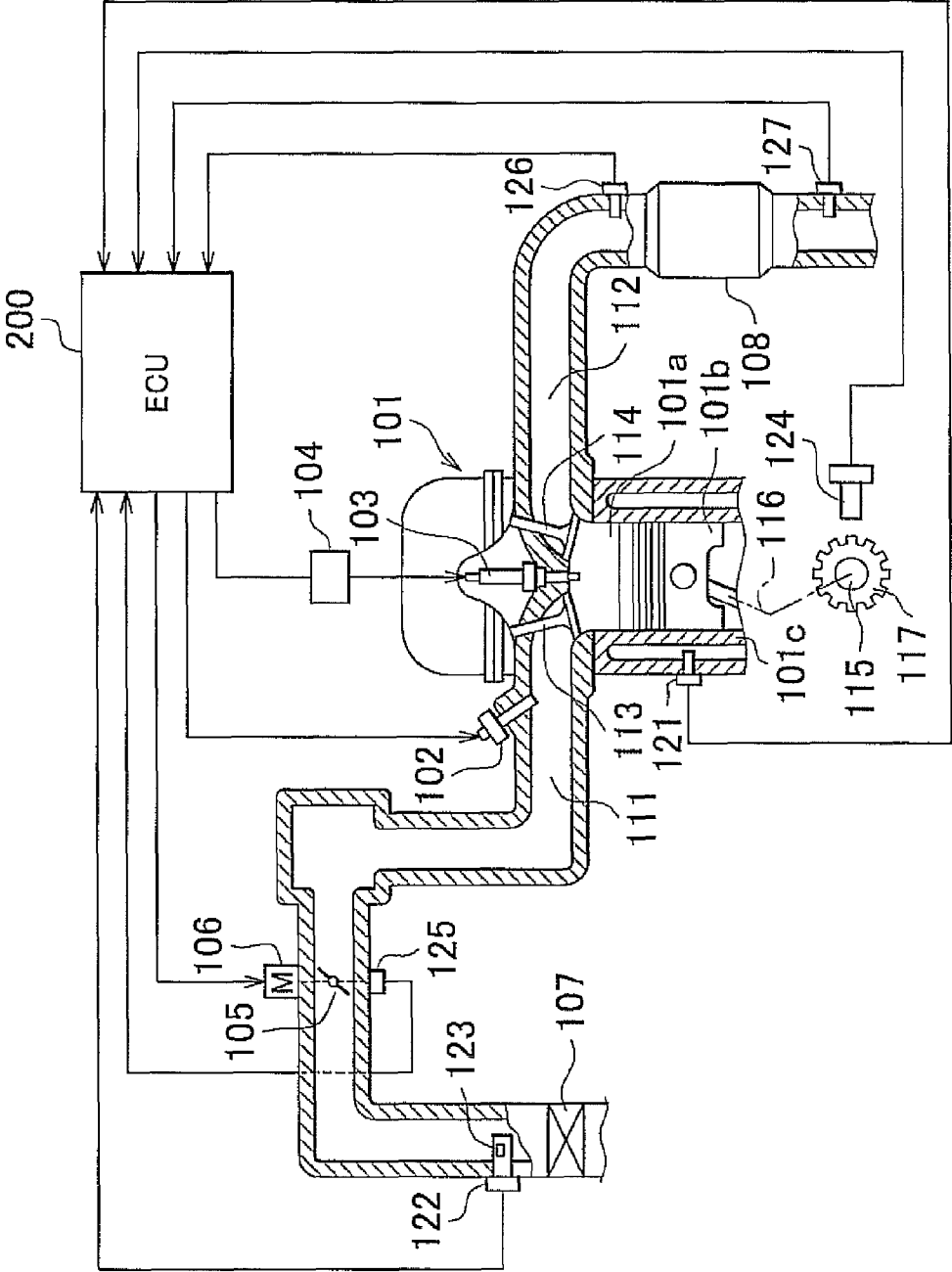
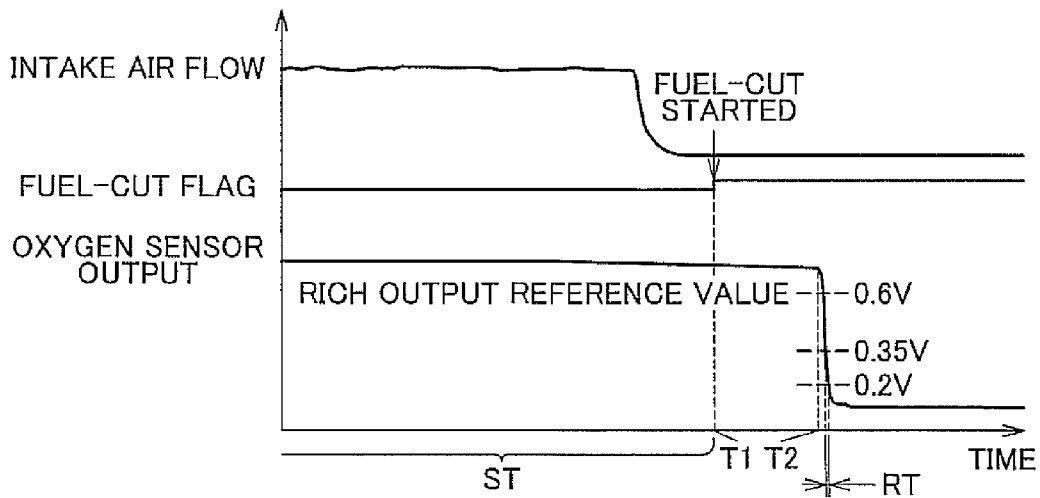


