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[Continued on next page]

(54) **Title:** ABNORMALITY DETERMINATION DEVICE FOR A NOX SENSOR IN A NOX STORAGE REDUCTION CATALYST USING AIR-FUEL RATIO CONTROL

[Fig. 7]

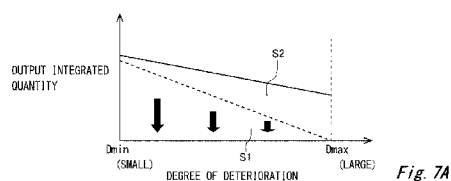


Fig. 7A

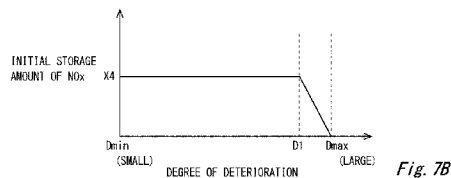


Fig. 7B

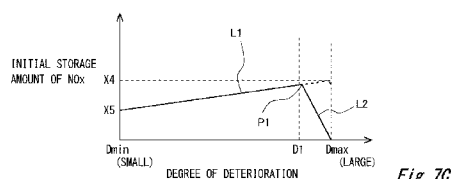


Fig. 7C

(57) **Abstract:** An improvement in the accuracy of abnormality determination of a NOx sensor, which is disposed at the downstream side of a NOx storage reduction catalyst, is attained. An abnormality determination of the NOx sensor is made based on an output integrated quantity which is an integrated quantity of detected values of the NOx sensor in a predetermined detection time period which includes at least a first detection time period of the NOx sensor corresponding to a time period in which predetermined air-fuel ratio control to enable ammonia to flow out from the NOx catalyst to the downstream side thereof is executed. In this case, by deciding a predetermined execution parameter with respect to the predetermined air-fuel ratio control based on the degree of deterioration of the NOx catalyst, and by further executing the predetermined air-fuel ratio control, an amount of ammonia generated in the NOx catalyst is adjusted.



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Description

Title of Invention: ABNORMALITY DETERMINATION DEVICE FOR A NOX SENSOR IN A NOX STORAGE REDUCTION CATALYST USING AIR-FUEL RATIO CONTROL

Technical Field

[0001] The present invention relates to an abnormality determination device which executes an abnormality determination with respect to a NOx sensor disposed at a downstream side of a NOx storage reduction catalyst.

Background Art

[0002] NOx in the exhaust gas discharged when an internal combustion engine is in a lean burn condition can be stored by a NOx storage reduction catalyst (hereinafter, also referred to simply as an "NOx catalyst"), and then, the NOx thus stored can be caused to release from the NOx catalyst and to be reduced to nitrogen by temporarily making rich the air-fuel ratio of the exhaust gas. Here, in order to control the reduction of NOx by the NOx catalyst, a NOx sensor for detecting the NOx in the exhaust gas is disposed at the downstream side of the NOx catalyst, so that it becomes possible to perform control such as the above-mentioned enrichment of the air-fuel ratio based on the detection of the sensor.

[0003] The NOx sensor is used in this manner, but when abnormality occurs in the NOx sensor, it becomes difficult to carry out the reduction of NOx by the NOx catalyst as expected, thus inviting deterioration of emissions. For this reason, it is required to determine the occurrence of the abnormality in an appropriate manner. For example, in the technology disclosed in a first patent literature, an amount of reducing agent equal to or more than an appropriate amount suitable for reducing the NOx stored in the NOx catalyst is supplied to the NOx catalyst, and the abnormality determination of the NOx sensor is made based on an output of the NOx sensor at that time. That is, this technology is to perform the abnormality determination, in a state where an amount of reducing agent which becomes surplus for the reduction of the NOx has been grasped in advance, by making use of the output of the NOx sensor corresponding to the surplus amount of the reducing agent.

Citation List

Patent Literature

- [0004] [PTL 1] Japanese patent laid-open publication No. 2009-46992
[PTL 2] Japanese patent laid-open publication No. 2003-120399
[PTL 3] Japanese patent laid-open publication No. 2012-82710
[PTL 4] Japanese patent laid-open publication No. 2009-156206
[PTL 5] Japanese patent laid-open publication No. 2012-233419

Summary of Invention

Technical Problem

- [0005] In cases where an amount of reducing agent more than suitable for reducing the NO_x stored in the NO_x catalyst is supplied to the NO_x catalyst, as in the case of the conventional technology, it becomes easy for ammonia to be generated in the NO_x catalyst. Accordingly, in the conventional technology, the ammonia thus generated is detected by the NO_x sensor together with NO_x, and the abnormality determination of the NO_x sensor is executed by the use of the detected value of the NO_x sensor. However, the ammonia generation ability of the NO_x catalyst changes according to the deterioration degree of the NO_x catalyst, and hence, the abnormality determination of the NO_x sensor according to the conventional technology is affected by the influence of the deterioration degree of the NO_x catalyst, and it is not easy to achieve the abnormality determination with high accuracy.
- [0006] In addition, the NO_x sensor is also generally used in order to determine the deterioration of the NO_x catalyst, so it is desired that the abnormality determination of the NO_x sensor be executed in a state where the influence received from the degree of deterioration of the NO_x catalyst has been suppressed as much as possible, but as mentioned above, the conventional technology is strongly subjected to the influence of the degree of deterioration of the NO_x catalyst, so it must still be the that an appropriate abnormality determination of the NO_x sensor is difficult to realize.
- [0007] The present invention has been made in view of the problem as referred to above, and has for its object to improve the accuracy of abnormality determination of a NO_x sensor which is disposed at the downstream side of a NO_x storage reduction catalyst.

Solution to Problem

- [0008] In the present invention, in order to solve the aforementioned problems, there has been adopted a configuration in which an amount of ammonia generated by a NO_x catalyst is adjusted based on the degree of deterioration of the NO_x catalyst, in a condition where a reducing agent is supplied to the NO_x catalyst at the time of performing an abnormality determination of the NO_x sensor. In this case, the degree of deterioration of the NO_x catalyst is calculated with the use of a predetermined deterioration parameter other than a detected value of the NO_x sensor. By performing the abnormality determination of the NO_x sensor according to such a configuration, the influence of the degree of deterioration of the NO_x catalyst can be reduced, thus making it possible to attain an improvement of accuracy in the abnormality determination of the NO_x sensor.
- [0009] Specifically, the present invention resides in an abnormality determination device for a NO_x sensor which is disposed in an exhaust passage of an internal combustion

engine at a downstream side of a NO_x storage reduction catalyst and is configured so as to be able to detect NO_x and ammonia in exhaust gas, the NO_x storage catalyst stores NO_x in the exhaust gas and reduces the NO_x stored therein by a supply of a reducing agent. And the abnormality determination device comprises: an air-fuel ratio control unit that executes predetermined air-fuel ratio control in which an air-fuel ratio of the exhaust gas discharged from the internal combustion engine and flowing into the NO_x storage reduction catalyst is controlled to be a rich air-fuel ratio that is richer than a stoichiometric air-fuel ratio, thereby to generate ammonia by means of the NO_x storage reduction catalyst; an abnormality determination unit that makes an abnormality determination of the NO_x sensor based on an output integrated quantity which is an integrated quantity of detected values of the NO_x sensor in a predetermined detection time period which includes at least a first detection time period of the NO_x sensor corresponding to a time period in which the predetermined air-fuel ratio control is being executed by the air-fuel ratio control unit; an acquisition unit that acquires a degree of deterioration of the NO_x storage reduction catalyst based on a predetermined deterioration parameter other than an output of the NO_x sensor; and an adjustment unit that decides a predetermined execution parameter with respect to the predetermined air-fuel ratio control based on the degree of deterioration of the NO_x storage reduction catalyst, and executes the predetermined air-fuel ratio control according to the predetermined execution parameter thus decided, thereby to adjust a generation amount of ammonia generated by the NO_x storage reduction catalyst such that the output integrated quantity falls within a predetermined allowable range irrespective of the degree of deterioration of the NO_x storage reduction catalyst.

[0010] The abnormality determination device for a NO_x sensor according to the present invention is a device which executes an abnormality determination with respect to the NO_x sensor which is disposed at the downstream side of the NO_x catalyst arranged in the exhaust passage. Here, the NO_x catalyst, when placed in a lean atmosphere by the exhaust gas flowing thereinto, stores or occludes the NO_x in the exhaust gas, and releases and reduces the stored NO_x by the reducing agent which is supplied to the NO_x catalyst by means of the predetermined air-fuel ratio control which is executed by the air-fuel ratio control unit, and in which the air-fuel ratio of the exhaust gas flowing into the NO_x catalyst is made to a rich air-fuel ratio that is richer than the stoichiometric air-fuel ratio, thereby to place the NO_x catalyst in a rich atmosphere. In addition, at the time of the predetermined air-fuel ratio control, ammonia is generated by the NO_x catalyst, as will be described later. This predetermined air-fuel ratio control is executed according to the predetermined execution parameter related thereto, and for example, the predetermined execution parameter is a parameter relevant to the formation of the rich atmosphere or the generation of ammonia. Here, note that the air-

fuel ratio control unit adjusts the amount of reducing agent such as HC contained in the exhaust gas from the internal combustion engine, and controls the air-fuel ratio of the exhaust gas.

[0011] In general, in the NO_x catalyst, there exist a noble metal such as platinum, etc., and a strong basic metal such as Ba, etc., which functions as a NO_x storage agent (NO_x occluder). In cases where the NO_x catalyst is in a state where it can exhibit its original function normally (hereinafter, referred to as a "normal state"), the function of storing NO_x in the lean atmosphere and the function of releasing and reducing the NO_x in the rich atmosphere, as mentioned above, are exhibited to a maximum extent, and at the same time, the ability of generating ammonia due to the reaction of the supplied agent and NO_x is also exhibited to a maximum extent.

[0012] In addition, the NO_x sensor disposed at the downstream side of the NO_x catalyst is configured so as to be able to detect NO_x and ammonia in the exhaust gas flowing out of the NO_x catalyst. Then, the NO_x sensor generates equivalent outputs with respect to the NO_x in the exhaust gas and ammonia, without distinguishing the NO_x and ammonia in the exhaust gas from each other. Here, when the predetermined air-fuel ratio control is executed by the air-fuel ratio control unit, the NO_x stored in the NO_x catalyst is released and reduced to N₂, as mentioned above, and ammonia is generated resulting from the released NO_x and the NO_x in the exhaust gas flowing from the internal combustion engine. In addition, a part of the released NO_x may flow out of the NO_x catalyst as it is (in this description, the NO_x having flowed out of the NO_x catalyst is referred to as an "outflow NO_x"). However, the NO_x sensor having the above-mentioned detection characteristics is able to detect the outflow NO_x and the generated ammonia.

[0013] Accordingly, in the abnormality determination device for a NO_x sensor according to the present invention, the abnormality determination unit executes the abnormality determination based on the integrated quantity of the detected values of the NO_x sensor in the predetermined detection time period which includes the first detection time period corresponding to a time period in which the predetermined air-fuel ratio control is executed, in other words, the first detection time period which is a time period in which the outflow NO_x and the generated ammonia can be detected. Because the first detection time period is included in the predetermined detection time period, the output integrated quantity of the NO_x sensor in the predetermined detection time period is a value which corresponds at least to a total amount of the outflow NO_x and the generated ammonia at the time of the predetermined air-fuel ratio control being executed. Accordingly, the abnormality determination unit executes the abnormality determination of the NO_x sensor in view of a phenomenon which occurs in the NO_x catalyst due to the predetermined air-fuel ratio control. For example, when the NO_x

catalyst is normal, the amount of the generated ammonia is in general relatively larger than the amount of the outflow NO_x, and hence, when the execution parameter of the predetermined air-fuel ratio control can be grasped in advance, the abnormality determination by the abnormality determination unit can be achieved by making a comparison between an actual output integrated quantity and an output integrated quantity which reflects the generation amount of ammonia assumed from the execution parameter in the case where the NO_x sensor is assumed to be normal.

[0014] However, in actuality, the NO_x catalyst deteriorates with the use thereof, and the above-mentioned NO_x reduction ability and the ammonia generation capacity thereof decrease. For that reason, even if the abnormality determination by the abnormality determination unit is executed under an assumption that the NO_x catalyst is always normal, in actuality, the output integrated quantity varies according to the degree of deterioration of the NO_x catalyst, so it is difficult to improve the accuracy in the determination. Accordingly, in the abnormality determination device for a NO_x sensor according to the present invention, the adjustment of the generation amount of ammonia under the predetermined air-fuel ratio control is executed through the decision of the predetermined execution parameter with respect to the predetermined air-fuel ratio control by the adjustment unit. In the adjustment by the adjustment unit, it is taken into consideration that those which are detected by the NO_x sensor under the predetermined air-fuel ratio control are mainly the outflow NO_x and the generated ammonia. The outflow of NO_x in the NO_x catalyst results from a decrease in the reduction reactivity thereof due to the deterioration of the NO_x catalyst, and so the degree of deterioration of the NO_x catalyst is directly reflected on the amount of the outflow NO_x, and there is only a small margin for the control of the deterioration of the NO_x catalyst. On the other hand, the generation amount of ammonia is an element with a relatively large control margin which can be adjusted to some extent by changing the predetermined execution parameter with respect to the predetermined air-fuel ratio control. Accordingly, the present inventor has constructed the adjustment unit by focusing on this adjustable generation amount of ammonia. That is, the adjustment unit decides the predetermined execution parameter with respect to the predetermined air-fuel ratio control in such a manner that the output integrated quantity falls within the predetermined allowable range irrespective of the degree of deterioration of the NO_x catalyst, in other word, the influence which the output integrated quantity receives from the degree of deterioration of the NO_x catalyst can be reduced as much as possible. Then, the amount of ammonia generated by the NO_x catalyst is adjusted by the predetermined air-fuel ratio control being executed according to the predetermined execution parameter thus decided.

[0015] Here, note that the degree of deterioration of the NO_x catalyst used in the decision of

the predetermined execution parameter by the adjustment unit is obtained by the acquisition unit based on the predetermined deterioration parameter other than the output of the NO_x sensor. Thus, the reason for not using the output of the NO_x sensor is that the abnormality determination device according to the present invention is intended to carry out the abnormality determination of the NO_x sensor in such a manner as not to be easily influenced by the degree of deterioration of the NO_x catalyst. If the degree of deterioration of the NO_x catalyst, which is calculated by using the output of the NO_x sensor, is used for the adjustment by the adjustment unit, when the NO_x sensor has an abnormality, the abnormality of the NO_x sensor will be reflected on that adjustment, and hence, it becomes difficult to realize the abnormality determination of the NO_x sensor which cannot be easily influenced by the degree of deterioration of the NO_x catalyst. As a mode of calculating the degree of deterioration of the NO_x catalyst based on the predetermined deterioration parameter other than the output of the NO_x sensor, there can be mentioned, by way of example, various well-known technologies such as the calculation of the deterioration degree of the NO_x catalyst based on an operation history of the internal combustion engine, the calculation using an output of an air-fuel ratio sensor arranged at the downstream side of the NO_x catalyst, etc.