FIG. 1



# FIG. 2A



# FIG. 2B

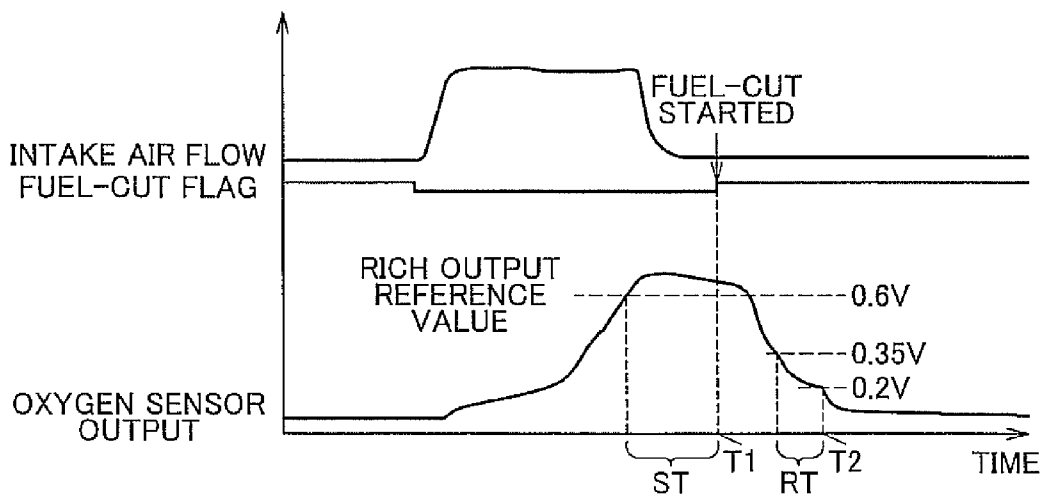


FIG. 3A

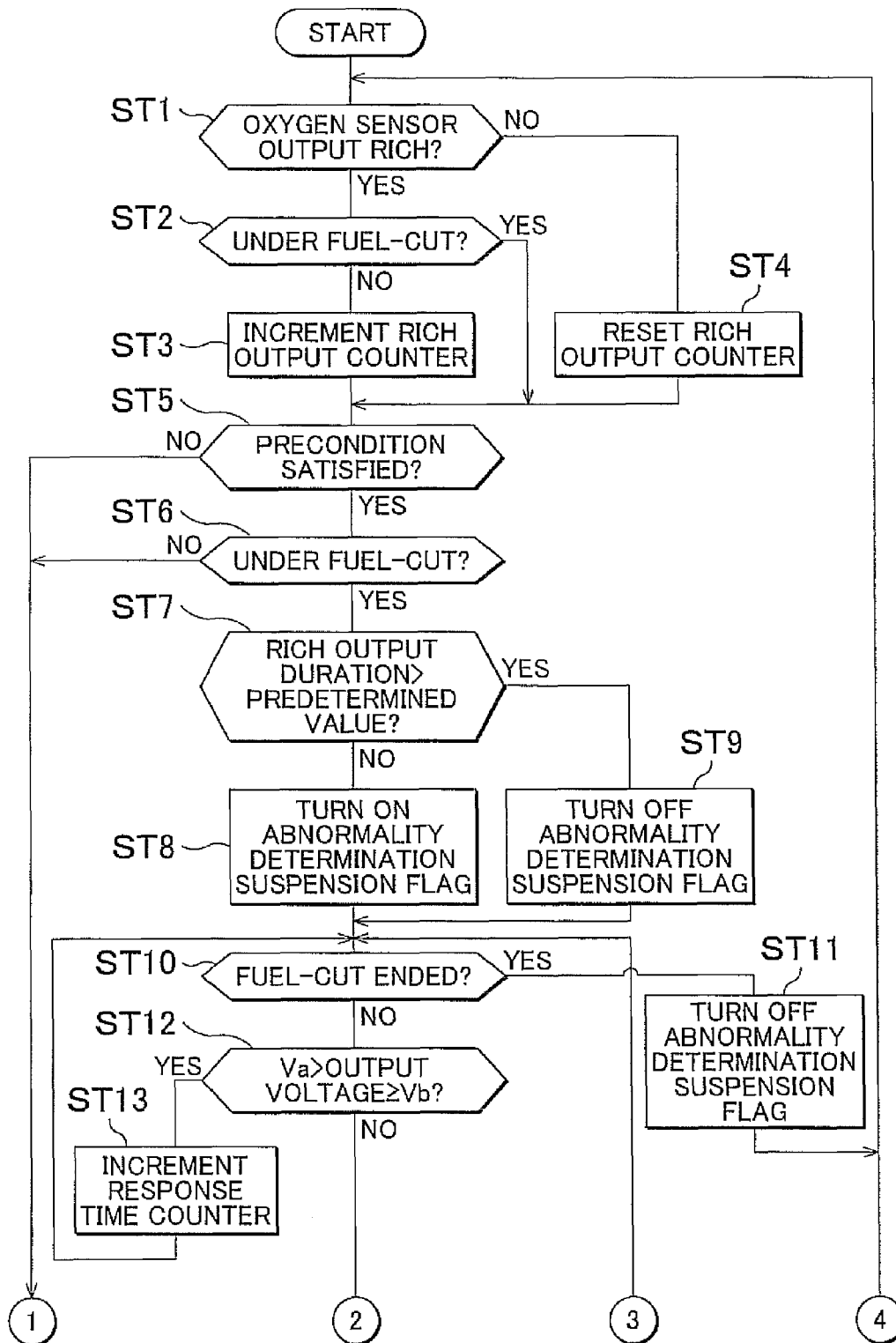


FIG. 3B

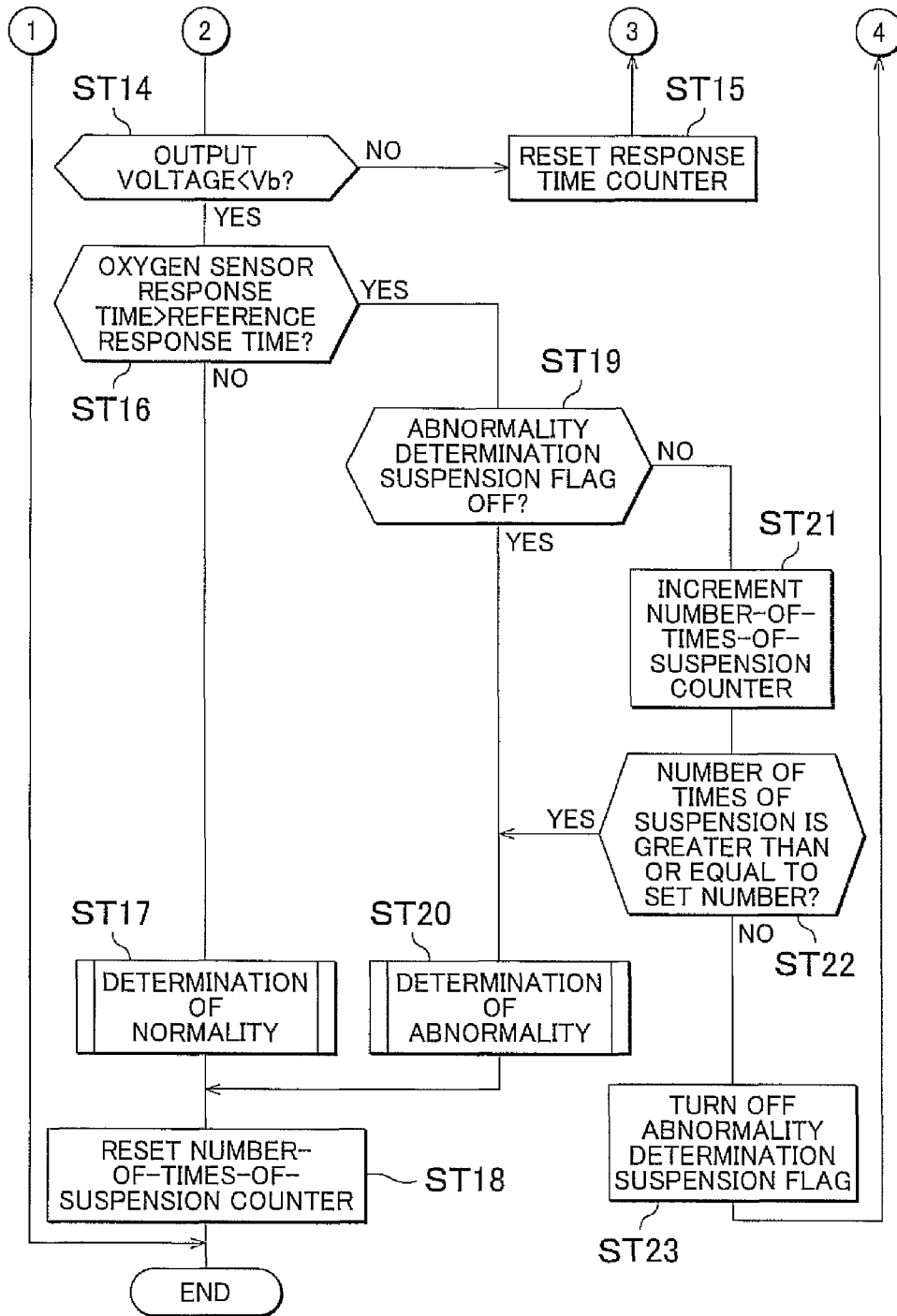


FIG. 4A

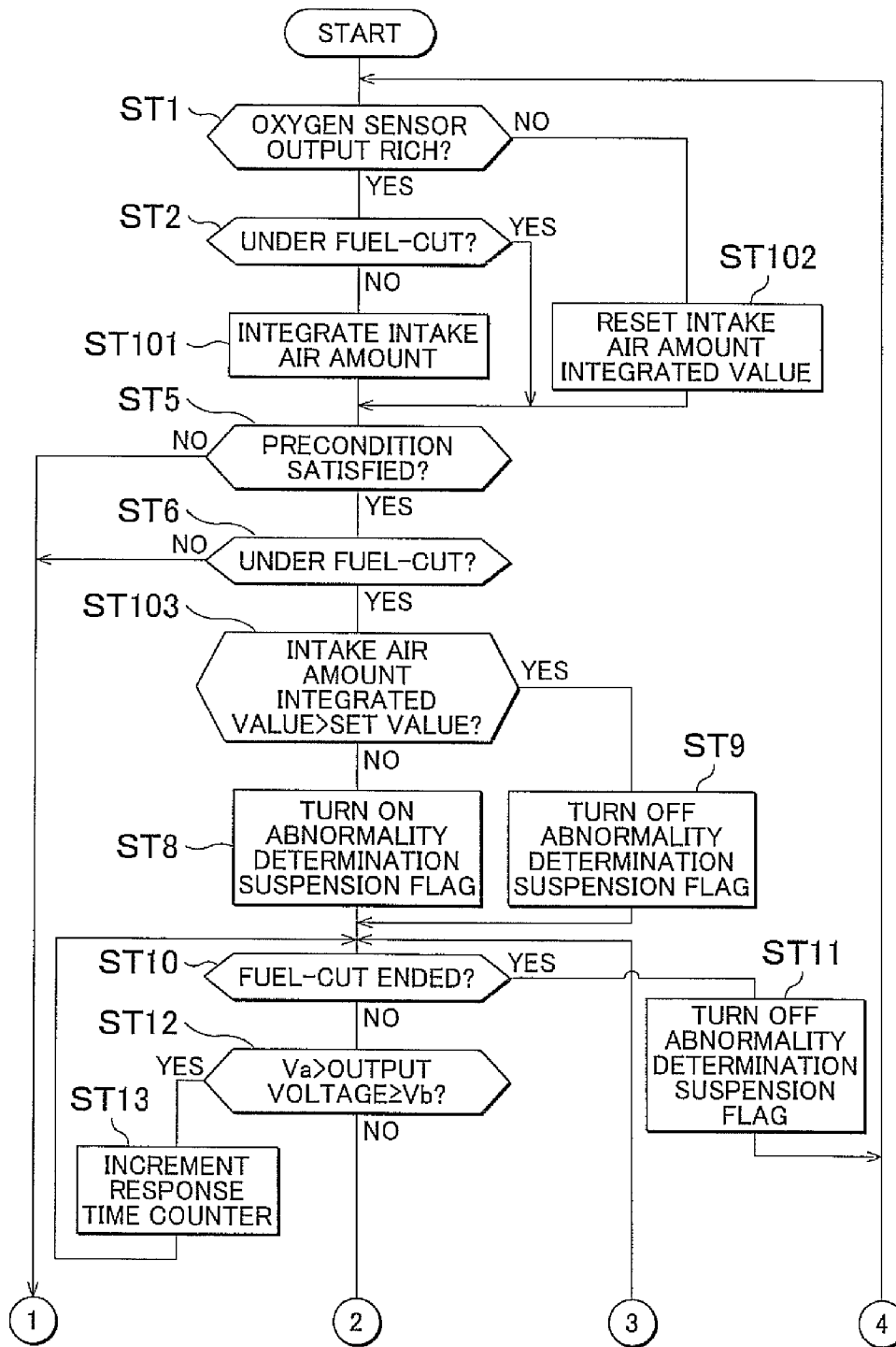
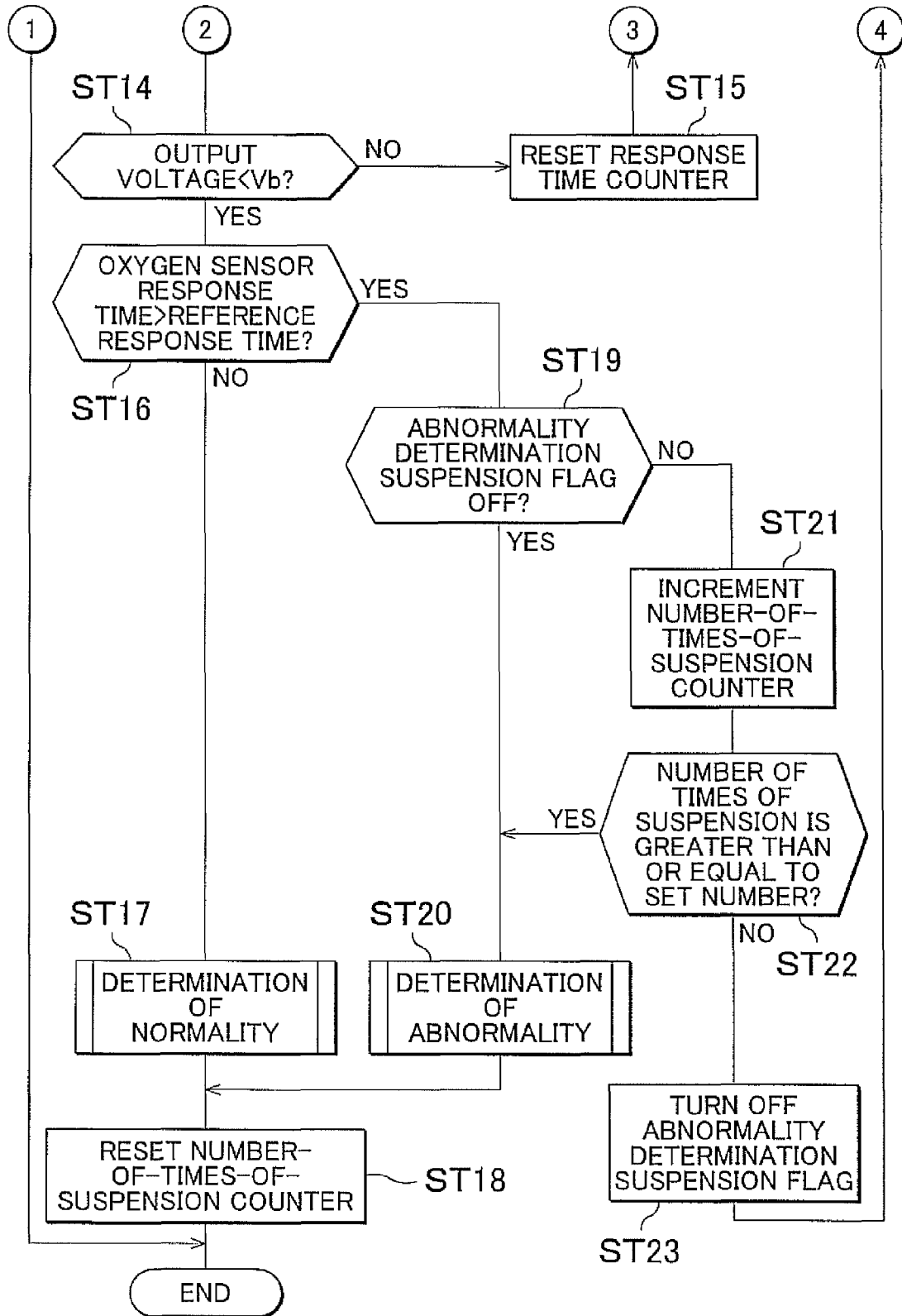


FIG. 4B



## ABNORMALITY DETERMINATION APPARATUS AND METHOD FOR OXYGEN SENSOR

### INCORPORATION BY REFERENCE

The disclosure of Japanese Patent Application No. 2009-039219 filed on Feb. 23, 2009 including the specification, drawings and abstract is incorporated herein by reference in its entirety.

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The invention relates to an abnormality determination apparatus for an oxygen sensor which determines the presence/absence of an abnormality of an oxygen sensor that is provided downstream of a catalytic converter of an internal combustion engine, and also to an abnormality determination method for the oxygen sensor.

#### 2. Description of the Related Art

In internal combustion engines, removal of exhaust gas components has been carried out through the use of catalysts for use for exhaust gas purification which are provided in an exhaust passageway. The removal of exhaust gas components by catalysts is efficiently performed if the air/fuel ratio of the mixture burned in the internal combustion engine is within a predetermined range. Therefore, it is a common practice to provide an oxygen sensor that detects the oxygen concentration in exhaust gas at an upstream side of a catalyst, and perform an air/fuel ratio feedback control of detecting the air/fuel ratio of mixture on the basis of an output signal of the oxygen sensor, and finding an air/fuel ratio correction value for the amount of fuel injection such that the detected air/fuel ratio becomes equal to a target air/fuel ratio, and correcting the amount of fuel injection to the increased or decreased side through the use of the air/fuel ratio correction value.

Furthermore, in order to grasp the state of removal of exhaust gas components by a catalyst, it is also a common practice to provide an oxygen sensor at the downstream side of the catalyst, and perform a so-called subsidiary feedback control of air/fuel ratio in which the air/fuel ratio of the exhaust gas having passed through the catalyst is detected on the basis of the output value of the oxygen sensor, and an amendment value for the air/fuel ratio correction value is calculated according to the detected air/fuel ratio.

In the foregoing subsidiary feedback control, since the output value of the oxygen sensor at the downstream side of the catalyst is utilized, occurrence of abnormality in the oxygen sensor will give rise to a risk of failing to perform normal control and, in turn, failing to sufficiently purify exhaust gas.