[0016] According to the abnormality determination device for a NO_x sensor constructed in this manner, the predetermined execution parameter of the predetermined air-fuel ratio control executed for abnormality determination is decided based on the degree of deterioration of the NO_x catalyst which is obtained based on the predetermined deterioration parameter other than the output of the NO_x sensor. As a result, the generation amount of ammonia generated by the predetermined air-fuel ratio control is adjusted, so that the output integrated quantity falls within the predetermined allowable range. Accordingly, the output integrated quantity in the predetermined detection time period becomes the integrated quantity of the detected values of the NO_x sensor in a state where the influence of the degree of deterioration of the NO_x catalyst at the time of execution of the abnormality determination is made to reduce as much as possible. As a result, it becomes possible to realize the abnormality determination of the NO_x sensor which cannot be easily influenced by the degree of deterioration of the NO_x catalyst.

[0017] Here, in the above-mentioned abnormality determination device for a NO_x sensor, the narrower the predetermined allowable range, the narrower becomes the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst. As a result of this, it is possible to improve the accuracy of the abnormality determination of the NO_x sensor by means of the abnormality determination unit. Accordingly, preferably, the predetermined allowable range is a range which is substantially equivalent to the output integrated quantity which is assumed

when the NOx storage reduction catalyst is at a maximum degree of deterioration. That is, in such a configuration, the predetermined allowable range is made small as much as possible, thus making it possible to achieve the abnormality determination of the NOx sensor, while eliminating the influence of the degree of deterioration of the NOx catalyst as much as possible.

[0018] Moreover, in the abnormality determination device for a NOx sensor mentioned until above, the predetermined execution parameter of the predetermined air-fuel ratio control may be at least any one of a storage amount of NOx stored in the NOx storage reduction catalyst at a time point at which the predetermined air-fuel ratio control is started, a value of the rich air-fuel ratio that is reached in the predetermined air-fuel ratio control, and a control time period in which the rich air-fuel ratio is continued in the predetermined air-fuel ratio control. That is, these predetermined execution parameters are each to decide the generation amount of ammonia to be generated by the predetermined air-fuel ratio control. For example, when the degree of deterioration of the NOx catalyst is the same, in general, the larger the storage amount of NOx becomes, the more the generation amount of ammonia will tend to increase, and the smaller the value of the rich air-fuel ratio becomes (i.e., the richer the air-fuel ratio becomes), the more the generation amount of ammonia tends to increase, and in addition, the longer the control time period becomes, the more the generation amount of ammonia tends to increase. Accordingly, it becomes possible to improve the accuracy in the abnormality determination of the NOx sensor, by adjusting the generation amount of ammonia based on these tendencies in such a manner that the output integrated quantity may fall in the predetermined allowable range.

[0019] Here, reference is made to specific modes of the decision of the predetermined execution parameter by the adjustment unit. First, in a first mode, the abnormality determination unit executes the abnormality determination of the NOx sensor based on an integrated quantity of detected values of the NOx sensor in the predetermined detection time period by using the first detection time period as the predetermined detection time period. In this case, the generation amount of ammonia in a case where the adjustment by the adjustment unit has been executed is an amount that is decreased in comparison with the generation amount of ammonia in a case where adjustment by the adjustment unit has not been executed, and a range of decrease of the generation amount of ammonia in a case of the degree of deterioration of the NOx storage reduction catalyst being small is set larger than a range of decrease of the generation amount of ammonia in a case of the degree of deterioration of the NOx storage reduction catalyst being large.

[0020] In this first mode, the first detection time period is set to the predetermined detection time period. Accordingly, in this case, the output integrated quantity of the NOx sensor

reflects the total amount of the amount of the outflow NO_x and the generation amount of ammonia resulting from the predetermined air-fuel ratio control. Here, a tendency can be found that the larger the degree of deterioration of the NO_x catalyst becomes, the smaller the generation amount of ammonia, and at the same time, the larger the amount of the outflow NO_x becomes. Then, the extent of decrease of the generation amount of ammonia becomes larger than the extent of increase of the amount of the outflow NO_x, so that the larger the degree of deterioration of the NO_x catalyst becomes, the smaller the output integrated quantity of the NO_x sensor with respect to the degree of deterioration of the NO_x catalyst tends to become. Accordingly, as mentioned above, the adjustment unit can suppress the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst, by deciding the predetermined execution parameter in such a manner that the extent of decrease in the case of the degree of deterioration of the NO_x catalyst being small becomes larger in comparison with the extent of decrease in the case of the deterioration degree being large. As a result of this, it is possible to attain an improvement in the accuracy of the abnormality determination of the NO_x sensor.

[0021] Then, as the specific setting of the predetermined execution parameter by the adjustment unit in this first mode, there can be mentioned by way of example the following adjustment modes, based on the correlation among the storage amount of NO_x, the value of the rich air-fuel ratio, the control time period, and the generation amount of ammonia, as referred to above. Firstly, when the storage amount of NO_x is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the storage amount of NO_x smaller in a case where the degree of deterioration of the NO_x storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large. Secondly, when the value of the rich air-fuel ratio is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the value of the rich air-fuel ratio larger, i.e., make the air-fuel ratio of the exhaust gas leaner, in a case where the degree of deterioration of the NO_x storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large. In addition, thirdly, when the control time period is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the control time period shorter in a case where the degree of deterioration of the NO_x storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large.

[0022] Next, in a second mode with respect to the decision of the predetermined execution parameter by the adjustment unit, the abnormality determination unit makes the abnormality determination of the NO_x sensor based on an integrated quantity of detected

values of the NO_x sensor in the predetermined detection time period, by using both of the first detection time period and a second detection time period as the predetermined detection time period, wherein the second detection time period is a time period before the first detection time period and corresponds to a time period in which the air-fuel ratio of the exhaust gas flowing into the NO_x storage reduction catalyst is controlled to be a lean air-fuel ratio that is leaner than the stoichiometric air-fuel ratio. In this case, the generation amount of ammonia in a case where an adjustment by the adjustment unit has been executed is an amount that is increased in comparison with the generation amount of ammonia in a case where an adjustment by the adjustment unit has not been executed, and a range of increase of the generation amount of ammonia in a case of the degree of deterioration of the NO_x storage reduction catalyst being small is set larger than a range of increase of the generation amount of ammonia in a case of the degree of deterioration of the NO_x storage reduction catalyst being large.

[0023] In this second mode, both of the first detection time period and the second detection time period are set to the predetermined detection time period. This second detection time period is a time period in which the exhaust gas of a lean air-fuel ratio before the predetermined air-fuel ratio control is executed flows in the NO_x catalyst, i.e., a time period in which when the NO_x catalyst is normal, the NO_x in the exhaust gas is being stored in the NO_x catalyst. However, when the NO_x storage capacity of the NO_x catalyst decreases due to the deterioration of the NO_x catalyst, there is a possibility that the NO_x, which should be originally stored in the NO_x catalyst in the second detection time period, may pass through the NO_x catalyst toward the downstream thereof, so that it may be detected by the NO_x sensor. Here, note that in this description, this NO_x thus having passed through the NO_x catalyst is referred to as passed-through NO_x. Accordingly, in this case, the output integrated quantity of the NO_x sensor reflects the amount of passed-through NO_x resulting from the degree of deterioration of the NO_x catalyst, in addition to the total amount of the amount of the outflow NO_x and the generation amount of ammonia resulting from the predetermined air-fuel ratio control.

[0024] Then, in this second mode, similar to the first mode, a tendency can be found that the larger the degree of deterioration of the NO_x catalyst becomes, the smaller the generation amount of ammonia, and at the same time, the larger the amount of the outflow NO_x becomes. Moreover, a tendency can be found that the larger the degree of deterioration of the NO_x catalyst becomes, the larger the amount of the passed-through NO_x becomes. This amount of the passed-through NO_x is, in other words, an amount of NO_x discharged without being reduced to nitrogen, and hence, even if the generation amount of ammonia and the amount of the outflow NO_x are taken into consideration, there is a tendency that the larger the degree of deterioration of the NO_x

catalyst becomes, the larger the output integrated quantity of the NOx sensor is made to become. Accordingly, as mentioned above, the adjustment unit can suppress the range of the variation in the output integrated quantity with respect to the degree of deterioration of the NOx catalyst, by setting the predetermined execution parameter in such a manner that the extent of increase in the case of the degree of deterioration of the NOx catalyst being small becomes larger in comparison with the extent of increase in the case of the deterioration degree being large. As a result of this, it is possible to attain an improvement in the accuracy of the abnormality determination of the NOx sensor.

[0025] Then, as the specific setting of the predetermined execution parameter by the adjustment unit in this second mode, there can be mentioned by way of example the following adjustment modes, based on the correlation among the storage amount of NOx, the value of the rich air-fuel ratio, the control time period, and the generation amount of ammonia, as referred to above. Firstly, when the storage amount of NOx is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the storage amount of NOx larger in a case where the degree of deterioration of the NOx storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large. Secondly, when the value of the rich air-fuel ratio is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the value of the rich air-fuel ratio smaller, i.e., make the air-fuel ratio of the exhaust gas richer, in a case where the degree of deterioration of the NOx storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large.

Advantageous Effects of Invention

[0026] According to the present invention, it is possible to attain an improvement in the accuracy of abnormality determination of a NOx sensor which is disposed at the downstream side of a NOx storage reduction catalyst.

Brief Description of Drawings

[0027] [fig.1]Fig. 1 is a diagram showing the schematic construction of an exhaust system of an internal combustion engine in which an abnormality determination device for a NOx sensor according to the present invention is disposed.

[fig.2]Figs. 2A through 2E are diagrams showing the changes over time of an output of the NOx sensor, a storage amount of NOx in a NOx catalyst, a rich spike flag, a supply amount of a reducing agent, and an air-fuel ratio of exhaust gas, respectively, at the time when abnormality determination control according to the abnormality determination device for a NOx sensor according to the present invention is executed.

[fig.3]Figs. 3A through 3C are diagrams showing the changes over time of the output of the NOx sensor for three kinds of degrees of deterioration of the NOx catalyst, at the time when abnormality determination control according to the abnormality determination device for a NOx sensor according to the present invention is executed.

[fig.4]Fig. 4 is a diagram showing incoming amounts and outgoing amounts of various kinds of components for two kinds of degrees of deterioration of the NOx catalyst, at the time when abnormality determination control according to the abnormality determination device for a NOx sensor according to the present invention is executed.

[fig.5]Figs. 5A through 5D are diagrams for explaining an output integrated quantity of the NOx sensor for the abnormality determination of the NOx sensor.

[fig.6]Figs. 6A through 6C are diagrams showing correlations between each of execution parameters of the rich spike control executed at the time of the abnormality determination control by the abnormality determination device for a NOx sensor according to the present invention, and a generation amount of ammonia at the time of the abnormality determination control.

[fig.7]Figs. 7A through 7C are first set of diagrams showing an adjustment example of an execution parameter of the rich spike control in the abnormality determination control by the abnormality determination device for a NOx sensor according to the present invention.

[fig.8]Figs. 8A through 8C are second set of diagrams showing an adjustment example of an execution parameter of the rich spike control in the abnormality determination control by the abnormality determination device for a NOx sensor according to the present invention.

[fig.9]Figs. 9A through 9C are third set of diagrams showing an adjustment example of an execution parameter of the rich spike control in the abnormality determination control by the abnormality determination device for a NOx sensor according to the present invention.

[fig.10]Fig. 10 is a diagram showing the correlation among an adjustment change of each of the execution parameters of the rich spike control executed at the time of the abnormality determination control by the abnormality determination device for a NOx sensor according to the present invention, and a change of each of various kinds of components in the exhaust gas.

[fig.11]Figs. 11A through 11D are diagrams showing the changes over time of the output of the NOx sensor corresponding to the adjustment of individual execution parameters of rich spike control, respectively, in the case where an integration time period of the output is made to be a first detection period corresponding to the rich spike control, in the abnormality determination control by the abnormality determination device for a NOx sensor according to the present invention.

[fig.12]Fig. 12 is a flow chart for the abnormality determination control by the abnormality determination device for a NOx sensor according to the present invention.

[fig.13]Figs. 13A through 13C are diagrams showing the changes over time of the output of the NOx sensor for two kinds of degrees of deterioration of the NOx catalyst in the case where an integration time period of the output is made to be both of a first detection period corresponding to rich spike control, and a second detection period corresponding to a lean operation period before the rich spike control, in the abnormality determination control by the abnormality determination device for a NOx sensor according to the present invention.

[fig.14]Figs. 14A through 14C are first set of diagrams showing an adjustment example of an execution parameter of the rich spike control in the abnormality determination control shown in Figs 13A through 13C.

[fig.15]Figs. 15A through 15C are second set of diagrams showing an adjustment example of an execution parameter of the rich spike control in the abnormality determination control shown in Figs 13A through 13C.

[fig.16]Figs. 16A through 16C are third set of diagrams showing an adjustment example of an execution parameter of the rich spike control in the abnormality determination control shown in Figs 13A through 13C.

[fig.17]Figs. 17A through 17D are diagrams showing the changes over time of the output of the NOx sensor corresponding to the adjustment of individual execution parameters of rich spike control, respectively, in the case where an integration time period of the output is made to be both of a first detection period corresponding to the rich spike control and a second detection period corresponding to a lean operation period before the rich spike control, in the abnormality determination control by the abnormality determination device for a NOx sensor according to the present invention.

[fig.18]Fig. 18 is a flow chart for the abnormality determination control shown in Fig. 13.

Description of Embodiments

[0028] Hereinafter, specific embodiments of the present invention will be described based on the attached drawings. However, the dimensions, materials, shapes, relative arrangements and so on of component parts described in the embodiments are not intended to limit the technical scope of the present invention to these alone in particular as long as there are no specific statements.

Example 1

[0029] Fig. 1 is a diagram showing the schematic construction of an exhaust system of an internal combustion engine in which an abnormality determination device for a NOx sensor according to this first embodiment of the present invention is installed. The

internal combustion engine 1 shown in Fig. 1 is a multiple cylinder engine for vehicle use, and is a spark ignition internal combustion engine, more specifically, a gasoline engine. However, the internal combustion engine to which the present invention is applied is not limited to a spark ignition internal combustion engine, but may be, for example, a compression ignition type internal combustion engine, i.e., a diesel engine. In addition, an exhaust passage 2 is connected to the internal combustion engine 1. In the middle of this exhaust passage 2, there is arranged a NO_x storage reduction catalyst (hereinafter, referred to as a NO_x catalyst) 3.

[0030] The NO_x catalyst 3 is constructed such that alumina (Al₂O₃), for example, is used as a carrier, and barium (Ba) acting as a NO_x absorbing component and platinum (Pt) acting as a catalyst component, for example, are supported on the carrier. This NO_x catalyst 3 has a function of storing NO_x contained in an incoming exhaust gas when the oxygen concentration of the exhaust gas is high (i.e., when the exhaust gas is in a state of a lean air-fuel ratio), and of releasing and reducing the stored NO_x to nitrogen when the oxygen concentration of the incoming exhaust gas becomes low and when a reducing agent exists (i.e., when the exhaust gas is in a state of a rich air-fuel ratio). Here, note that the word "storage" in this description is used as a term which includes temporary adsorption of NO_x as well.

[0031] In addition, a NO_x sensor 4 for measuring the concentration of NO_x in the exhaust gas is arranged in the exhaust passage 2 at a location downstream of the NO_x catalyst 3. The NO_x sensor 4 outputs a current signal proportional to the concentration of NO_x in the exhaust gas. In particular, the NO_x sensor 4 is able to detect not only the NO_x in the exhaust gas but also ammonia in the exhaust gas, and is a so-called limiting current type NO_x sensor. The NO_x sensor 4 decomposes the NO_x in the exhaust gas (in particular NO) into nitrogen and oxygen in the interior thereof, and generates a current output which is proportional to the amount of oxygen ions by the movement of oxygen ions based on the oxygen between its electrodes. On the other hand, the NO_x sensor 4 decomposes the ammonia in the exhaust gas into NO and water in the interior thereof, further decomposes the NO into nitrogen and oxygen, and thereafter generates a current output due to the same principle as in the case of NO_x. For that reason, the NO_x sensor 4 emits an output proportional to a sum concentration of the concentration of NO_x and the concentration of ammonia, and cannot emit distinguished outputs by distinguishing the concentration of NO_x and the concentration of ammonia from each other.

[0032] Moreover, a pair of air-fuel ratio sensors 5, 6 each for measuring the air-fuel ratios of the exhaust gas are arranged in the exhaust passage 2 at locations downstream and upstream of the NO_x catalyst 3, respectively. The air-fuel ratio sensors 5, 6 are each a so-called wide range (or broad band) air-fuel ratio sensor, which is able to con-

tinuously detect the air-fuel ratio over a relatively wide range, and which outputs a signal proportional to the air-fuel ratio.

[0033] In the internal combustion engine 1 constructed as stated above, there is arranged in combination therewith an ECU 10 which is an electronic control unit for controlling the internal combustion engine 1. This ECU 10 controls the operating state of the internal combustion engine 1 in accordance with the operating conditions of the internal combustion engine 1 or driver's requirements. In addition, besides the above-mentioned sensors, an accelerator opening sensor 12, which serves to detect an engine load by outputting an electrical signal corresponding to an amount by which a driver depressed an accelerator pedal 11, and a crank position sensor 13, which serves to detect the number of revolutions per minute of the engine, are connected to the ECU 10 through electrical wiring, and the output signals of these variety of kinds of sensors are inputted to the ECU 10.

[0034] Here, in the internal combustion engine 1, from the point of view of an increase in fuel economy, etc., a lean burn operation (hereinafter referred to simply as a "lean operation") is executed in which a target air-fuel ratio is set to a value higher than a stoichiometric air-fuel ratio, i.e., a leaner value than that. During the lean operation, a combustion condition such as an amount of fuel injection, etc., is controlled in a feedback manner so that the air-fuel ratio detected by the air-fuel ratio sensor 6 becomes the target air-fuel ratio (lean air-fuel ratio). The NO_x discharged from the internal combustion engine 1 during the lean operation is reduced and removed by means of the NO_x catalyst 3. That is, in the course of the lean operation, the air-fuel ratio of the exhaust gas is leaner than the stoichiometric air-fuel ratio, so the NO_x catalyst 3 executes storage of the NO_x in the exhaust gas. On the other hand, when the NO_x catalyst 3 stores the NO_x up to a saturation state, exhaust gas air-fuel ratio control for temporarily supplying exhaust gas richer than the stoichiometric air-fuel ratio to the NO_x catalyst 3, i.e., rich spike control, is executed by means of so-called post injection, etc., in which fuel is injected at a later stage of the expansion stroke or in the exhaust stroke in the internal combustion engine 1 thereby to cause a large amount of unburnt fuel to be contained in the exhaust gas, so that the stored NO_x in the NO_x catalyst 3 is made to be released therefrom for reduction and removal. The reducing components (HC, CO, H₂) contained in this rich exhaust gas function as a reducing agent which serves to cause the stored NO_x to be released from the NO_x catalyst 3, and to carry out the reduction and removal of the released NO_x.

[0035] Here, note that modes other than the above can also be adopted for the rich spike control. For example, there is a method in which a reducing agent supply valve is separately arranged in the exhaust passage 2 at the upstream side of the NO_x catalyst 3, so that the reducing agent is supplied into the exhaust gas by executing the opening

control of the reducing agent supply valve. As the reducing agent, there may be used anything that can generate reducing components such as HC, CO, etc., in the exhaust gas, and for example, the fuel in the internal combustion engine 1 can be used.

[0036] However, in cases where the reducing agent is supplied to the NO_x catalyst 3 according to the rich spike control, nitrogen in the exhaust gas reacts with the reducing components inside the NO_x catalyst 3 thereby to generate ammonia. Then, the ammonia thus generated reacts with the NO_x released from the NO_x catalyst 3, as a result of which the NO_x is reduced to nitrogen. On the other hand, when an excessive amount of the reducing agent is supplied, the NO_x stored in the NO_x catalyst 3 is all released therefrom and reduced, and besides, ammonia is generated by a surplus amount of the reducing components which have not been used for the release and reduction of the NO_x, and flows out to the downstream side of the NO_x catalyst 3. This ammonia that flowed out is detected by the NO_x sensor 4, as mentioned above.

[0037] The abnormality determination device for the NO_x sensor 4 according to this embodiment executes abnormality determination control, by making use of the detecting characteristics of the above-mentioned NO_x sensor 4. That is, in the abnormality determination control, by causing the NO_x catalyst 3 to store a predetermined amount of NO_x, and by supplying, through the above-mentioned rich spike control, an excessive amount of the reducing agent more than an amount suitable for executing the release and reduction of the stored NO_x (hereinafter referred to as a "suitable amount") to the NO_x catalyst 3, it is determined, based on the output of the NO_x sensor 4 at this time, whether the NO_x sensor 4 is abnormal. When the excessive amount of the reducing agent is supplied to the NO_x catalyst 3, ammonia is generated by a surplus amount of the reducing agent which has not been used for the release and reduction of the stored NO_x, and the ammonia thus generated is detected by the NO_x sensor 4. An initial storage amount of NO_x (hereinafter referred to as an "initial storage amount of NO_x") at an initial time point at which the rich spike control is started is known in the abnormality determination control, and with respect to a suitable amount of the reducing agent (i.e., an amount of reducing agent suitable without excess or deficiency for executing the release and reduction of the NO_x stored at the time of the start of the rich spike control) corresponding to this initial storage amount of NO_x, the correlation thereof with the initial storage amount of NO_x can also have been obtained in advance through experiments or the like. Accordingly, in the rich spike control at the time of abnormality determination control, by supplying a predetermined surplus amount of the reducing agent to the NO_x catalyst 3 in addition to the suitable amount, the NO_x sensor 4 emits an output which corresponds to the surplus amount of the reducing agent, as a result of which it is possible to make the abnormality determination of the NO_x sensor 4 by monitoring the output of this NO_x sensor 4.

- [0038] Accordingly, the overall content of the abnormality determination control will be explained based on Figs. 2A through 2E. Figs. 2A through 2E show, by solid lines, the change over time of the output of the NO_x sensor 4, the change over time of the storage amount of NO_x in the NO_x catalyst 3, the change over time of a rich spike flag indicating the state of execution of the rich spike control, the change over time of the accumulated amount of supply of the reducing agent supplied to the NO_x catalyst 3 throughout the rich spike control, and the change over time of the air-fuel ratio of the exhaust gas downstream of the NO_x catalyst 3 (i.e., the air-fuel ratio detected by the air-fuel ratio sensor 5), respectively, at the time when the abnormality determination control is executed. Here, note that a broken line in Fig. 2A represents the change over time of the amount of NO_x contained in the exhaust gas flowing into the NO_x catalyst 3 (i.e., the exhaust gas discharged from the internal combustion engine 1), and a broken line in Fig. 2E represents the change over time of the air-fuel ratio of the exhaust gas flowing into the NO_x catalyst 3. In addition, the individual changes over time shown in Figs. 2A through 2E are in the case where the degree of deterioration of the NO_x catalyst 3 is a minimum degree of deterioration.
- [0039] Specifically, in the internal combustion engine 1, the lean operation is executed until a time point t1 at which the abnormality determination control is started. During this time period, NO_x in the incoming exhaust gas is being stored, and when the amount of the exhaust gas thus stored arrives at a predetermined initial amount of storage X0 (at the time point t1), the rich spike flag is turned on by the NO_x catalyst 3, so that the ECU 10 detects that the rich spike control is able to be executed. Accordingly, the ECU 10 starts the rich spike control at the time point t1, so that the supply of the reducing agent to the NO_x catalyst 3 is started. Here, note that the change over time of the storage amount of NO_x in the NO_x catalyst 3 can be calculated based on the change over time of the amount of NO_x in the exhaust gas estimated from the operating state of the internal combustion engine 1 (the engine load, the rotation speed of the internal combustion engine, or the like).
- [0040] The air-fuel ratio of the exhaust gas, which flows into the NO_x catalyst 3 when this rich spike control is being executed, is made to a predetermined rich air-fuel ratio, as shown in Fig. 2E, so that the release and reduction of the stored NO_x in the NO_x catalyst 3 and the generation of ammonia are promoted. Then, when the cumulative amount of the supplied reducing agent in the rich spike control shown in Fig. 2D arrives at an excessive amount of supply X1 which corresponds to the initial storage amount of NO_x X0 (at a time point t2), the rich spike flag will be returned to "off", and the ECU 10, which has detected this, will end the rich spike control. In addition, with the end of the rich spike control, the cumulative amount of the supplied reducing agent is reset at the time point t2. Here, note that, as shown in Fig. 2E, when the reductive

reaction of the stored NO_x is executed in the NO_x catalyst 3, the air-fuel ratio of the exhaust gas at the downstream side of the NO_x catalyst 3 is maintained in the vicinity of the stoichiometric air-fuel ratio, but when the reductive reaction ends, the air-fuel ratio of the exhaust gas changes to a rich side, and hence, the end time of the rich spike control may be determined by detecting the change over time of the air-fuel ratio of the exhaust gas. After the end of the rich spike control, the lean operation is again executed.

[0041] With the above-mentioned rich spike control being executed between the time point t1 and the time point t2 in this manner, the release and reduction of the stored NO_x and the generation of ammonia are executed in the NO_x catalyst 3, and the ammonia in the exhaust gas flowing out of the NO_x catalyst 3 is detected by the NO_x sensor 4, so that the abnormality determination of the NO_x sensor 4 is executed by the use of the output thereof. Here, note that in actuality, in the case of the release and reduction of the stored NO_x, the NO_x thus released may not be reduced completely, but may flow out to the downstream side of the NO_x catalyst 3 as it is, and such NO_x will also be detected by the NO_x sensor 4. Accordingly, the NO_x flowing out to the downstream side of the NO_x catalyst 3 in this manner at the time of the rich spike control is referred to as "outflow NO_x" in this description, and it is detected by the NO_x sensor 4 together with the generated ammonia, so that the output of the NO_x sensor 4 is utilized for abnormality determination control.

[0042] Then, in the abnormality determination control, the output of the NO_x sensor 4 obtained through the above-mentioned rich spike control, i.e., the output of the NO_x sensor 4 obtained by detecting the generated ammonia and the outflow NO_x, is integrated in a predetermined detection time period, and the abnormality determination of the NO_x sensor 4 is executed based on an integrated output value of the NO_x sensor 4. The integrated output value of the NO_x sensor 4 shows an actual detection result of the NO_x sensor 4 when a predetermined amount of detection target components has been supplied to the NO_x sensor 4 through the rich spike control, and hence, it becomes possible to carry out the abnormality determination of the NO_x sensor 4 by comparing the integrated output value with predetermined threshold values for determination (e.g., X2 and X3 shown in Fig. 5D to be described later). In order to carry out such abnormality determination control in an appropriate manner, it is necessary to detect the amount of ammonia generated through the rich spike control by means of the NO_x sensor 4 in a suitable manner, and for this purpose, the predetermined detection time period is set. In order to detect the ammonia generated resulting from the reducing agent supplied to the NO_x catalyst 3 through the rich spike control by means of the NO_x sensor 4, a lapse of a predetermined time period is required from a start time point of the rich spike control (supply). Accordingly, as an example of the prede-

terminated detection time period, there can be adopted a time period from the end time point t2 until a time point t3 after a fixed time period has elapsed from the start time point t1 of the rich spike control. This time period from the time point t1 to the time point t3 corresponds to a first detection time period which corresponds to a time period in which there is executed the rich spike control which is predetermined air-fuel ratio control according to the present invention. Here, note that other examples of the predetermined detection time period will be described later in a second embodiment.

[0043] In this manner, in the rich spike control for the abnormality determination of the NO_x sensor 4, it is necessary to generate ammonia by supplying an excessive amount of the reducing agent to the NO_x catalyst 3. The generation amount of ammonia at this time has a correlation with an execution parameter of the rich spike control, and when the execution parameter changes, the generation amount of ammonia will also change. For that reason, in the conventional technology, in order to make an ammonia generation condition constant at the time of the abnormality determination control of the NO_x sensor 4, the execution parameter of the rich spike control may be fixed to a specific condition. Here, note that as the execution parameter of the rich spike control which has a correlation with the generation of ammonia, there can be mentioned the above-mentioned initial storage amount of NO_x, the value of a rich air-fuel ratio which can be reached at the time of the rich spike control (hereinafter, referred to as an "air-fuel ratio at the time of the rich spike control"), and a control time period in which the air-fuel ratio at the time of the rich spike control is continued in the rich spike control (hereinafter, referred to as a "rich spike time period").