Therefore, it has been proposed to adopt an apparatus that executes a fuel cut of stopping the fuel injection from fuel injection valves, and then determines the presence/absence of an abnormality of the oxygen sensor on the basis of the degree of change in the output value of the oxygen sensor at the downstream side of the catalyst after the output value begins to change to a value that shows a leaner state at the time of introduction of fresh air into the exhaust passageway (e.g., see Japanese Patent Application Publication No. 9-170966 (JP-A-9-170966), Japanese Patent Application Publication No. 2003-343339 (JP-A-2003-343339), and Japanese Patent Application Publication No. 2008-169776 (JP-A-2008-169776)).

For example, the apparatuses disclosed in JP-A-9-170966 and JP-A-2008-169776 measure as a response time the amount of time that is taken for the output value of the oxygen

sensor at the downstream side of the catalyst to change from a first threshold value to a second threshold value that shows a leaner state than the first threshold value after the fuel cut is executed. Then, if this response time is longer than a reference response time that is set beforehand, it is determined that the oxygen sensor at the downstream side of the catalyst is abnormal.

By the way, even when the oxygen sensor at the downstream side of the catalyst is not abnormal, it sometimes happens that the output value of the oxygen sensor gradually changes to a value that shows the leaner state, during the period after the fuel cut is executed but before fresh air reaches the oxygen sensor at the downstream side of the catalyst (hereinafter, this phenomenon will be referred to also as "pre-fresh-air-arrival output decline phenomenon"). If despite occurrence of this phenomenon, the abnormality determination regarding the oxygen sensor is performed on the basis of the response time, there is possibility of making a false determination that the oxygen sensor is abnormal when the oxygen sensor is actually normal.

In order to reduce such false determinations as much as possible, the apparatus disclosed in JP-A-2008-169776 determines whether or not fresh air has reached the oxygen sensor at the upstream side of the catalyst, and detects the output value produced by the catalyst-downstream-side oxygen sensor immediately after it is determined that fresh air has reached the upstream-side oxygen sensor. Then, if the detected output value is less than or equal to a criterion value that is set beforehand, the apparatus prohibits the determination that the catalyst-downstream-side oxygen sensor is abnormal.

As stated above, the apparatus disclosed in JP-A-2008-169776 determines whether or not the foregoing pre-fresh-air-arrival output decline phenomenon has occurred on the basis of the output value of the catalyst-downstream-side oxygen sensor that is produced immediately after the arrival of fresh air at the catalyst-upstream-side oxygen sensor. However the accuracy of this determination cannot be said to be sufficiently high, and therefore has been desired to be further improved.

### SUMMARY OF THE INVENTION

The invention provides an abnormality determination apparatus for an oxygen sensor provided on the downstream side of a catalyst which restrains a false determination that is caused by a phenomenon in which the output value of the oxygen sensor gradually changes to a value that shows a leaner state after the fuel cut is started but before fresh air reaches the oxygen sensor at the downstream side of the catalyst, and which improves the accuracy of the determination as to the presence/absence of the occurrence of the phenomenon so as to allow more efficient abnormality determination regarding the oxygen sensor, and an abnormality determination method for an oxygen sensor.

An oxygen sensor abnormality determination apparatus in accordance with a first aspect of the invention includes: a catalyst provided in an exhaust passageway of an internal combustion engine; an oxygen sensor provided in the exhaust passageway on a downstream side of the catalyst; a rich-output continuation time acquisition portion that acquires a rich-output continuation time during which output value of the oxygen sensor continues being an output value that shows a rich state before a fuel cut is started; a first determination portion that determines whether or not the rich-output continuation time acquired by the rich-output continuation time acquisition portion is longer than a set continuation time that



is set beforehand; a second determination portion that determines whether or not, after the fuel cut is started, degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from a first reference value to a second reference value that shows a leaner state than the first reference value is more gradual than a set degree of change that is set beforehand; and a third determination portion that determines whether or not the oxygen sensor is abnormal based on a result of determination by the first determination portion and a result of determination by the second determination portion.

In the first aspect of the invention, the third determination portion may determine that the oxygen sensor is abnormal if it is determined by the first determination portion that the rich-output continuation time is longer than the set continuation time and it is determined by the second determination portion that the degree of change is more gradual than the set degree of change.

According to the oxygen sensor abnormality determination apparatus having a construction as described above, it is determined that the oxygen sensor is abnormal in the case where the rich-output continuation time is longer than the set continuation time that is set beforehand, and where after the fuel cut is started, the degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from the first reference value to the second reference value that shows the leaner state than the first reference value is more gradual than the set degree of change that is set beforehand. The rich-output continuation time serves as a parameter that accurately shows how much the catalyst is filled with rich-gas components. Therefore, by setting an appropriate value as the set continuation time, it becomes possible to improve the accuracy of the determination as to whether or not there occurs the phenomenon in which the output value of the oxygen sensor gradually changes to a value that shows the leaner state after the fuel cut is started but before fresh air reaches the oxygen sensor at the downstream side of the catalyst.

An oxygen sensor abnormality determination apparatus in accordance with a second aspect of the invention includes: a catalyst provided in an exhaust passageway of an internal combustion engine; an oxygen sensor provided in the exhaust passageway on a downstream side of the catalyst; a gas amount calculation portion that calculates an amount of gas that is one of an amount of intake air and an amount of exhaust gas that is taken into or discharged from the internal combustion engine during a time during which the output value of the oxygen sensor continues being an output value that shows a rich state before the fuel cut is started; a fourth determination portion that determines whether or not the amount of gas calculated by the gas amount calculation portion is larger than a set value that is set beforehand; a fifth determination portion that determines whether or not, after the fuel cut is started, a degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from a first reference value to a second reference value that shows a leaner state than the first reference value is more gradual than a set degree of change that is set beforehand; and a sixth determination portion that determines whether or not the oxygen sensor is abnormal based on a result of determination by the fourth determination portion and a result of determination by the fifth determination portion.

In the second aspect of the invention, the sixth determination portion may determine that the oxygen sensor is abnormal if it is determined by the fourth determination portion that the amount of gas is larger than the set value and it is deter-

mined by the fifth determination portion that the degree of change is more gradual than the set degree of change.

According to the oxygen sensor abnormality determination apparatus having a construction as described above, it is determined that the oxygen sensor is abnormal in the case where the amount of intake air or the amount of exhaust gas calculated by the gas amount calculation portion is larger than the set value that is set beforehand, and where after the fuel cut is started, the degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from the first reference value to the second reference value that shows the leaner state than the first reference value is more gradual than the set degree of change that is set beforehand. The amount of intake air or the amount of exhaust gas during the output value continues showing the rich state prior to starting the fuel cut calculated by the gas amount calculation portion serves as a parameter that accurately shows how much the catalyst is filled with rich-gas components. Therefore, by setting an appropriate value as the set value, it becomes possible to improve the accuracy of the determination as to whether or not there occurs the phenomenon in which the output value of the oxygen sensor gradually changes to a value that shows the leaner state after the fuel cut is started but before fresh air reaches the oxygen sensor at the downstream side of the catalyst.

Besides, in the first aspect and the second aspect of the invention, the second determination portion and the fifth determination portion may determine whether or not, after the fuel cut is started, a response time that is taken for the output value of the oxygen sensor to change from the first reference value to the second reference value is longer than a reference response time that is set beforehand.

Besides, in the first aspect of the invention, the third determination portion may avoid determining that the oxygen sensor is abnormal, but may determine again whether or not the oxygen sensor is abnormal after a next time the fuel cut is started, if it is determined by the first determination portion that the rich-output continuation time is not longer than the set continuation time and it is determined by the second determination portion that the degree of change is more gradual than the set degree of change.

Besides, in the second aspect of the invention, the sixth determination portion may avoid determining that the oxygen sensor is abnormal, but may determine again whether or not the oxygen sensor is abnormal after a next time the fuel cut is started, if it is determined by the fourth determination portion that the amount of gas is not larger than the set value and it is determined by the fifth determination portion that the degree of change is more gradual than the set degree of change.

The oxygen sensor abnormality determination apparatus having the foregoing construction, while achieving the foregoing effects, is able to restrain false determination caused by the phenomenon in which the output value of the oxygen sensor gradually changes to a value that shows the leaner state after the fuel cut starts but before fresh air reaches the oxygen sensor at the downstream side of the catalyst.

Besides, in the first aspect of the invention, the third determination portion may determine that the oxygen sensor is abnormal, if a determination that the rich-output continuation time is not longer than the set continuation time and a determination that the degree of change is more gradual than the set degree of change are made consecutively a pre-set number of times by the first determination portion and the second determination portion, respectively.

Besides, in the second aspect of the invention, the sixth determination portion may determine that the oxygen sensor is abnormal, if a determination that the amount of gas is not

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larger than the set value and a determination that the degree of change is more gradual than the set degree of change are made consecutively a pre-set number of times by the fourth determination portion and the fifth determination portion, respectively.

If the oxygen sensor is normal, it is rare that a negative determination made by the first determination portion and a affirmative determination made by the second determination portion, or a negative determination made by the fourth determination portion and a affirmative determination made by the fifth determination portion are made consecutively many times. Therefore, in the foregoing construction, determination of abnormality of the oxygen sensor can be made early, so that the burden on the control apparatus can be lessened.

Besides, in the first aspect and the second aspect of the invention, the third determination portion and the sixth determination portion, respectively, may determine that the oxygen sensor is normal if it is determined by the second determination portion or the fifth determination portion that the degree of change is not more gradual than the set degree of change.

A third aspect of the invention is an abnormality determination method for an oxygen sensor provided in a portion of an exhaust passageway of an internal combustion engine which is on a downstream side of a catalyst that is provided in the exhaust passageway, the method including: acquiring a rich-output continuation time during which output value of the oxygen sensor continues being an output value that shows a rich state before a fuel cut is started; performing a first determination of determining whether or not the rich-output continuation time is longer than a set continuation time that is set beforehand; performing a second determination of determining whether or not, after the fuel cut is started, degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from a first reference value to a second reference value that shows a leaner state than the first reference value is more gradual than a set degree of change that is set beforehand; and determining whether or not the oxygen sensor is abnormal based on a result of the first determination and a result of the second determination.

A fourth aspect of the invention is an abnormality determination method for an oxygen sensor provided in a portion of an exhaust passageway of an internal combustion engine which is on a downstream side of a catalyst that is provided in the exhaust passageway, the method including: calculating an amount of gas that is one of an amount of intake air and an amount of exhaust gas that is taken into or discharged from the internal combustion engine during a time during which the output value of the oxygen sensor continues being an output value that shows a rich state before the fuel cut is started; performing a fourth determination of determining whether or not the amount gas is larger than a set value that is set beforehand; performing a fifth determination of determining whether or not, after the fuel cut is started, degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from a first reference value to a second reference value that shows a leaner state than the first reference value is more gradual than a set degree of change that is set beforehand; and determining whether or not the oxygen sensor is abnormal based on a result of the fourth determination and a result of the fifth determination.

According to the oxygen sensor abnormality determination apparatuses and methods of the first to fourth aspects of the invention, it becomes possible to restrain a false determination caused by a phenomenon in which the output value of

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the oxygen sensor gradually changes to a value that shows the leaner state after the fuel cut is started but before fresh air reaches the oxygen sensor at the downstream side of the catalyst, and to improve the accuracy of the determination as to the presence/absence of the occurrence of the phenomenon so as to allow more efficient process of abnormality determination regarding the oxygen sensor.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The features, advantages, and technical and industrial significance of this invention will be described in the following detailed description of example embodiments of the invention with reference to the accompanying drawings, in which like numerals denote like elements, and wherein:

FIG. 1 is a schematic diagram showing an engine of a vehicle equipped with an abnormality determination apparatus for an oxygen sensor in accordance with an embodiment of the invention and surroundings of the engine;

FIGS. 2A and 2B are time charts showing the amount of intake air of the engine, an idle flag, a fuel cut flag, the output value of a downstream-side oxygen sensor, etc.;

FIGS. 3A and 3B show a flowchart of a process that is executed by an abnormality determination apparatus for an oxygen sensor in accordance with a first embodiment of the invention; and

FIGS. 4A and 4B show a flowchart of a process that is executed by an abnormality determination apparatus for an oxygen sensor in accordance with a second embodiment of the invention.

#### DETAILED DESCRIPTION OF EMBODIMENTS

[FIRST EMBODIMENT] A first embodiment of the invention will be described with reference to the drawings. FIG. 1 shows a general construction of an engine 101 of a vehicle in which an abnormality determination apparatus for an oxygen sensor in accordance with an embodiment of the invention and surroundings of the engine 101. In addition, FIG. 1 shows the construction of only one of the cylinders of the engine 101.

The engine 101 is, for example, a four-cylinder gasoline engine, and includes pistons 101b each of which partially defines a combustion chamber 101a in one of the corresponding cylinders, and also includes a crankshaft 115. Each piston 101b is linked to the crankshaft 115 via a connecting rod 116. The reciprocating motion of the piston 101b is converted into rotary motion of the crankshaft 115 by the connecting rods 116.

A signal rotor 117 is attached to the crankshaft 115. A crank position sensor 124 is installed near the signal rotor 117. The crank position sensor 124 generates pulse signals while the crankshaft 115 is rotating.

A cylinder block 101c of the engine 101 is provided with a water temperature sensor 121 that detects the engine cooling water temperature. An ignition plug 103 is disposed in each combustion chamber 101a of the engine 101. The ignition timing of the ignition plugs 103 is adjusted by an igniter 104. The igniter 104 is driven by an electronic control unit (ECU) 200.

An intake passageway 111 and an exhaust passageway 112 are connected to the combustion chambers 101a of the engine 101. Intake valves 113 are provided between the intake passageway 111 and the combustion chambers 101a, and exhaust valves 114 are provided between the combustion chambers 101a and the exhaust passageway 112. The intake valves 113 and the exhaust valves 114 are driven to open and close by

rotation of an intake camshaft and rotation of an exhaust camshaft, respectively, to both of which rotation of the crankshaft **115** is transmitted.

An air cleaner **107**, a hot-wire type air flow meter **122**, an intake air temperature sensor **123** (provided within an air flow meter **122**), and an electronically controlled throttle valve **105** for adjusting the amount of intake air of the engine **101** are disposed on the intake passageway **111** of the engine **101**. The throttle valve **105** is driven by a throttle motor **106**. The degree of opening of the throttle valve **105** is detected by a throttle opening degree sensor **125**.

Besides, injectors **102** for fuel injection are installed in the intake passageway **111**. The injectors **102** are supplied with fuel at a predetermined pressure from a fuel tank by a fuel pump, and fuel is injected from the injectors **102** into the intake passageway **111**. The injected fuel is mixed with intake air to form a mixture that is introduced into the combustion chamber **101a** of the engine **101**. The mixture introduced into the combustion chambers **101a** is ignited by the ignition plugs **103** to burn and explode. Due to the burning and explosion in the combustion chambers **101a** of air-fuel mixture, the pistons **101b** reciprocate, rotating the crankshaft **115**.

A three-way catalyst **108** that purifies exhaust gas is provided in the exhaust passageway **112** of the engine **101**. The three-way catalyst **108** has a function of purifying exhaust gas by oxidizing HC and CO in exhaust gas and reducing NOx in the same exhaust gas during a state in which the combustion is carried out at or around the stoichiometric air/fuel ratio.

Furthermore, an air/fuel ratio sensor **126** that detects the oxygen concentration in exhaust gas is provided in the exhaust passageway **112** of the engine, at an upstream side of the three-way catalyst **108**.

Besides, an oxygen sensor **127** that detects the oxygen concentration in exhaust gas is provided at the downstream side of the three-way catalyst **108** (and, hereinafter, will be referred to also as "downstream-side oxygen sensor **127**"). The downstream-side oxygen sensor **127** responds to both rich-gas components (CO, HC, etc.) and lean-gas components (oxygen components) in exhaust gas, and outputs a voltage that is greater than or equal to a predetermined value (e.g., 0.6 V) when the air/fuel ratio is richer than the stoichiometric air/fuel ratio, and outputs a voltage less than a predetermined value (e.g., 0.2 V) when the air/fuel ratio is leaner than the stoichiometric air/fuel ratio. In this embodiment, if the output voltage of the oxygen sensor **127** is greater than or equal to "0.6 V", the air/fuel ratio is determined as being "rich". If the output voltage thereof is less than "0.2 V", the air/fuel ratio is determined as being "lean".