[0044] Here, the catalytic performance of the NO_x catalyst 3 decreases as sintering of the catalyst components in the interior thereof due to thermal deterioration or the deterioration thereof due to sulfur poisoning occurs. Accordingly, the larger the degree of deterioration of the NO_x catalyst 3 becomes, the lower the NO_x storage ability, the reduction ability and the ammonia generation ability become. For that reason, as shown in Figs. 3A through 3C, it has been found out that at the time of the abnormality determination of the NO_x sensor 4, the output of the NO_x sensor 4 in the rich spike control is influenced by the degree of deterioration of the NO_x catalyst 3 to a large extent. In Figs. 3A through 3C, solid lines indicate that the changes over time of the output of the NO_x sensor 4 at the time of the rich spike control according to the degree of deterioration of the NO_x catalyst 3. Specifically, the solid line in Fig. 3A indicates the change over time of the sensor output in the case where the degree of deterioration of the NO_x catalyst 3 is a minimum degree (in a normal state); the solid line in Fig. 3B indicates the change over time of the sensor output in the case where the degree of deterioration of the NO_x catalyst 3 is a medium degree; and the solid line in Fig. 3C indicates the change over time of the sensor output in the case where the degree of de-

terioration of the NOx catalyst 3 is a maximum degree. Here, note that broken lines in Fig. 3A and Fig. 3B indicate the changes over time of the amount of NOx of the exhaust gas flowing into the NOx catalyst 3 in the above-mentioned cases, respectively.

[0045] As shown in Fig. 3A and 3B, in an initial time period in which the rich spike control has been started (i.e., in a time period immediately after the time point t1), the outflow NOx is detected by the NOx sensor 4 in accordance with the release of the NOx stored in the NOx catalyst 3, but thereafter, the ammonia generated with the reduction of the released NOx is detected by the NOx sensor 4. For that reason, in a state where the NOx catalyst 3 has suitable catalytic performance, two peaks characteristic in the change over time of the sensor output appear in the predetermined detection time period (i.e., the predetermined detection time period shown in Figs. 3A through 3C matches a first detection time period according to the present invention) in which the output of the NOx sensor 4 is integrated for executing the abnormality determination thereof. Here, a first peak corresponds to the outflow NOx, and a second peak corresponds to the generated ammonia.

[0046] In cases where the NOx catalyst 3 is in the normal state, as shown in Fig. 3A, the peak corresponding to the outflow NOx is relatively small, and the generation of ammonia by the catalytic action of the NOx catalyst 3 is executed in an active manner, so that the peak corresponding to the generated ammonia becomes large. Then, when the degree of deterioration of the NOx catalyst 3 becomes gradually large, as shown in Fig. 3B, the peak corresponding to the outflow NOx becomes large, resulting from the decrease in the reduction action of the NOx catalyst 3 due to the deterioration thereof, etc., and at the same time, the peak corresponding to the generated ammonia becomes small, resulting from the decrease in the ammonia generation action of the NOx catalyst 3 due to the deterioration thereof. Thus, in cases where the degree of deterioration of the NOx catalyst 3 becomes a maximum state and the catalytic action thereof is lost, the NOx contained in the exhaust gas having flowed into the NOx catalyst 3 at the time of the rich spike control will pass through the NOx catalyst 3 as it is, and will be detected by the NOx sensor 4, as a result of which the change over time of the output of the NOx sensor 4 shown in Fig. 3C will appear.

[0047] In this manner, the output of the NOx sensor 4 at the time of the rich spike control for abnormality determination is affected by the influence of the degree of deterioration of the NOx catalyst 3 to a large extent. Now, based on Fig. 4, reference will be made to how the degree of deterioration of the NOx catalyst 3 will affect the output integrated quantity of the NOx sensor 4 used for the abnormality determination of the NOx sensor 4. Fig. 4 shows, by way of example and comparison, the inflow amounts of various kinds of components flowing into the NOx catalyst 3 and the outflow

amounts thereof flowing out of the NOx catalyst 3, when the operation conditions of the internal combustion engine (i.e., the condition of the lean operation and the condition of the rich spike control) are made the same, in the case where the NOx catalyst 3 is in the normal state (i.e., in a state in which the change over time of the output in Fig. 3A can be shown), and in the case where the degree of deterioration of the NOx catalyst 3 is maximum (i.e., in a state in which the change over time of the output in Fig. 3C can be shown). The NOx in the various components during the lean operation is NOx which flows out of the internal combustion engine 1 when the lean operation is being executed in the internal combustion engine 1, and is basically NOx which becomes a target to be stored by the NOx catalyst 3. In addition, the NOx flowing into the NOx catalyst 3 during the rich spike control is NOx which flows out of the internal combustion engine 1 when the rich spike control for the abnormality determination of the NOx sensor 4 is being executed, whereas the NOx flowing out of the NOx catalyst 3 during the rich spike control corresponds to the above-mentioned outflow NOx. Moreover, the nitrogen during the rich spike control is nitrogen which is generated by reduction of the stored NOx released by means of the rich spike control, and which flows out of the NOx catalyst 3. Further, the ammonia during the rich spike control is ammonia which is generated by means of the rich spike control and which flows out of the NOx catalyst 3. The output integrated quantity of the NOx sensor represents a total amount of the NOx and ammonia in the exhaust gas passing through the NOx sensor 4.

[0048] As can be understood from Fig. 4, in the case where the NOx catalyst 3 is in the normal state, NOx of 100 mol discharged during the lean operation is stored in the NOx catalyst 3. Then, when the rich spike control is thereafter executed, NOx of 50 mol will flow into the NOx catalyst 3 accompanying the enrichment of the air-fuel ratio of the exhaust gas, so that nitrogen of 60 mol and ammonia of 80 mol are generated by the reductive reaction and ammonia generation due to the NOx catalyst 3. At this time, the amount of the outflow NOx becomes a relatively small amount of 10 mol. On the other hand, in cases where the degree of deterioration of the NOx catalyst is the maximum, when the lean operation and the rich spike control are executed similarly, NOx of 100 mol discharged during the lean operation will pass through the NOx catalyst 3 as it is. Here, note that in this description, the NOx having passed through the NOx catalyst 3 during the lean operation in this manner is referred to as "passed-through NOx". Then, because the degree of deterioration is the maximum, the NOx during the rich spike control, which is in the amount of 50 mol and has been discharged from the internal combustion engine 1, will pass through the NOx catalyst 3 as it is. Also, note that in the case where the degree of deterioration is the maximum, the storage of NOx is not substantially executed, so that outflow NOx will not be

produced, and nitrogen and ammonia will not be generated by the reductive reaction of the outflow NO_x.

[0049] Here, the predetermined detection time period, which is the time period in which the output of the NO_x sensor 4 is integrated for abnormality determination thereof, is a time period (i.e., a time period between the time points t1 and t3 shown in Figs. 2A through 2E) corresponding to the time period in which the rich spike control is executed, and hence, the output integrated quantity of the NO_x sensor 4 in the case of the NO_x catalyst 3 being in the normal state becomes an integrated quantity corresponding to 90 mol which is a sum total of an outflow NO_x of 10 mol and an amount of generated ammonia of 80 mol. On the other hand, the output integrated quantity of the NO_x sensor 4 in the case where the degree of deterioration of the NO_x catalyst 3 is the maximum becomes an integrated quantity corresponding to an amount of the passed-through NO_x of 50 mol which has passed through the NO_x catalyst 3 during the rich spike control. Thus, the output integrated quantity of the NO_x sensor 4 for abnormality determination is affected by the influence of the degree of deterioration of the NO_x catalyst 3 which is located at the upstream side of the NO_x sensor 4, and does not become a constant value with respect to the degree of deterioration the NO_x catalyst 3.

[0050] In consideration of the comparison result shown in Fig. 4, more specific reference will be made to the influence which the degree of deterioration of the NO_x catalyst 3 has on the output integrated quantity, based on Figs. 5A through 5D. In cases where the execution parameter of the rich spike control in the internal combustion engine 1 is made the same, the larger the degree of deterioration of the NO_x catalyst 3 becomes, the smaller the amount of ammonia generated in the NO_x catalyst 3 by means of the rich spike control becomes, so that it becomes zero at the time of the maximum deterioration thereof, as shown in Fig. 5A. On the other hand, the larger the degree of deterioration of the NO_x catalyst 3 becomes, the larger the outflow amount of the NO_x generated in the NO_x catalyst 3 at the time of the rich spike control becomes. However, the range of the variation in the generation amount of ammonia with respect to the degree of deterioration of the NO_x catalyst 3 is larger than that in the outflow amount of the NO_x, as a result of which when the variation in the generation amount of ammonia and the variation in the outflow amount of the NO_x are superposed with each other, from the point of view of the output of the NO_x sensor 4, there is a tendency in which the larger the degree of deterioration of the NO_x catalyst 3 becomes, the lower becomes the output integrated quantity of the NO_x sensor 4, which has been obtained by integrating the output thereof in the predetermined detection time period corresponding to the time period in which the rich spike control is being executed for abnormality determination, as shown in Fig. 5C. Here, note that a region

shown by S1 in Fig. 5C is the output integrated quantity which corresponds to the generation amount of ammonia, and a region shown by S2 therein is the output integrated quantity which corresponds to the outflow amount of the NO_x.

[0051] In order to make the abnormality determination of the NO_x sensor 3 possible in the entire range of the degree of deterioration of the NO_x catalyst 3, in cases where the output integrated quantity of the NO_x sensor 4 with respect to the degree of deterioration of the NO_x catalyst 3 varies to a large extent in this manner (e.g., in the case shown in Fig. 4, an output integrated quantity at the time of the NO_x catalyst 3 being normal becomes 1.8 times as large as an output integrated quantity at the time of the NO_x catalyst 3 being at the maximum degree of deterioration), it is necessary to set threshold values for abnormality determination which provide predetermined margins with respect to a maximum value and a minimum value of the output integrated quantity, respectively. For example, in the case shown in Fig. 4, 100 mol is set for an upper limit side threshold value, and 40 mol is set for a lower limit side threshold value based on the fact that the output integrated quantity in the normal state of the NO_x catalyst 3 is 90 mol and the output integrated quantity at the time of the maximum degree of deterioration of the NO_x catalyst 3 is 50 mol. For that reason, when the output integrated quantity of the NO_x sensor 4 varies to a large extent in this manner, the range of the upper and lower limit threshold values will be set wide in view of that variation, as a result of which it becomes difficult to enhance the accuracy of the abnormality determination of the NO_x sensor 4.

[0052] In order to improve the accuracy of the abnormality determination of the NO_x sensor 4 based on the output integrated quantity, it is useful to make the output integrated quantity of the NO_x sensor 4 fall within a predetermined range permitted in order to ensure the accuracy in the determination irrespective of the degree of deterioration of the NO_x catalyst 3. Then, the more the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst is suppressed (i.e., the smaller the variation range becomes), the narrower the above-mentioned predetermined allowable range can be set, thus making it possible to improve the accuracy of the abnormality determination of the NO_x sensor 4. Accordingly, in the abnormality determination device for the NO_x sensor 4 according to the present invention, in order to make the output integrated quantity of the NO_x sensor 4 within the allowable range irrespective of the degree of deterioration of the NO_x catalyst 3, the execution parameter of the rich spike control for abnormality determination is adjusted in such a manner that the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst 3 is suppressed.

[0053] In addition, from the point of view of the improvement in the precision of abnormality determination, it is ideally preferable that the output integrated quantity

become constant irrespective of the degree of deterioration of the NOx catalyst 3, in order that there is no variation in the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3, as shown in Fig. 5D. By doing in this manner, the range between the lower limit threshold value X2 and the upper limit threshold value X3 for abnormality determination can be narrowed as much as possible, thus contributing to the improvement in the accuracy of the determination. Here, note that in cases where no variation is made in the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3 in this manner, it is preferable that as a value of the output integrated quantity, there be adopted an output integrated quantity in the case where the degree of deterioration of the NOx catalyst 3 is assumed to become the maximum. This is because at the time of the maximum deterioration, the catalytic action of the NOx catalyst 3 has dropped decreased to a large extent, so that an adjustment margin for the execution parameter of the rich spike control cannot be secured to a sufficient extent. The details for this will be described later.

[0054] Here, as explained based on Fig. 4, the generation amount of ammonia, the outflow amount of the NOx, and the amount of the passed-through NOx are reflected on the output integrated quantity for abnormality determination. Among these, the outflow amount of the NOx and the amount of the passed-through NOx are values which are directly decided by the degree of deterioration of the NOx catalyst 3, so it is difficult to adjust the values of these amounts. On the other hand, the generation amount of ammonia is subjected to the influence of the degree of deterioration of the NOx catalyst 3, but is a value which can also be varied by the execution parameter of the rich spike control. Accordingly, based on Figs. 6A through 6C, reference will be made to adjustment modes for the execution parameter of the rich spike control for suppressing the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3.

[0055] As described above, the initial storage amount of NOx, the air-fuel ratio at the time of the rich spike control, and the rich spike time period are each mentioned as the execution parameter of the rich spike control which has a correlation with the generation amount of ammonia. A schematic correlation between the initial storage amount of NOx and the generation amount of ammonia is shown in Fig. 6A. A schematic correlation between the air-fuel ratio at the time of the rich spike control and the generation amount of ammonia is shown in Fig. 6B. A schematic correlation between the rich spike time period and the generation amount of ammonia is shown in Fig. 6C. Here, note that the generation amount of ammonia on the axis of ordinate in each of Fig. 6A through 6C is a cumulative quantity of the amount of ammonia generated in the time period in which the rich spike control is executed. Also, the cor-

relations shown in Figs. 6A through 6C are in the case where the degree of deterioration of the NO_x catalyst 3 is not the maximum degree of deterioration but the predetermined degree of deterioration.