The ECU **200** is an electronic control unit that includes a CPU, a ROM, a RAM, a back-up RAM, etc. The ROM stores various control programs, and data that is referred to when such a control program is executed. The CPU executes computation processes on the basis of the various control programs and data stored in the ROM. The RAM is a memory for temporarily storing results of computations performed by the CPU, and data and the like input from various sensors. The back-up RAM is a non-volatile memory for storing data and the like that needs to be stored during a stop of the engine **101**.

The ECU **200**, as shown in FIG. 1, is connected to various sensors, including the water temperature sensor **121**, the air flow meter **122**, the intake air temperature sensor **123**, the crank position sensor **124**, the throttle opening degree sensor **125**, the air/fuel ratio sensor **126**, the downstream-side oxygen sensor **127**, etc. Besides, the ECU **200** is also connected to the injectors **102**, the igniter **104** of the ignition plugs **103**, the throttle motor **106** of the throttle valve **105**, etc.

The ECU **200** executes various controls of the engine **1**, including a fuel injection control of the injectors **102**, an ignition control of the ignition plugs **103**, etc., on the basis of detection signals from various sensors mentioned above.

Besides, the ECU **200** performs an abnormality determination process of determining whether or not the downstream-side oxygen sensor **127** is abnormal.

[ABNORMALITY DETERMINATION PROCESS] Hereinafter, the abnormality determination process of the downstream-side oxygen sensor **127** will be described in detail.

FIGS. 2A and 2B are time charts showing the amount of intake air of the engine **101** before and after execution of the fuel cut, an idle flag that shows whether or not the engine **101** is in an idle state, a fuel-cut flag that shows whether or not the engine **101** is in a fuel cut state, the output value of the downstream-side oxygen sensor **127**, etc. It is to be noted herein that the output value of the downstream-side oxygen sensor **127** is the output value provided when the downstream-side oxygen sensor **127** is normal.

FIG. 2A shows an example of results of an experiment in the case where the output value of the downstream-side oxygen sensor **127** rapidly declines to a value that shows a lean state when fresh air arrives at the downstream-side oxygen sensor **127** (shown by time T2) after the fuel cut is executed. FIG. 2B shows an example of results of an experiment in the case where the above-described "pre-fresh-air-arrival output decline phenomenon" has occurred.

The inventors of the present application have found that if the output value of the downstream-side oxygen sensor **127** continues being a rich output value exceeding a predetermined rich output reference value (in this embodiment, 0.6 V) for a predetermined time or longer prior to the time of starting a fuel cut (time T1), the possibility of occurrence of the pre-fresh-air-arrival output decline phenomenon is low as shown in FIG. 2A, and, on the other hand, if the downstream-side oxygen sensor **127** of the output value does not continue being the rich output value as mentioned above for the predetermined time or longer prior to the time of starting the fuel cut (time T1), the possibility of occurrence of the pre-fresh-air-arrival output decline phenomenon is high as shown in FIG. 2B.

A reason why occurrence of the "pre-fresh-air-arrival output decline phenomenon" can be predicted according to the continuation time ST of the rich output value of the downstream-side oxygen sensor **127** prior to the starting time of the fuel cut is speculated as follows.

In the case where the continuation time ST of the rich output value of the downstream-side oxygen sensor **127** prior to the start of a fuel cut is long, the three-way catalyst **108** is generally filled with rich gas components (CO, XHC, etc.) by the time of start of the fuel cut. Accordingly, it is considered that even when the engine **101** shifts to an idle state or a fuel cut state and therefore the amount of flow of exhaust gas sharply reduces, a sufficient amount of rich gas components flows out from the three-way catalyst **108** and therefore the output value of the oxygen sensor **127** remains a rich output value until fresh air reaches the downstream-side oxygen sensor **127**.

On the other hand, if the continuation time ST of the rich output value of the downstream-side oxygen sensor **127** prior to the start of a fuel cut is short, the three-way catalyst **108** is not very much filled with rich gas component at the time of the start of the fuel cut. Accordingly, it is considered that when the engine **101** shifts to the idle state or the fuel cut state and therefore the amount of flow of exhaust gas sharply reduces, a sufficient amount of rich gas components does not flow out

from the three-way catalyst **108** during the period until fresh air reaches the downstream-side oxygen sensor **127**, and the output value of the oxygen sensor **127** does not remain a rich output value during that period.

Therefore, in this embodiment, a rich-output continuation time ST during which the output value of the downstream-side oxygen sensor **127** continues being a rich output value before a fuel cut starts is acquired, and it is determined whether or not the latest rich-output continuation time ST after the fuel cut has started is longer than a set continuation time that is set beforehand (hereinafter, this determination will also be referred to as “first determination”). Then, on the basis of a result of the first determination and a result of the second determination, abnormality determination regarding the downstream-side oxygen sensor **127** is performed.

In the second determination, it is determined whether or not, after the fuel cut is started, the degree of change in the output value of the downstream-side oxygen sensor **127** in a predetermined range in which the output value of the downstream-side oxygen sensor **127** changes from a value that shows a rich state to a value that shows a lean state is more gradual than a set degree of change that is set beforehand. Concretely, it is determined whether or not, after a fuel cut is started, a response time RT that is taken for the output value of the oxygen sensor to change from a first reference value (e.g., 0.35 V in this embodiment) to a second reference value (e.g., 0.2 V in this embodiment) that shows a leaner state than the first reference value is longer than a reference response time that is set beforehand.

Then, in the case where an affirmative determination is made in the first determination and an affirmative determination is also made in the second determination, it is determined that the downstream-side oxygen sensor **127** is abnormal. That is, in the case where the rich-output continuation time ST prior to the start of the fuel cut is longer than the set continuation time and where the response time RT is longer than the reference response time, it is determined that the downstream-side oxygen sensor **127** is abnormal.

Besides, in the case where a negative determination is made in the first determination and an affirmative determination is made in the second determination, it is not determined that the downstream-side oxygen sensor **127** is abnormal, but the determination is suspended, and re-determination is performed after the next time the fuel cut is started. That is, in the case where the rich-output continuation time ST prior to the start of the fuel cut is shorter than the set continuation time and where the response time RT is longer than the reference response time, it is not determined that the downstream-side oxygen sensor **127** is abnormal, but the determination is suspended and re-determination is performed after the next time the fuel cut is started.

Besides, if a negative determination is made in the second determination, it is determined that the downstream-side oxygen sensor **127** is normal regardless of a result of determination in the first determination. That is, in the case where the response time RT is shorter than the reference response time, it is determined that the downstream-side oxygen sensor **127** is normal regardless of the rich-output continuation time ST prior to the start of the fuel cut.

Hereinafter, with reference to the flowchart shown in FIGS. **3A** and **3B**, a processing procedure of the abnormality determination regarding the downstream-side oxygen sensor **127** that is performed by the abnormality determination apparatus for the oxygen sensor will be described. Incidentally, this processing procedure is repeatedly executed by the ECU **200** at every predetermined period. Besides, the ECU **200** manages a fuel-cut flag that shows the on/off state of the fuel cut,

the idle flag, an abnormality determination suspension flag, a rich-output counter, a response time counter, a number-of-times-of-suspension counter, etc.

Firstly, in step ST1, it is determined whether or not the output value of the downstream-side oxygen sensor **127** is a rich output value (e.g., a value exceeding 0.6 V). If an affirmative determination is made in this step, the process proceeds to step ST2. On the other hand, if a negative determination is made in this step, the process proceeds to step ST4.

In step ST2, it is determined whether or not the engine **101** is in the fuel cut state. This is determined on the basis of the state of the fuel-cut flag. Then, if an affirmative determination is made in this step, the process proceeds to step ST5. On the other hand, if a negative determination is made in this step, the process proceeds to step ST3.

In step ST3, the rich-output counter is incremented by “1”. In step ST4 following the negative determination in step ST1, the rich-output counter is reset.

In step ST5, it is determined whether or not a precondition to the downstream-side oxygen sensor **127** starting to do the concentration monitoring has been satisfied. As the precondition, it is determined whether or not, for example, the temperature of the downstream-side oxygen sensor **127** and the temperature of the three-way catalyst **108** have reached the prescribed temperatures thereof, respectively. If an affirmative determination is made in this step, the process proceeds to step ST6. On the other hand, if a negative determination is made in this step, a series of processes temporarily ends.

In step ST6, it is determined whether or not the engine **101** is under the fuel cut. This determination is also made on the basis of the state of the fuel-cut flag. If an affirmative determination is made in this step, the process proceeds to step ST7. If a negative determination is made in this step, the series of processes temporarily ends.

In step ST7, it is determined whether or not the rich-output continuation time during which the output value of the downstream-side oxygen sensor **127** continues being the rich output value is longer than a set continuation time (predetermined value) that is set beforehand. Concretely, it is determined whether or not the value of the rich-output counter is larger than a value that corresponds to the foregoing set continuation time. If an affirmative determination is made in this step, the process proceeds to step ST9. On the other hand, if a negative determination is made in this step, the process proceeds to step ST8.

In step ST8, the abnormality determination suspension flag is turned on. In step ST9, the abnormality determination suspension flag is turned off.

In step ST10, it is determined whether or not the fuel cut has ended. This is also determined on the basis of the state of the fuel-cut flag. If an affirmative determination is made in this step, the process proceeds to step ST11. On the other hand, if a negative determination is made in this step, the process proceeds to step ST12.

In step ST11, the abnormality determination suspension flag is turned off. Then, the process returns to step ST1.

In step ST12, it is determined whether or not the output value (output voltage) of the downstream-side oxygen sensor **127** is a value between a first reference value  $V_a$  (e.g., 0.35 V) and a second reference value  $V_b$  (e.g., 0.2 V) that is lower than the first reference value  $V_a$ . If an affirmative determination is made in this step, the process proceeds to step ST13. On the other hand, if a negative determination is made in this step, the process proceeds to step ST14.

In step ST13, the response time counter is incremented by “1”. Then, the process returns to step ST10.

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In step ST14, it is determined whether or not the output value of the downstream-side oxygen sensor 127 is less than the second reference value  $V_b$  (e.g., 0.2 V). If an affirmative determination is made in this step, the process proceeds to step ST16. On the other hand, if a negative determination is made in this step, the process proceeds to step ST15.

In step ST15, the response time counter is reset to "0". Then, the process is returned to step ST10.

In step ST16, it is determined whether or not the response time RT of the downstream-side oxygen sensor 127 is longer than a reference response time that is set beforehand. Concretely, it is determined whether or not the counter value of the response time counter is greater than a value that corresponds to the aforementioned reference response time. If an affirmative determination is made in this step, the process proceeds to step ST19. On the other hand, if a negative determination is made in this step, the process proceeds to step ST17.

In step ST17, it is determined that the downstream-side oxygen sensor 127 is normal.

In step ST18, the number-of-times-of-suspension counter is reset to "0".

In step ST19, it is determined whether or not the abnormality determination suspension flag is off. If an affirmative determination is made in this step, the process proceeds to step ST20. On the other hand, if a negative determination is made in this step, the process proceeds to step ST21.

In step ST20, it is determined that the downstream-side oxygen sensor 127 is abnormal. Then, the process proceeds to step ST18. Along with this abnormality determination, it is also possible to perform a process of informing, for example, a driver or the like, that the downstream-side oxygen sensor 127 has abnormality, for example, a process of lighting a predetermined lamp, or the like.

In step ST21, the number-of-times-of-suspension counter is incremented by 1.

In step ST22, it is determined whether or not the number of times of suspension is greater than or equal to a preset number of times (e.g., twice, or the like). Concretely, it is determined whether or not the number-of-times-of-suspension counter value is greater than or equal to a preset value (e.g., 2 or the like). If an affirmative determination is made in this step, the process proceeds to step ST20. That is, it is compulsorily determined that the oxygen sensor 127 is abnormal. On the other hand, if a negative determination is made in this step, the process proceeds to step ST23.

In step ST23, the abnormality determination suspension flag is turned off. Then, the process returns to step ST1.

The processing procedure of the abnormality determination regarding the downstream-side oxygen sensor 127 which has been described above with reference to the flowchart will be further described supplementarily below.

The process of steps ST1 to ST4 is a process for acquiring the rich-output continuation time during which the output value of the downstream-side oxygen sensor 127 continues being a rich output value before the fuel-cut is started.

The process of steps ST7 to ST9 is a process for determining whether or not the acquired rich-output continuation time is longer than the set continuation time that is set beforehand (first determination).

The process of steps ST12 to ST15 is a process for determining whether or not the response time RT that is taken for the output value of the downstream-side oxygen sensor 127 to change from the pre-set first reference value to the pre-set second reference value is longer than the pre-set reference response time (second determination).

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The process of steps ST16 to ST20 is a process for determining the downstream-side oxygen sensor 127 as being abnormal in the case where an affirmative determination is made in the first determination and where an affirmative determination is also made in the second determination. Besides, the process also includes a process for avoiding determining that the downstream-side oxygen sensor 127 is abnormal in the case where a negative determination is made in the first determination and where an affirmative determination is made in the second determination, and for then performing re-determination (performing the series of processes again) after the next time the fuel cut is started. Besides, the process also includes a process for determining that the downstream-side oxygen sensor 127 is normal regardless of the result of the first determination if a negative determination is made in the second determination.

The process of steps ST19 to ST23 is a process for determining that the downstream-side oxygen sensor 127 is abnormal in the case where a negative determination in the first determination and an affirmative determination in the second determination are made consecutively a number of times that is set beforehand.

[SECOND EMBODIMENT] Hereinafter, a second embodiment of the invention will be described. Incidentally, the following description will be made only with regard to differences from the first embodiment, and description of substantially the same constructions and processing operations as the oxygen sensor abnormality determination apparatus according to the first embodiment is omitted.

The second embodiment is different from the first embodiment in the process of the foregoing first determination. That is, the abnormality determination apparatus for an oxygen sensor in accordance with the second embodiment calculates an amount of intake air of the engine 101 during the period during which the output value of the downstream-side oxygen sensor 127 continues being a rich output value before a fuel cut starts, and then performs a fourth determination of determining whether or not, after the fuel cut is started, the calculated amount of intake air is greater than a set value that is set beforehand. In addition, the intake air amount is acquired by integrating, moment-by-moment, the amount of flow of intake air that the ECU 20 acquires from the air flow meter 122.

By the way, the amount of air taken into the engine 101 during the period during which the output value of the downstream-side oxygen sensor 127 continues being a rich output value before the fuel cut is started is considered to have a correlation with the degree of filling of the rich gas components within the three-way catalyst 108 at the time of starting the fuel cut. If the amount of intake air of the engine 101 during the foregoing period is large, the three-way catalyst 108 is generally filled with rich gas components. As a result, even when the engine 101 shifts to the idle state or the fuel cut state and therefore the amount of flow of exhaust gas sharply reduces, a sufficient amount of rich gas components flows out from the three-way catalyst 108 until fresh air reaches the downstream-side oxygen sensor 127. Due to this, it is considered that the output value of the oxygen sensor 127 remains a rich output value. On the other hand, if the amount of intake air of the engine 101 during the foregoing period is small, the three-way catalyst 108 is not very much filled with rich gas components. As a result, when the engine 101 shifts to the idle state or the fuel cut state and the amount of flow of exhaust gas sharply reduces, a sufficient amount of rich gas components does not flow out from the three-way catalyst 108 during the duration until fresh air reaches the down-

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stream-side oxygen sensor **127**. Due to this, it is considered that the output value of the oxygen sensor **127** does not remain a rich output value.

Hereinafter, a processing procedure of abnormality determination regarding the downstream-side oxygen sensor **127** in an oxygen sensor abnormality determination apparatus in accordance with the second embodiment will be described on the basis of the flowchart shown in FIG. **4**.

Incidentally, substantially the same processes as those in the first embodiment are denoted by the same reference characters, and descriptions thereof are omitted, and only differences from the first embodiment will be described. In this series of process operations, the ECU **200** manages the fuel-cut flag that shows the on/off state of the fuel cut, the abnormality determination suspension flag, the rich-output counter, the response time counter and the number-of-times-of-suspension counter, and also manages an intake air amount integrated value described below.

If a negative determination is made in step **ST1**, the process of step **ST102** is performed, and then the process of step **ST5** is performed. In step **ST102**, the intake air flow integrated value is reset to "0".

If a negative determination is made in step **ST2**, the process of step **ST101** is subsequently performed, and then the process of step **ST5** is performed. In step **ST101**, a latest amount of intake air is added to the already-calculated intake air amount integrated value. This latest amount of intake air is obtained, for example, by multiplying the latest amount of flow of intake air that the ECU **200** acquires on the basis of the output value of the air flow meter **122** by a predetermined small time.