[0056] Here, the more the initial storage amount of NO_x, the more the generation amount of ammonia tends to increase, as shown in Fig. 6A. Accordingly, in cases where it is necessary to decrease the generation amount of ammonia according to the degree of deterioration of the NO_x catalyst 3, in order to eliminate the variation in the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst 3, the initial storage amount of NO_x to decide the start timing of the rich spike control should only be decreased, whereas on the contrary, in cases where it is necessary to increase the generation amount of ammonia according to the degree of deterioration of the NO_x catalyst 3, the initial storage amount of NO_x should only be increased. In addition, as shown in Fig. 6B, the generation amount of ammonia comes to a peak (maximum) when the air-fuel ratio at the time of the rich spike control is in the vicinity of a predetermined air-fuel ratio AF1, and the generation amount of ammonia decreases as the air-fuel ratio at the time of the rich spike control becomes away from the predetermined air-fuel ratio AF1. This is because the generation of ammonia from NO is executed under a rich atmosphere and the consumption of hydrogen for the ammonia generation comes to a peak at the predetermined air-fuel ratio AF1. Accordingly, in cases where it is necessary to decrease the generation amount of ammonia according to the degree of deterioration of the NO_x catalyst 3, in order to eliminate the variation in the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst 3, the air-fuel ratio at the time of the rich spike control should only be shifted to a lean air-fuel ratio side within a range from AF1 to the stoichiometric air-fuel ratio, whereas on the contrary, in cases where it is necessary to increase the generation amount of ammonia according to the degree of deterioration of the NO_x catalyst 3, the air-fuel ratio at the time of the rich spike control should only be shifted to a rich air-fuel ratio side within the range from AF1 to the stoichiometric air-fuel ratio.

[0057] Moreover, as shown in Fig. 6C, the longer the rich spike time period, the more the generation amount of ammonia tends to increase, but when the rich spike time period becomes longer than a time period RS1, the increase in the generation amount of ammonia stops. This is because the NO_x stored in the NO_x catalyst 3 is used for the generation of ammonia so that when the rich spike time period becomes long and the stored NO_x has been consumed, ammonia will no longer be generated. Accordingly, in order to adjust the generation amount of ammonia according to the degree of deterioration of the NO_x catalyst 3, the rich spike time period is adjusted within a region in which the generation amount of ammonia varies according to the change of the rich spike time period, i.e., within a region in which the rich spike time period becomes

equal to or less than RS1. Then, in order to eliminate the variation in the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3, in cases where it is necessary to decrease the generation amount of ammonia according to the degree of deterioration of the NOx catalyst 3, the rich spike time period is made short, whereas on the contrary, in cases where it is necessary to increase the generation amount of ammonia, the rich spike time period is made long.

[0058] Here, based on Figs. 7A through 7C, Figs. 8A through 8C and Figs. 9A through 9C, reference will be made to adjustment modes for the execution parameter of the rich spike control for suppressing the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3, in cases where the predetermined detection time period is made to the first detection time period which corresponds to the time period in which the rich spike control is executed.

(1) First Adjustment Mode

As a first adjustment mode, reference will be made, based on Figs. 7A through 7C, to the suppression of the range of the variation of the output integrated quantity through the adjustment of the initial storage amount of NOx which is an execution parameter of the rich spike control. Fig. 7A is a diagram showing the variation in the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3, and is substantially the same as the contents shown in Fig. 5C. Thus, an improvement in the accuracy of the failure determination of the NOx sensor 4 is prohibited due to the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3, as mentioned above. In this adjustment mode, in order to suppress the range of the variation of the output integrated quantity with respect to this the degree of deterioration, adjustment of the initial storage amount of NOx is executed, based on the correlation between the initial storage amount of NOx and the generation amount of ammonia as shown in Fig. 6A, in such a manner that the smaller the degree of deterioration of the NOx catalyst 3, the larger the extent of decrease of the generation amount of ammonia due to the rich spike control becomes. The extent of decrease referred to herein represents an extent of decrease of the generation amount of ammonia in the course of the change thereof from before adjustment to after adjustment. This is the same in the second and third adjustment modes to be described later. Here, note that an arrow shown in Fig. 7A is an image that has a length reflecting the above-mentioned extent of decrease of the generation amount of ammonia. By achieving such a decrease in the generation amount of ammonia, it becomes possible to suppress the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3.

[0059] Reference will be made to specific adjustment of the initial storage amount of NOx

based on Figs. 7B and 7C. Fig. 7B shows a set value of the initial storage amount of NO_x in the rich spike control before an adjustment for suppression of the range of the variation of the output integrated quantity is executed, and Fig. 7C shows a set value of the initial storage amount of NO_x in the rich spike control in the case where the above-mentioned adjustment has been executed. As shown in Fig. 7B, before the adjustment, the initial storage amount of NO_x is maintained at X4 in a range from a minimum degree of deterioration D_{min} of the NO_x catalyst 3 to D1 which is near a maximum degree of deterioration D_{max} thereof. Then, in a region where the degree of deterioration of the NO_x catalyst 3 is from D1 to D_{max}, the initial storage amount of NO_x decreases gradually. The reason for the initial storage amount of NO_x being set in this manner is that when the degree of deterioration of the NO_x catalyst 3 exceeds D1, an amount of NO_x which can be actually stored in the NO_x catalyst 3 decreases to a remarkable extent, so that the NO_x catalyst 3 becomes unable to store an amount of NO_x which is assumed when the degree of deterioration is equal to or less than D1. In this manner, with the NO_x catalyst 3 having a relatively large degree of deterioration, the initial storage amount of NO_x is made lower in accordance with the decreasing amount of NO_x which can be stored, so that rich spike control is made to be executed at an early stage. As a result of this, the reduction of NO_x in the exhaust gas will be executed, while suppressing the generation of the passed-through NO_x.

[0060] Then, in order to suppress the range of the variation of the output integrated quantity, an adjustment is executed with respect to the initial storage amount of NO_x set as shown in Fig. 7B in such a manner that the correlation between the degree of deterioration and the initial storage amount of NO_x becomes as shown in Fig. 7C. In the initial storage amount of NO_x after this adjustment, an initial storage amount of NO_x X5 at the time of the degree of deterioration of the NO_x catalyst 3 being the minimum degree of deterioration D_{min} is set smaller than the above-mentioned value X4, and the initial storage amount of NO_x increases toward X4 as the degree of deterioration becomes larger. More specifically, the correlation between the degree of deterioration and the initial storage amount of NO_x as shown in Fig. 7C is formed by a straight line L1, which connects between a point represented by the minimum degree of deterioration D_{min} and the initial storage amount of NO_x X5, and a point represented by the maximum degree of deterioration D_{max} and the initial storage amount of NO_x X4, and by a straight line L2 in the range where the degree of deterioration is from D1 to D_{max}. Here, note that an intersection of the straight line L1 and the straight line L2 is represented by P1. Thus, the setting of the initial storage amount of NO_x is adjusted in this manner, so that in a region where the degree of deterioration of the NO_x catalyst 3 is smaller than a degree of deterioration corresponding to the intersection P1, the smaller the degree of deterioration, the smaller the initial storage amount of NO_x is

adjusted to be. As a result, the extent of decrease of the generation amount of ammonia at the time of the rich spike control in the case of the degree of deterioration being small becomes larger than that at the time of the rich spike control in the case of the degree of deterioration being large, and hence, the output integrated quantity with respect to the degree of deterioration becomes substantially constant, so that the range of the variation of the output integrated quantity with respect to the degree of deterioration can be made small.

[0061] Here, note that in this adjustment mode, the straight line L1 is set to pass through a point at which the initial storage amount of NO_x becomes X4 at the time of the maximum degree of deterioration D_{max}, and this is due to the following reason: in the case of assuming that there is no decrease in the initial storage amount of NO_x in a high deterioration region (D1 - D_{max}), an amount of adjustment (an extent of decrease) of the generation amount of ammonia at the maximum degree of deterioration D_{max} is made to be zero, i.e., the adjustment of the generation amount of ammonia is made not to be performed. This is to take into consideration that the action of the NO_x catalyst 3 to generate ammonia is extremely low at the time of the maximum deterioration thereof, and that it is hard to ensure a margin for the adjustment thereof.

[0062] In addition, in this adjustment mode, in the region from the degree of deterioration corresponding to the intersection P1 to the maximum degree of deterioration D_{max}, the initial storage amount of NO_x is still in the state where it decreases in accordance with the increasing degree of deterioration, resulting from the catalyst deterioration as mentioned above, and adjustment processing with respect to the initial storage amount of NO_x is not substantially executed. For that reason, in cases where the degree of deterioration of the NO_x catalyst 3 is in that region, the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst 3 cannot be adjusted to a sufficient extent. However, in cases where the degree of deterioration of the NO_x catalyst 3 belongs to a relatively wide range from the minimum degree of deterioration D_{min} to the above-mentioned degree of deterioration corresponding to the intersection P1, the output integrated quantity with respect to the degree of deterioration can be made substantially constant, as mentioned above, as a result of which the range of the upper and lower limit threshold values for the abnormality determination of the NO_x sensor 4 can be narrowed as much as possible, thus making it possible to say that an improvement in accuracy of the abnormality determination can be attained.

[0063] (2) Second Adjustment Mode

As a second adjustment mode, reference will be made, based on Figs. 8A through 8C, to the suppression of the range of the variation of the output integrated quantity

through the adjustment of the air-fuel ratio at the time of the rich spike control which is an execution parameter of the rich spike control. Fig. 8A shows the same contents as shown in Fig. 7A, so the detailed explanation thereof is omitted. In this adjustment mode, in order to suppress the range of the variation of the output integrated quantity with respect to this degree of deterioration, adjustment of the air-fuel ratio at the time of the rich spike control is executed, based on the correlation between the air-fuel ratio at the time of the rich spike control and the generation amount of ammonia as shown in Fig. 6B, in such a manner that the smaller the degree of deterioration of the NO_x catalyst 3, the larger the extent of decrease of the generation amount of ammonia due to the rich spike control becomes. By achieving such a decrease in the generation amount of ammonia, it becomes possible to suppress the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst 3.

[0064] Reference will be made to specific adjustment of the air-fuel ratio at the time of the rich spike control based on Figs. 8B and 8C. Fig. 8B shows a set value of the air-fuel ratio at the time of the rich spike control in the course of the rich spike control before the above-mentioned adjustment for the suppression of the range of the variation of the output integrated quantity is executed, and Fig. 8C shows a set value of the air-fuel ratio at the time of the rich spike control in the course of the rich spike control when the above-mentioned adjustment has been executed. As shown in Fig. 8B, before the adjustment, the air-fuel ratio at the time of the rich spike control is maintained at X6 in an entire deterioration range from the minimum degree of deterioration D_{min} of the NO_x catalyst 3 to the maximum degree of deterioration D_{max} thereof. Here, note that the value X6 is an air-fuel ratio at a side leaner than AF1 shown in Fig. 6B.

[0065] Then, in order to suppress the range of the variation of the output integrated quantity, an adjustment is executed with respect to the air-fuel ratio at the time of the rich spike control set as shown in Fig. 8B in such a manner that the correlation between the degree of deterioration and the air-fuel ratio at the time of the rich spike control becomes as shown in Fig. 8C. In the air-fuel ratio at the time of the rich spike control after this adjustment, an air-fuel ratio X7 at the time of the rich spike control when the degree of deterioration of the NO_x catalyst 3 is the minimum degree of deterioration D_{min} is set larger than the above-mentioned value X6 (i.e., set to a value at the lean side), and the air-fuel ratio at the time of the rich spike control decreases (i.e., becomes rich) toward X6 as the degree of deterioration becomes larger. Here, note that the air-fuel ratio X7 is richer than the stoichiometric air-fuel ratio. More specifically, the correlation between the degree of deterioration and the air-fuel ratio at the time of the rich spike control, which is shown in Fig. 8C, is formed by a straight line which connects between a point represented by the minimum degree of deterioration D_{min} and the air-

fuel ratio X7 at the time of the rich spike control, and a point represented by the maximum degree of deterioration Dmax and the air-fuel ratio X6 at the time of the rich spike control. Thus, by adjusting the setting of the air-fuel ratio at the time of the rich spike control, the air-fuel ratio at the time of the rich spike control is adjusted so as to be larger (i.e., to a value at the lean side) as the degree of deterioration is smaller. As a result, the extent of decrease of the generation amount of ammonia at the time of the rich spike control in the case of the degree of deterioration being small becomes larger than that at the time of the rich spike control in the case of the degree of deterioration being large, and hence, the output integrated quantity with respect to the degree of deterioration becomes substantially constant, so that the range of the variation of the output integrated quantity with respect to the degree of deterioration can be made small.

[0066] Here, note that in this adjustment mode, the above-mentioned straight line is set to pass through the point at which the air-fuel ratio at the time of the rich spike control becomes X6 at the time of the maximum degree of deterioration Dmax. Similar to the case of the initial storage amount of NOx, this is to take into consideration that the action of the NOx catalyst 3 to generate ammonia is extremely low at the time of the maximum deterioration thereof, and that it is hard to ensure a margin for the adjustment thereof.

[0067] (3) Third Adjustment Mode

As a third adjustment mode, reference will be made, based on Figs. 9A through 9C, to the suppression of the range of the variation of the output integrated quantity through the adjustment of the rich spike time period which is an execution parameter of the rich spike control. Fig. 9A is the same as the contents shown in Fig. 7A, so the detailed explanation thereof is omitted. In this adjustment mode, in order to suppress the range of the variation of the output integrated quantity with respect to this degree of deterioration, adjustment of the rich spike time period is executed, based on the correlation between the rich spike time period and the generation amount of ammonia as shown in Fig. 6C, in such a manner that the smaller the degree of deterioration of the NOx catalyst 3, the larger the extent of decrease of the generation amount of ammonia due to the rich spike control becomes. By achieving such a decrease in the generation amount of ammonia, it becomes possible to suppress the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3.

[0068] Reference will be made to specific adjustment of the rich spike time period based on Figs. 9B and 9C. Fig. 9B shows a set value of the rich spike time period in the rich spike control before the above-mentioned adjustment for the suppression of the range of the variation of the output integrated quantity is executed, and Fig. 9C shows a set

value of the rich spike time period in the rich spike control when the above-mentioned adjustment has been executed. As shown in Fig. 9B, before the adjustment, the rich spike time period is maintained at X8 in the entire deterioration range of the NOx catalyst 3 from the minimum degree of deterioration Dmin to the maximum degree of deterioration Dmax. Here, note that the value X8 is a time period shorter than RS1 shown in Fig. 6C.