After an affirmative determination is made in step **ST6**, the process of step **ST103** is performed. In step **ST103**, it is determined whether or not the intake air amount integrated value is larger than a set value that is set beforehand. If an affirmative determination is made in this step, the process proceeds to step **ST9**. On the other hand, if a negative determination is made in this step, the process proceeds to step **ST8**.

Next, the processing procedure of the abnormality determination regarding the downstream-side oxygen sensor **127** which has been described above with reference to the flowchart shown in FIG. **4** will be further described supplementarily below.

The process of steps **ST1**, **ST2**, **ST101** and **ST102** is a process for calculating an amount of air taken into the engine **101** during the period during which the output value of the downstream-side oxygen sensor **127** continues being a rich output value before the fuel cut starts.

The process of steps **ST103**, **ST8** and **ST9** is a process for determining whether or not the amount of air taken into the engine **101** during the period during which the output value of the downstream-side oxygen sensor **127** continues being a rich output value before the fuel cut starts is larger than a set value that is set beforehand.

[OTHER EMBODIMENTS] In the fourth determination in the second embodiment, it is also possible to calculate the amount of exhaust gas from the engine **101** instead of the amount of intake air of the engine **101**, and to determine whether or not the obtained amount of exhaust gas is larger than a set value that is set beforehand.

The invention is not limited to the foregoing embodiments. What is claimed is:

1. An oxygen sensor abnormality determination apparatus comprising:

a catalyst provided in an exhaust passageway of an internal combustion engine;

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an oxygen sensor provided in the exhaust passageway on a downstream side of the catalyst;

a rich-output continuation time acquisition portion that acquires a rich-output continuation time during which an output value of the oxygen sensor continues being an output value that shows a rich state before a fuel cut is started;

a first determination portion that determines whether or not the rich-output continuation time acquired by the rich-output continuation time acquisition portion is longer than a set continuation time that is set beforehand;

a second determination portion that determines whether or not, after the fuel cut is started, a degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from a first reference value to a second reference value that shows a leaner state than the first reference value is more gradual than a set degree of change that is set beforehand; and

a third determination portion that determines whether or not the oxygen sensor is abnormal based on a result of determination by the first determination portion and a result of determination by the second determination portion.

2. The oxygen sensor abnormality determination apparatus according to claim 1, wherein

the third determination portion determines that the oxygen sensor is abnormal if it is determined by the first determination portion that the rich-output continuation time is longer than the set continuation time and it is determined by the second determination portion that the degree of change is more gradual than the set degree of change.

3. The oxygen sensor abnormality determination apparatus according to claim 1, wherein

the second determination portion determines whether or not, after the fuel cut is started, a response time that is taken for the output value of the oxygen sensor to change from the first reference value to the second reference is longer than a reference response time that is set beforehand.

4. The oxygen sensor abnormality determination apparatus according to claim 1, wherein

the third determination portion avoids determining that the oxygen sensor is abnormal, but determines again whether or not the oxygen sensor is abnormal after a next time the fuel cut is started, if it is determined by the first determination portion that the rich-output continuation time is not longer than the set continuation time and it is determined by the second determination portion that the degree of change is more gradual than the set degree of change.

5. The oxygen sensor abnormality determination apparatus according to claim 4, wherein

the third determination portion determines that the oxygen sensor is abnormal, if a determination that the rich-output continuation time is not longer than the set continuation time and a determination that the degree of change is more gradual than the set degree of change are made consecutively a pre-set number of times by the first determination portion and the second determination portion, respectively.

6. The oxygen sensor abnormality determination apparatus according to claim 1, wherein

the third determination portion determines that the oxygen sensor is normal if it is determined by the second determination portion that the degree of change is not more gradual than the set degree of change.

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7. The oxygen sensor abnormality determination apparatus according to claim 1, wherein

the second determination portion determines whether or not, after the fuel cut is started, the degree of change in the output value of the oxygen sensor in a predetermined range in which the output value of the oxygen sensor changes from a value that shows a rich state to a value that shows a lean state is more gradual than the set degree of change.

8. An oxygen sensor abnormality determination apparatus comprising:

a catalyst provided in an exhaust passageway of an internal combustion engine;

an oxygen sensor provided in the exhaust passageway on a downstream side of the catalyst;

an gas amount calculation portion that calculates an amount of gas that is one of an amount of intake air and an amount of exhaust gas that is taken into or discharged from the internal combustion engine during a time during which an output value of the oxygen sensor continues being an output value that shows a rich state before the fuel cut is started;

a fourth determination portion that determines whether or not the amount of gas calculated by the gas amount calculation portion is larger than a set value that is set beforehand;

a fifth determination portion that determines whether or not, after the fuel cut is started, a degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from a first reference value to a second reference value that shows a leaner state than the first reference value is more gradual than a set degree of change that is set beforehand; and

a sixth determination portion that determines whether or not the oxygen sensor is abnormal based on a result of determination by the fourth determination portion and a result of determination by the fifth determination portion.

9. The oxygen sensor abnormality determination apparatus according to claim 8, wherein

the sixth determination portion determines that the oxygen sensor is abnormal if it is determined by the fourth determination portion that the amount of gas is larger than the set value and it is determined by the fifth determination portion that the degree of change is more gradual than the set degree of change.

10. The oxygen sensor abnormality determination apparatus according to claim 8, wherein

the fifth determination portion determines whether or not, after the fuel cut is started, a response time that is taken for the output value of the oxygen sensor to change from the first reference value to the second reference is longer than a reference response time that is set beforehand.

11. The oxygen sensor abnormality determination apparatus according to claim 8, wherein the sixth determination portion avoids determining that the oxygen sensor is abnormal, but determines again whether or not the oxygen sensor is abnormal after a next time the fuel cut is started, if it is determined by the fourth determination portion that the amount of gas is not larger than the set value and it is determined by the fifth determination portion that the degree of change is more gradual than the set degree of change.

12. The oxygen sensor abnormality determination apparatus according to claim 11, wherein

the sixth determination portion determines that the oxygen sensor is abnormal, if a determination that the amount of gas is not larger than the set value and a determination

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that the degree of change is more gradual than the set degree of change are made consecutively a pre-set number of times by the fourth determination portion and the fifth determination portion, respectively.

13. The oxygen sensor abnormality determination apparatus according to claim 8, wherein

the sixth determination portion determines that the oxygen sensor is normal if it is determined by the fifth determination portion that the amount of gas is not larger than the set value.

14. The oxygen sensor abnormality determination apparatus according to claim 8, wherein

the fifth determination portion determines whether or not, after the fuel cut is started, the degree of change in the output value of the oxygen sensor in a predetermined range in which the output value of the oxygen sensor changes from a value that shows a rich state to a value that shows a lean state is more gradual than the set degree of change.

15. An abnormality determination method for an oxygen sensor provided in a portion of an exhaust passageway of an internal combustion engine which is on a downstream side of a catalyst that is provided in the exhaust passageway, comprising:

acquiring a rich-output continuation time during which an output value of the oxygen sensor continues being an output value that shows a rich state before a fuel cut is started;

performing a first determination of determining whether or not the rich-output continuation time is longer than a set continuation time that is set beforehand;

performing a second determination of determining whether or not, after the fuel cut is started, a degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from a first reference value to a second reference value that shows a leaner state than the first reference value is more gradual than a set degree of change that is set beforehand; and

determining whether or not the oxygen sensor is abnormal based on a result of the first determination and a result of the second determination.

16. An abnormality determination method for an oxygen sensor provided in a portion of an exhaust passageway of an internal combustion engine which is on a downstream side of a catalyst that is provided in the exhaust passageway, comprising:

calculating an amount of gas that is one of an amount of intake air and an amount of exhaust gas that is taken into or discharged from the internal combustion engine during a time during which an output value of the oxygen sensor continues being an output value that shows a rich state before a fuel cut is started;

performing a fourth determination of determining whether or not the amount of gas is larger than a set value that is set beforehand;

performing a fifth determination of determining whether or not, after the fuel cut is started, a degree of change in the output value of the oxygen sensor when the output value of the oxygen sensor changes from a first reference value to a second reference value that shows a leaner state than the first reference value is more gradual than a set degree of change that is set beforehand; and

determining whether or not the oxygen sensor is abnormal based on a result of the fourth determination and a result of the fifth determination.