[0069] Then, in order to suppress the range of the variation of the output integrated quantity, an adjustment is executed with respect to the rich spike time period set as shown in Fig. 9B in such a manner that the correlation between the degree of deterioration and the rich spike time period becomes as shown in Fig. 9C. In the rich spike time period after this adjustment, a rich spike time period X9 when the degree of deterioration of the NOx catalyst 3 is the minimum degree of deterioration Dmin is set shorter than the above-mentioned value X8, and the rich spike time period increases toward X8 as the degree of deterioration becomes larger. More specifically, the correlation between the degree of deterioration and the rich spike time period, which is shown in Fig. 9C, is formed by a straight line which connects between a point represented by the minimum degree of deterioration Dmin and the rich spike time period X9, and a point represented by the maximum degree of deterioration Dmax and the rich spike time period X8. Thus, by adjusting the setting of the rich spike time period, the rich spike time period is adjusted so as to be shorter as the degree of deterioration is smaller. As a result, the extent of decrease of the generation amount of ammonia at the time of the rich spike control in the case of the degree of deterioration being small becomes larger than that at the time of the rich spike control in the case of the degree of deterioration being large, and hence, the output integrated quantity with respect to the degree of deterioration becomes substantially constant, so that the range of the variation of the output integrated quantity with respect to the degree of deterioration can be made small.

[0070] Here, note that in this adjustment mode, the above-mentioned straight line is set to pass through the point at which the rich spike time period becomes X8 at the time of the maximum degree of deterioration Dmax. Similar to the case of the initial storage amount of NOx, this is to take into consideration that the action of the NOx catalyst 3 to generate ammonia is extremely low at the time of the maximum deterioration thereof, and that it is hard to ensure a margin for the adjustment thereof.

[0071] Thus, by adopting the adjustment modes (the first through third adjustment modes) for the execution parameters of the rich spike control shown in Figs. 7A - 7C through Figs. 9A - 9C, it is possible to suppress the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3, thereby making it possible to improve the accuracy in the abnormality determination of

the NOx sensor 4. Here, note that as long as the accuracy in the abnormality determination of the NOx sensor 4 is within an allowable level, in order to suppress the range of the variation of the output integrated quantity, any of the first through third adjustment modes may be adopted, or two or three of these adjustment modes may be adopted in combination as appropriate.

[0072] < Detailed Discussion with respect to the Adjustment of the Execution Parameters of the Rich Spike Control >

Here, in the above-mentioned adjustment modes, the suppression of the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3 is attained, by adjusting the generation amount of ammonia in the rich spike control according to the degree of deterioration of the NOx catalyst 3 through the adjustment of the execution parameters of the rich spike control. However, in these adjustment modes, in cases where the above-mentioned execution parameters of the rich spike control are adjusted, not only the amount of generation of ammonia but also the amount of NOx in the exhaust gas flowing into the NOx catalyst 3 during the lean operation or during the rich spike control will be influenced. The amount of NOx during the lean operation or during the rich spike control is reflected on the output integrated quantity of the NOx sensor 4 according to the predetermined detection time period for the abnormality determination of the NOx sensor 4. Here, note that in this first embodiment, the predetermined detection time period corresponds to a time period in which the rich spike control is being executed, as mentioned above, so NOx during the rich spike control is reflected on the output integrated quantity. The reflection of NOx during the lean operation on the output integrated quantity will be explained in detail in a second embodiment to be described later.

[0073] In view of the above, in order to suppress the range of the variation of the output integrated quantity with respect to this degree of deterioration of the NOx catalyst 3 in a more suitable manner, it can be the that it is preferable to perform the adjustment of the execution parameters of the rich spike control by taking into consideration the influence of the adjustment on the amount of NOx in the exhaust gas flowing into the NOx catalyst 3 during the lean operation or during the rich spike control. Accordingly, Fig. 10 shows how the generation amount of ammonia during the rich spike control, the amount of NOx flowing into the NOx catalyst 3 during the rich spike control, and the amount of NOx flowing into the NOx catalyst 3 during the lean operation vary, i.e., tendencies of variation thereof, with the above-mentioned adjustment of the execution parameters being executed.

[0074] As shown in Fig. 6A, when the initial storage amount of NOx increases, the generation amount of ammonia during the rich spike control increases, but on the contrary, when the initial storage amount of NOx decreases, the generation amount of

ammonia during the rich spike control decreases. This initial storage amount of NO_x is also an element which decides the starting time point of the rich spike control, but it does not give a tendency of variation to the amount of NO_x flowing into the NO_x catalyst 3 during the rich spike control. On the other hand, when the initial storage amount of NO_x increases, the starting time point of the rich spike control is delayed, and the lean operation time period is extended by the time of delay, so that the amount of NO_x flowing into the NO_x catalyst 3 during the lean operation increases, whereas when the initial storage amount of NO_x decreases, the amount of NO_x flowing into the NO_x catalyst 3 during the lean operation decreases.

[0075] Next, with respect to the air-fuel ratio at the time of the rich spike control, as shown in Fig. 6B, when the air-fuel ratio at the time of the rich spike control is made rich in an air-fuel ratio region at a leaner side than the air-fuel ratio AF1, the generation amount of ammonia during the rich spike control increases, but on the contrary, when the air-fuel ratio at the time of the rich spike control is made lean, the generation amount of ammonia during the rich spike control decreases. In addition, when the air-fuel ratio at the time of the rich spike control is made rich, combustion is executed in a state where the amount of oxygen in a combustion chamber of the internal combustion engine 1 is small, so that the amount of NO_x flowing into the NO_x catalyst 3 during the rich spike control decreases, but on the contrary, when the air-fuel ratio at the time of the rich spike control is made lean, the amount of NO_x flowing into the NO_x catalyst 3 during the rich spike control increases. Here, note that the air-fuel ratio at the time of the rich spike control does not give a tendency of variation to the amount of NO_x flowing into the NO_x catalyst 3 during the lean operation.

[0076] Then, with respect to the rich spike time period, as shown in Fig. 6C, when the rich spike time period is made long in a time region shorter than the time period RS1, the generation amount of ammonia during the rich spike control increases, and on the contrary, when the rich spike time period is made short, the generation amount of ammonia during the rich spike control decreases. In addition, when the rich spike time period is made long, an amount of NO_x increased by the rich spike control is supplied to the NO_x catalyst 3 over a long time period, so that the amount of NO_x flowing into the NO_x catalyst 3 during the rich spike control, of course, decreases, but on the contrary, when the rich spike time period is made short, the amount of NO_x flowing into the NO_x catalyst 3 during the rich spike control decreases. Here, note that the rich spike time period does not give a tendency of variation to the amount of NO_x flowing into the NO_x catalyst 3 during the lean operation.

[0077] Based on the tendencies of variation shown in this Fig. 10, a detailed discussion with respect to the adjustment of the execution parameters of the rich spike control is executed. In the first embodiment, the predetermined detection time period cor-

responds to a time period in which the rich spike control is being executed, as mentioned above, and in this case, as shown in Figs. 7A - 7C through Figs. 9A - 9C, in order to suppress the range of the variation of the output integrated quantity with respect to this degree of deterioration of the NOx catalyst 3, it is preferable that the initial storage amount of NOx be adjusted to decrease, or the air-fuel ratio at the time of the rich spike control be adjusted to be leaner, or the rich spike time period be adjusted to be shorter, as the degree of deterioration of the NOx catalyst 3 becomes smaller. Accordingly, in Figs. 11A through 11D, the changes over time of the output of the NOx sensor 4 when these individual adjustments were executed are shown by solid lines, respectively, and the changes over time of the amount of NOx flowing into the NOx catalyst 3 when these individual adjustments were executed are shown by broken lines, respectively. Specifically, Fig. 11A shows the individual changes over time in the case where there was no adjustment of the execution parameters; Fig. 11B shows the individual changes over time in the case where the initial storage amount of NOx was adjusted to decrease; Fig. 11C shows the individual changes over time in the case where the air-fuel ratio at the time of the rich spike control was adjusted to be lean; and Fig. 11D shows the individual changes over time in the case where the rich spike time period was adjusted to be short.

[0078] In the case where the initial storage amount of NOx has been adjusted to decrease, as shown in Fig. 11B, a time point $t1'$ at which the rich spike control is started is made earlier than the start time point $t1$ in the case where an other execution parameter has been adjusted. At this time, owing to the decrease in the initial storage amount of NOx, the outflow amount of the NOx becomes somewhat (slightly) smaller and the generation amount of ammonia also becomes smaller, in comparison with the case where no adjustment of the execution parameter has been made. However, with respect to the amount of NOx flowing into the NOx catalyst 3 during the rich spike control, it is unchanged in comparison with the case no adjustment of the execution parameter has been made.

[0079] Next, in the case where the air-fuel ratio at the time of the rich spike control is adjusted to be lean, as shown in Fig. 11C, a start time point of the rich spike control is the same as in the case where no adjustment of the execution parameter has been made. However, although the outflow amount of the NOx is unchanged in the case of no adjustment of the execution parameter, the generation amount of ammonia becomes smaller than that in the case of no adjustment of the execution parameter. On the other hand, with the air-fuel ratio at the time of the rich spike control being adjusted to be lean, the amount of NOx flowing into the NOx catalyst 3 during the rich spike control becomes larger than that in the case of no adjustment of the execution parameter.

[0080] Then, in the case where the rich spike time period is adjusted to be short, as shown in

Fig. 11D, a start time point of the rich spike control is the same as in the case where no adjustment of the execution parameter has been made. However, although the outflow amount of the NOx is unchanged in the case of no adjustment of the execution parameter, the generation amount of ammonia becomes smaller than that in the case of no adjustment of the execution parameter. On the other hand, with the rich spike time period being adjusted to be short, the amount of NOx flowing into the NOx catalyst 3 during the rich spike control becomes smaller than that in the case of no adjustment of the execution parameter.

[0081] Here, as shown in Fig. 4 and Fig. 5C, a factor in which the output integrated quantity of the NOx sensor 4 varies with respect to the degree of deterioration of the NOx catalyst 3 in the case of setting the predetermined detection time period to a time period corresponding to the time period in which the rich spike control is being executed is that the generation amount of ammonia, the outflow amount of the NOx, and the amount of the passed-through NOx change according to the degree of deterioration. Accordingly, it is considered that in order to suppress the range of the variation of the output integrated quantity, it is most preferable to perform lean adjustment of the air-fuel ratio at the time of the rich spike control in which in the case where the degree of deterioration of the NOx catalyst 3 is relatively small, the amount of ammonia to be generated is made to decrease, whereas in the case where the degree of deterioration of the NOx catalyst 3 is relatively large, the amount of passed-through NOx is made to increase. Here, note that in the case where the degree of deterioration of the NOx catalyst 3 is relatively small, even if the amount of inflow NOx during the rich spike control is increased by this lean adjustment, NOx is appropriately reduced by the catalytic action of the NOx catalyst 3, so it is hard for the passed-through NOx to occur.

[0082] In addition, it is preferable that the lean adjustment of the air-fuel ratio at the time of the rich spike control be followed by the decreasing adjustment of the initial storage amount of NOx in which the generation amount of ammonia is decreased, though the amount of inflow NOx during the rich spike control is unchanged. Moreover, in the shortening adjustment of the rich spike time period, the amount of inflow NOx during the rich spike control is decreased, and hence, it is preferable to adopt an adjustment to perform the shortening adjustment of the rich spike time period and the lean adjustment of the air-fuel ratio at the time of the rich spike control at the same time, or an adjustment to perform the shortening adjustment of the rich spike time period and the decreasing adjustment of the initial storage amount of NOx at the same time. Here, note that this does not hinder the independent adoption of the shortening adjustment of the rich spike time period, but as long as the accuracy in the abnormality determination of the NOx sensor 4 leads to a desirable and appropriate level, the shortening ad-

justment of the rich spike time period may be adopted independently, so that the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3 is suppressed, and the output integrated quantity is made to fall within the predetermined allowable range.

[0083] < Flow for Abnormality Determination Control >

A flow for the abnormality determination control of the NOx sensor 4 is shown in Fig. 12, based on the adjustment modes referred to above for the execution parameters of the rich spike control for suppressing the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3. This abnormality determination control is executed by the ECU 10, as appropriate. First, in step S101, it is determined whether a precondition for performing the determination of abnormality of the NOx catalyst 4 is satisfied. As the precondition, there is mentioned the completion of the estimation of the degree of deterioration of the NOx catalyst 3. This control is to perform the abnormality determination of the NOx sensor 4 by deciding an execution parameter of the rich spike control according to the degree of deterioration of the NOx catalyst 3, and hence, it is not preferable to estimate the degree of deterioration of the NOx catalyst 3 used for this control, by making use of the NOx sensor 4 which is a target of the determination. Accordingly, the degree of deterioration of the NOx catalyst 3 for this control should be obtained, without using the NOx sensor 4.

[0084] As an estimation mode of the degree of deterioration of the NOx catalyst 3, there is mentioned an estimation of the degree of deterioration using a storage amount of NOx which is calculated by using the output of the air-fuel ratio sensor 5 at the time of the rich spike control being executed, for example, as disclosed in Japanese patent laid-open publication No. 2000-34946, etc.

[0085] In addition, as another method of estimating the degree of deterioration of the NOx catalyst 3, such an estimation may be made based on the operation history of the internal combustion engine 1. The longer the time period in which the NOx catalyst 3 is exposed to a high temperature atmosphere, the more thermal deterioration occurs, and the lower the NOx reduction ability thereof becomes. Accordingly, the degree of thermal deterioration of the NOx catalyst 3 can be estimated, based on the operational history in which the temperature of the exhaust gas flowing into the NOx catalyst 3 becomes equal to or higher than a predetermined temperature.

[0086] Then, when an affirmative determination is made in step S101, the control flow goes to step S102, whereas when a negative determination is made, this control is ended. Subsequently, in step S102, the execution parameter of the rich spike control for the abnormality determination of the NOx sensor 4 is decided based on an estimated degree of deterioration of the NOx catalyst 3 which becomes a basis for the affirmative

determination made in step S101. The decision of the execution parameter is executed based on a control map on the ECU 10 in which the above-mentioned correlations between the degree of deterioration after the adjustment and the individual execution parameters, as shown in Fig. 7C, Fig. 8C and Fig. 9C, or based on similar correlations therebetween in consideration of the combination of the execution parameters after the adjustment, as explained based on Fig. 12. After the processing of the step S102 is completed, the routine goes to step S103.

[0087] In step S103, it is determined whether the rich spike control for the abnormality determination of the NOx sensor 4 can be executed. Specifically, from the point of view of the generation of ammonia in the NOx catalyst 3 according to the rich spike control, it is determined whether the temperature of the NOx catalyst 3 is equal to or more than a predetermined activation temperature, or whether the storage amount of NOx in the NOx catalyst 3 becomes equal to or more than the initial storage amount of NOx, which has been set as one of the execution parameters for the rich spike control, or the like. Here, note that the determination in step S103 is executed according to the initial storage amount of NOx which has been decided in step S102. When an affirmative determination is made in step S103, the routine goes to step S104, whereas when a negative determination is made, the routine is ended.

[0088] In step S104, the rich spike control is executed according to the execution parameter thus decided, and then in step S105, the integration of the output of the NOx sensor 4 is executed. Thereafter, in step S106, it is determined based on the lapse of the rich spike time period whether the rich spike control has been ended. When an affirmative determination is made in step S106, the routine goes to step S107, whereas when a negative determination is made, the routine returns to step S104, and the processings in step S104 and onward are repeated again. Here, note that immediately after an affirmative determination is made in step S106, the integration of the output of the NOx sensor 4 is in a continued state.

[0089] In step S107, it is determined whether the output integration of the NOx sensor 4 being executed in step S104 has been ended, i.e., whether the predetermined detection time period has elapsed. With respect to the predetermined detection time period, this is a time period which is required for the reducing agent supplied to the NOx catalyst 3 by means of the rich spike control to react in the NOx catalyst 3, and which is also required for the result of the reaction to be detected by the NOx sensor 4, as mentioned above. Accordingly, a determination may be made that the integration of the output of the NOx sensor 4 is ended, for example, at a time point at which the predetermined time period has elapsed from the end of the rich spike control, i.e., when a time period of (t3 - t2) has elapsed, as shown in Fig. 2. When an affirmative determination is made in step S107, the routine goes to step S108, whereas when a negative determination is

made, the processing of step S107 is repeated again.

[0090] Subsequently, in step S108, the abnormality determination of the NOx sensor 4 is made based on the output integrated quantity of the NOx sensor 4 obtained by the preceding processings thus far executed. Because the output integrated quantity has been obtained through the above-mentioned decision of the execution parameter of the rich spike control, the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3 is in an appropriately suppressed state, e.g., in a state as shown in Fig. 5D. Accordingly, for example, in the case where the output integrated quantity falls within a range from X2 inclusive to X3 inclusive, a determination is made that the NOx sensor 4 is normal. On the other hand, in the case where the output integrated quantity is less than X2, a determination is made that the NOx sensor 4 is in an abnormal state due to the reduction of gain, i.e., in a state having abnormality in which the output of the NOx sensor 4 is smaller than that which should be originally obtained. In addition, in the case where the output integrated quantity is more than X3, a determination is made that the NOx sensor 4 is in an abnormal state due to the enlargement of gain, i.e., in a state having abnormality in which the output of the NOx sensor 4 is larger than that which should be originally obtained.

[0091] According to this control, the abnormality determination of the NOx sensor 4 is executed in a state where the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3 is suppressed, so that the accuracy of the abnormality determination can be improved in a suitable and appropriate manner.

Example 2

[0092] Reference will be made to a second embodiment for the abnormality determination control of the NOx sensor 4 according to the present invention, based on Figs. 13A - 13C through Fig. 18. The abnormality determination control according to the second embodiment is different from that according to the first embodiment in that a time period, in which the output integration of the NOx sensor 4 for abnormality determination is executed, is made to include both of a rich spike time period corresponding to the time period in which the rich spike control is being executed (i.e., this rich spike time period corresponding to a first detection time period according to the present invention) and a lean operation time period which is executed before the rich spike time period (this lean operation time period corresponding to a second detection time period according to the present invention). Specifically, in Fig. 13A, there are shown the change over time of the output of the NOx sensor 4 (solid line) and the change over time of the amount of NOx (broken line) contained in the exhaust gas flowing into the

NOx catalyst 3, similar to Fig. 2A. The degree of deterioration of the NOx catalyst 3 corresponding to Fig. 13A is a minimum degree of deterioration. Then, the predetermined detection time period in this embodiment includes both a time period during the lean operation (time point t4 - time point t1), and a time period (time point t1 - time point t3) corresponding to the time period in which the rich spike control is being executed, and the integrated quantity of the output of the NOx sensor 4 in the predetermined detection time period corresponds to the area of a region hatched by diagonal lines in Fig. 13A.

[0093] Here, note that the time point t4 at which the second detection time period starts is a time point at which a time period in which the last rich spike control preceding the current rich spike control executed from the time point t1 to the time point t2 was executed ended. Then, the second detection time period is earlier than the first detection time period, but is a time period which has such a length in which the integrated quantity of the detected output of the NOx sensor 4 is influenced in accordance with the degree of deterioration of the NOx catalyst 3 by means of the NOx flowing into the NOx catalyst 3 continuously due to the lean operation, as will be described later. As long as these conditions are satisfied, the second detection time period may be continuous with the first detection time period, or may be a time period which is set non-continuously from the first detection time period.

[0094] Then, in Fig. 13B, the output integrated quantity of the NOx sensor 4 in the case of the degree of deterioration of the NOx catalyst 3 being a maximum degree of deterioration is shown by a region hatched by diagonal lines. Here, note that the change over time of the output of the NOx sensor 4 shown in Fig. 13B corresponds to the change over time of the amount of NOx in the exhaust gas flowing into the NOx catalyst 3 shown by the broken line in Fig. 13A. As can be understood from a comparison between Fig. 13A and Fig. 13B, in the case where the predetermined detection time period is composed of both the first detection time period and the second detection time period, there exists a clear difference in the output integrated quantity of the NOx sensor 4 for abnormality determination according to the degree of deterioration of the NOx catalyst 3.

[0095] Accordingly, in Fig. 13C, there are shown, by way of example and comparison, the inflow amounts of various kinds of components flowing into the NOx catalyst 3 and the outflow amounts thereof flowing out of the NOx catalyst 3, when the operation conditions of the internal combustion engine (i.e., the condition of the lean operation and the condition of the rich spike control) are made the same, in the case where the degree of deterioration of the NOx catalyst 3 is the minimum degree, and in the case where the degree of deterioration thereof is the maximum degree, with the predetermined detection time period being composed of both the first detection time period

and the second detection time period. Here, note that the various kinds of components as well as the inflow amounts and the outflow amounts thereof are the same as those shown in Fig. 4, and hence, the detailed explanation thereof is omitted.

[0096] Here, because the predetermined detection time period is composed of both the first detection time period and the second detection time period, the output integrated quantity of the NO_x sensor 4 in the case of the degree of deterioration of the NO_x catalyst 3 being the maximum degree becomes an integrated quantity corresponding to 90 mol which is a sum total of an outflow NO_x of 10 mol and an amount of generated ammonia of 80 mol, without requiring a consideration of the passed-through NO_x. On the other hand, the output integrated quantity of the NO_x sensor 4 in the case where the degree of deterioration of the NO_x catalyst 3 is the maximum becomes an integrated quantity corresponding to an amount of the passed-through NO_x of 150 mol which has passed through the NO_x catalyst 3 during the lean operation and during the rich spike control. Thus, the output integrated quantity of the NO_x sensor 4 for abnormality determination is affected by the influence of the degree of deterioration of the NO_x catalyst 3 which is located at the upstream side of the NO_x sensor 4, and does not become a constant value with respect to the degree of deterioration the NO_x catalyst 3.

[0097] Accordingly, based on Fig. 14A, more specific reference will be made to the influence which the degree of deterioration of the NO_x catalyst 3 has on the output integrated quantity, in consideration of this result. Here, note that regions S1, S2 in Fig. 14A are the same as those shown in Fig. 5C, so the detailed explanation thereof is omitted. That is, the output integrated quantity in this second embodiment is obtained by adding an integrated quantity corresponding to a region S3 to the output integrated quantity in the first embodiment. This region S3 means an integrated value of the amount of NO_x which passed through the NO_x catalyst 3 during the lean operation. Using the example shown in Fig. 13C, the output integrated quantity corresponding to S3 at the time of the NO_x catalyst 3 being the minimum deterioration is zero, and the output integrated quantity corresponding to S3 at the time of the NO_x catalyst 3 being the maximum deterioration is 150 mol. Thus, the larger the degree of deterioration of the NO_x catalyst 3, the more the amount of the passed-through NO_x becomes. Accordingly, when the output integrated quantities corresponding to the regions S1, S2, S3 are added up, there is a tendency in which the larger the degree of deterioration of the NO_x catalyst 3 becomes, the larger becomes the output integrated quantity of the NO_x sensor 4, which has been obtained by integrating the output thereof in the predetermined detection time period for abnormality determination, as shown in Fig. 14A.

[0098] Accordingly, in this second embodiment, for the same purpose as in the first embodiment, the adjustment of the execution parameter of the rich spike control for abnormality determination is executed; so that the range of the variation of the output in-

egrated quantity with respect to above-mentioned the degree of deterioration of the NO_x catalyst can be suppressed. Then, the modes of the adjustment will be explained below with reference to Figs. 14A - 14C through Figs. 16A - 16C.

(1) First Adjustment Mode

As a first adjustment mode, reference will be made, based on Figs. 14A through 14C, to the suppression of the range of the variation of the output integrated quantity through the adjustment of the initial storage amount of NO_x which is an execution parameter of the rich spike control. Fig. 14A is a diagram showing the variation in the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst 3, as mentioned above. In this adjustment mode, in order to suppress the range of the variation of the output integrated quantity with respect to this the degree of deterioration, adjustment of the initial storage amount of NO_x is executed, based on the correlation between the initial storage amount of NO_x and the generation amount of ammonia as shown in Fig. 6A, in such a manner that the smaller the degree of deterioration of the NO_x catalyst 3, the larger the extent of increase of the generation amount of ammonia due to the rich spike control becomes. The extent of increase referred to herein represents an extent of increase of the generation amount of ammonia in the course of the change thereof from before adjustment to after adjustment. This is the same in the second and third adjustment modes to be described later. Here, note that an arrow shown in Fig. 14A is an image that has a length reflecting the above-mentioned extent of increase of the generation amount of ammonia. By achieving such an increase in the generation amount of ammonia, it becomes possible to suppress the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NO_x catalyst 3.

[0099] Reference will be made to specific adjustment of the initial storage amount of NO_x based on Figs. 14B and 14C. Fig. 14B shows a set value of the initial storage amount of NO_x in the rich spike control before the above-mentioned adjustment for the suppression of the range of the variation of the output integrated quantity is executed, and is the same as the contents shown in Fig. 7B of the first embodiment. In addition, Fig. 14C shows a set value of the initial storage amount of NO_x in the rich spike control when the above-mentioned adjustment has been executed. Then, in order to suppress the range of the variation of the output integrated quantity, an adjustment is executed with respect to the initial storage amount of NO_x set as shown in Fig. 14B in such a manner that the correlation between the degree of deterioration and the initial storage amount of NO_x becomes as shown in Fig. 14C. In the initial storage amount of NO_x after this adjustment, an initial storage amount of NO_x X5' at the time of the degree of deterioration of the NO_x catalyst 3 being the minimum degree of deterioration D_{min} is set larger than the above-mentioned value X4, and the initial storage amount of NO_x

decreases toward X4 as the degree of deterioration becomes larger. More specifically, the correlation between the degree of deterioration and the initial storage amount of NOx as shown in Fig. 14C is formed by a straight line L3, which connects between a point represented by the minimum degree of deterioration Dmin and the initial storage amount of NOx X5', and a point represented by the maximum degree of deterioration Dmax and the initial storage amount of NOx X4, and by a straight line L4 including a straight line in the range where the degree of deterioration is from D1 to Dmax. Here, note that an intersection of the straight line L3 and the straight line L4 is represented by P2. Thus, the setting of the initial storage amount of NOx is adjusted in this manner, so that in a region where the degree of deterioration of the NOx catalyst 3 is smaller than D1, the smaller the degree of deterioration, the larger the initial storage amount of NOx is adjusted to be. As a result, the extent of increase of the generation amount of ammonia at the time of the rich spike control in the case of the degree of deterioration being small becomes larger than that at the time of the rich spike control in the case of the degree of deterioration being large, and hence, the output integrated quantity with respect to the degree of deterioration becomes substantially constant, so that the range of the variation of the output integrated quantity with respect to the degree of deterioration can be made small.

[0100] Here, note that in this adjustment mode, the straight line L3 is set to pass through a point at which the initial storage amount of NOx becomes X4 at the time of the maximum degree of deterioration Dmax, and this is due to the following reason: in the case of assuming that there is no decrease in the initial storage amount of NOx in a high deterioration region (D1 - Dmax), an amount of adjustment (an extent of increase) of the generation amount of ammonia at the maximum degree of deterioration Dmax is made to be zero, i.e., the adjustment of the generation amount of ammonia is made not to be performed. This is to take into consideration that the action of the NOx catalyst 3 to generate ammonia is extremely low at the time of the maximum deterioration thereof, and that it is hard to ensure a margin for the adjustment thereof.

[0101] In addition, in this adjustment mode, in the region from D1 to the maximum degree of deterioration Dmax, the initial storage amount of NOx is still in the state where it decreases in accordance with the increasing degree of deterioration, resulting from the catalyst deterioration as mentioned above, and adjustment processing with respect to the initial storage amount of NOx is not substantially executed. For that reason, in cases where the degree of deterioration of the NOx catalyst 3 is in that region, the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3 cannot be adjusted to a sufficient extent. However, in cases where the degree of deterioration of the NOx catalyst 3 belongs to a relatively wide range from the minimum degree of deterioration Dmin to the degree of de-

rioration D1, the output integrated quantity with respect to the degree of deterioration can be made substantially constant, as mentioned above, as a result of which the range of the upper and lower limit threshold values for the abnormality determination of the NOx sensor 4 can be narrowed as much as possible, thus making it possible to say that an improvement in accuracy of the abnormality determination can be attained.

[0102] (2) Second Adjustment Mode

As a second adjustment mode, reference will be made, based on Figs. 15A through 15C, to the suppression of the range of the variation of the output integrated quantity through the adjustment of the air-fuel ratio at the time of the rich spike control which is an execution parameter of the rich spike control. Fig. 15A is the same as the contents shown in Fig. 14A, so the detailed explanation thereof is omitted. In this adjustment mode, in order to suppress the range of the variation of the output integrated quantity with respect to this degree of deterioration, adjustment of the air-fuel ratio at the time of the rich spike control is executed, based on the correlation between the air-fuel ratio at the time of the rich spike control and the generation amount of ammonia as shown in Fig. 6B, in such a manner that the smaller the degree of deterioration of the NOx catalyst 3, the larger the extent of increase of the generation amount of ammonia due to the rich spike control becomes. By achieving such an increase in the generation amount of ammonia, it becomes possible to suppress the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3.

[0103] Reference will be made to specific adjustment of the air-fuel ratio at the time of the rich spike control based on Figs. 15B and 15C. Fig. 15B shows a set value of the air-fuel ratio at the time of the rich spike control in the course of the rich spike control before the above-mentioned adjustment for the suppression of the range of the variation of the output integrated quantity is executed, and is the same as the contents shown in Fig. 8B of the first embodiment. In addition, Fig. 15C shows a set value of the air-fuel ratio at the time of the rich spike control in the course of the rich spike control when the above-mentioned adjustment has been executed. As shown in Fig. 15B, before the adjustment, the air-fuel ratio at the time of the rich spike control is maintained at X6 in an entire deterioration range from the minimum degree of deterioration Dmin of the NOx catalyst 3 to the maximum degree of deterioration Dmax thereof. Here, note that the value X6 is an air-fuel ratio at a side leaner than AF1 shown in Fig. 6B.

[0104] Then, in order to suppress the range of the variation of the output integrated quantity, an adjustment is executed with respect to the air-fuel ratio at the time of the rich spike control set as shown in Fig. 15B in such a manner that the correlation between the degree of deterioration and the air-fuel ratio at the time of the rich spike control

becomes as shown in Fig. 15C. In the air-fuel ratio at the time of the rich spike control after this adjustment, an air-fuel ratio $X7'$ at the time of the rich spike control when the degree of deterioration of the NO_x catalyst 3 is the minimum degree of deterioration D_{min} is set smaller than the above-mentioned value $X6$ (i.e., set to a value at the rich side), and the air-fuel ratio at the time of the rich spike control increases (i.e., becomes lean) toward $X6$ as the degree of deterioration becomes larger. More specifically, the correlation between the degree of deterioration and the air-fuel ratio at the time of the rich spike control, which is shown in Fig. 15C, is formed by a straight line which connects between a point represented by the minimum degree of deterioration D_{min} and the air-fuel ratio $X7'$ at the time of the rich spike control, and a point represented by the maximum degree of deterioration D_{max} and the air-fuel ratio $X6$ at the time of the rich spike control. Thus, by adjusting the setting of the air-fuel ratio at the time of the rich spike control, the air-fuel ratio at the time of the rich spike control is adjusted so as to be smaller (i.e., to a value at the rich side) as the degree of deterioration is smaller. As a result, the extent of increase of the generation amount of ammonia at the time of the rich spike control in the case of the degree of deterioration being small becomes larger than that at the time of the rich spike control in the case of the degree of deterioration being large, and hence, the output integrated quantity with respect to the degree of deterioration becomes substantially constant, so that the range of the variation of the output integrated quantity with respect to the degree of deterioration can be made small.

[0105] Here, note that in this adjustment mode, the above-mentioned straight line is set to pass through the point at which the air-fuel ratio at the time of the rich spike control becomes $X6$ at the time of the maximum degree of deterioration D_{max} . Similar to the case of the initial storage amount of NO_x, this is to take into consideration that the action of the NO_x catalyst 3 to generate ammonia is extremely low at the time of the maximum deterioration thereof, and that it is hard to ensure a margin for the adjustment thereof.

[0106] (3) Third Adjustment Mode

As a third adjustment mode, reference will be made, based on Figs. 16A through 16C, to the suppression of the range of the variation of the output integrated quantity through the adjustment of the rich spike time period which is an execution parameter of the rich spike control. Fig. 16A is the same as the contents shown in Fig. 14A, so the detailed explanation thereof is omitted. In this adjustment mode, in order to suppress the range of the variation of the output integrated quantity with respect to this degree of deterioration, adjustment of the rich spike time period is executed, based on the correlation between the rich spike time period and the generation amount of ammonia as shown in Fig. 6C, in such a manner that the smaller the degree of deterioration of the

NOx catalyst 3, the larger the extent of increase of the generation amount of ammonia due to the rich spike control becomes. By achieving such an increase in the generation amount of ammonia, it becomes possible to suppress the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3.

[0107] Reference will be made to specific adjustment of the rich spike time period based on Figs. 16B and 16C. Fig. 16B shows a set value of the rich spike time period in the rich spike control before the above-mentioned adjustment for the suppression of the range of the variation of the output integrated quantity is executed, and is the same as the contents shown in Fig. 9B of the first embodiment. In addition, Fig. 16C shows a set value of the rich spike time period in the rich spike control when the above-mentioned adjustment has been executed. As shown in Fig. 16B, before the adjustment, the rich spike time period is maintained at X8 in an entire deterioration range from the minimum degree of deterioration Dmin of the NOx catalyst 3 to the maximum degree of deterioration Dmax thereof. Here, note that the value X8 is a time period shorter than RS1 shown in Fig. 6C.

[0108] Then, in order to suppress the range of the variation of the output integrated quantity, an adjustment is executed with respect to the rich spike time period set as shown in Fig. 16B in such a manner that the correlation between the degree of deterioration and the rich spike time period becomes as shown in Fig. 16C. In the rich spike time period after this adjustment, a rich spike time period X9' when the degree of deterioration of the NOx catalyst 3 is the minimum degree of deterioration Dmin is set longer than the above-mentioned value X8, and the rich spike time period decreases toward X8 as the degree of deterioration becomes larger. Here, note that the value X9' is a time period shorter than RS1 shown in Fig. 6C. More specifically, the correlation between the degree of deterioration and the rich spike time period, which is shown in Fig. 16C, is formed by a straight line which connects between a point represented by the minimum degree of deterioration Dmin and the rich spike time period X9', and a point represented by the maximum degree of deterioration Dmax and the rich spike time period X8. Thus, by adjusting the setting of the rich spike time period, the rich spike time period is adjusted so as to be longer as the degree of deterioration is smaller. As a result, the extent of increase of the generation amount of ammonia at the time of the rich spike control in the case of the degree of deterioration being small becomes larger than that at the time of the rich spike control in the case of the degree of deterioration being large, and hence, the output integrated quantity with respect to the degree of deterioration becomes substantially constant, so that the range of the variation of the output integrated quantity with respect to the degree of deterioration can be made small.

- [0109] Here, note that in this adjustment mode, the above-mentioned straight line is set to pass through the point at which the rich spike time period becomes X8 at the time of the maximum degree of deterioration Dmax. Similar to the case of the initial storage amount of NOx, this is to take into consideration that the action of the NOx catalyst 3 to generate ammonia is extremely low at the time of the maximum deterioration thereof, and that it is hard to ensure a margin for the adjustment thereof.
- [0110] Thus, by adopting the adjustment modes (the first through third adjustment modes) for the execution parameters of the rich spike control shown in Figs. 14A - 14C through Figs. 16A - 16C, it is possible to suppress the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3, thereby making it possible to improve the accuracy in the abnormality determination of the NOx sensor 4. Here, note that as long as the accuracy in the abnormality determination of the NOx sensor 4 is within an allowable level, in order to suppress the range of the variation of the output integrated quantity, any of the first through third adjustment modes may be adopted, or two or three of these adjustment modes may be adopted in combination as appropriate.
- [0111] < Detailed Discussion with respect to the Adjustment of the Execution Parameters of the Rich Spike Control >

Here, note that in this second embodiment, too, based on the tendencies of variation shown in this Fig. 10, a detailed discussion with respect to the adjustment of the execution parameters of the rich spike control is executed. In this second embodiment, the predetermined detection time period corresponds to both the lean operation time period and the rich spike time period in which the rich spike control is being executed, as mentioned above, and in this case, as shown in Figs. 14A - 14C through Figs. 16A - 16C, in order to suppress the range of the variation of the output integrated quantity with respect to this degree of deterioration of the NOx catalyst 3, it is preferable that the initial storage amount of NOx be adjusted to increase, or the air-fuel ratio at the time of the rich spike control be adjusted to be richer, or the rich spike time period be adjusted to be longer, as the degree of deterioration of the NOx catalyst 3 becomes smaller. Accordingly, in Figs. 17A through 17D, the changes over time of the output of the NOx sensor 4 when these individual adjustments were executed are shown by solid lines, respectively, and the changes over time of the amount of NOx flowing into the NOx catalyst 3 when these individual adjustments were executed are shown by broken lines, respectively. Specifically, Fig. 17A shows the individual changes over time in the case where there was no adjustment of the execution parameters; Fig. 17B shows the individual changes over time in the case where the initial storage amount of NOx was adjusted to increase; Fig. 17C shows the individual changes over time in the case where the air-fuel ratio at the time of the rich spike control was adjusted to be rich; and

Fig. 17D shows the individual changes over time in the case where the rich spike time period was adjusted to be long.

- [0112] In the case where the initial storage amount of NO_x has been adjusted to decrease, as shown in Fig. 17B, a time point t1' at which the rich spike control is started is made later than the start time point t1 in the case where another execution parameter has been adjusted. At this time, owing to the increase in the initial storage amount of NO_x, the outflow amount of the NO_x becomes somewhat (slightly) larger and the generation amount of ammonia also becomes larger, in comparison with the case where no adjustment of the execution parameter has been made. In addition, due to the delay in the start of the rich spike control, the lean operation time period extends, and the amount of NO_x during the lean operation also increases.
- [0113] Next, in the case where the air-fuel ratio at the time of the rich spike control is adjusted to be rich, as shown in Fig. 17C, a start time point of the rich spike control is the same as in the case where no adjustment of the execution parameter has been made. However, although the outflow amount of the NO_x is unchanged in the case of no adjustment of the execution parameter, the generation amount of ammonia becomes larger than that in the case of no adjustment of the execution parameter. On the other hand, with the air-fuel ratio at the time of the rich spike control being adjusted to be rich, the amount of NO_x flowing into the NO_x catalyst 3 during the rich spike control becomes smaller than that in the case of no adjustment of the execution parameter. Here, note that the amount of NO_x during the lean operation is the same as in the case of no adjustment of the execution parameter.
- [0114] Then, in the case where the rich spike time period is adjusted to be long, as shown in Fig. 17D, a start time point of the rich spike control is the same as in the case where no adjustment of the execution parameter has been made. However, although the outflow amount of the NO_x is unchanged in the case of no adjustment of the execution parameter, the generation amount of ammonia becomes larger than that in the case of no adjustment of the execution parameter. On the other hand, with the rich spike time period being adjusted to be long, the amount of NO_x flowing into the NO_x catalyst 3 during the rich spike control becomes larger than that in the case of no adjustment of the execution parameter. Here, note that the amount of NO_x during the lean operation is the same as in the case of no adjustment of the execution parameter.
- [0115] Here, as shown in Fig. 14A, etc., a factor in which the output integrated quantity of the NO_x sensor 4 varies with respect to the degree of deterioration of the NO_x catalyst 3 in the case of setting the predetermined detection time period to both of the lean operation time period and a time period corresponding to the time period in which the rich spike control is being executed is that the generation amount of ammonia, the outflow amount of the NO_x, and the amount of the passed-through NO_x change

according to the degree of deterioration. Accordingly, it is considered that in order to suppress the range of the variation of the output integrated quantity, it is most preferable to perform rich adjustment of the air-fuel ratio at the time of the rich spike control in which in the case where the degree of deterioration of the NOx catalyst 3 is relatively small, the amount of ammonia to be generated is made to increase, whereas in the case where the degree of deterioration of the NOx catalyst 3 is relatively large, the amount of passed-through NOx is made to decrease.

[0116] In addition, with respect to the adjustment to increase the initial storage amount of NOx or the adjustment to extend the rich spike time period, the amount of inflow NOx during the lean operation or during the rich spike control is made to increase, and hence, it is preferable to adopt an adjustment to perform the increasing adjustment of the initial storage amount of NOx and the rich adjustment of the air-fuel ratio at the time of the rich spike control at the same time, or an adjustment to perform the extending adjustment of the rich spike time period and the rich adjustment of the air-fuel ratio at the time of the rich spike control at the same time. Here, note that this does not hinder the independent adoption of the increasing adjustment of the initial storage amount of NOx or the extending adjustment of the rich spike time period, but as long as the accuracy in the abnormality determination of the NOx sensor 4 leads to a desirable and appropriate level, the increasing adjustment of the initial storage amount of NOx or the extending adjustment of the rich spike time period may be adopted independently, so that the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3 is suppressed, and the output integrated quantity is made to fall within the predetermined allowable range.

[0117] < Flow for Abnormality Determination Control >

A flow for the abnormality determination control of the NOx sensor 4 in this second embodiment is shown in Fig. 18, based on the adjustment modes referred to above for the execution parameters of the rich spike control for suppressing the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3. This abnormality determination control is executed by the ECU 10, as appropriate. Here, note that with respect to those processings which are included in the abnormality determination control shown in Fig. 18, and which are equivalent to the processings included in the abnormality determination control shown in Fig. 12, the detailed explanation thereof is omitted, by attaching the same reference numerals to the corresponding processings.

[0118] In this abnormality determination control, after the processing of step S102 ends, the routine goes to step S201. Then, in step S201, it is determined whether when the internal combustion engine 1 is in the lean operation, a condition for starting the output integration of the NOx sensor 4 for abnormality determination has been satisfied. That

is, the processing of step S201 is to determine the start of the second detection time period in the predetermined detection time period. In this embodiment, at an end time point of a detection time period corresponding to the rich spike control executed at the latest (i.e., the last first detection time period), it is determined that the condition for starting the output integration has been satisfied. When an affirmative determination is made in step S201, the routine goes to step S202, whereas when a negative determination is made, the routine is ended. Then, in step S202, the integration of the output of the NOx sensor 4 is executed as in the processing of step S105 shown in Fig. 12. Thereafter, when the processing of step S202 is completed, the processing of step S103 and thereafter will be executed. Here, note that in this control, the integration of the sensor output is started in the above-mentioned step S202, and hence, the processing of step S105 itself is not included.

[0119] According to this control, the abnormality determination of the NOx sensor 4 is executed in a state where the range of the variation of the output integrated quantity with respect to the degree of deterioration of the NOx catalyst 3 is suppressed with the output integrated quantity falling within the predetermined allowable range, as a result of which the accuracy of the abnormality determination can be improved in a suitable and appropriate manner.

Reference Signs List

- [0120]
- 1 internal combustion engine
 - 2 exhaust passage
 - 3 NOx storage reduction catalyst (NOx catalyst)
 - 4 NOx sensor
 - 5 air-fuel ratio sensor
 - 6 air-fuel ratio sensor
 - 10 ECU
 - 11 accelerator pedal
 - 12 accelerator opening sensor
 - 13 crank position sensor

Claims

[Claim 1]

An abnormality determination device for a NO_x sensor which is disposed in an exhaust passage of an internal combustion engine at a downstream side of a NO_x storage reduction catalyst and is configured so as to be able to detect NO_x and ammonia in exhaust gas, the NO_x storage catalyst stores NO_x in the exhaust gas and reduces the NO_x stored therein by a supply of a reducing agent, the abnormality determination device comprising:

- an air-fuel ratio control unit that executes predetermined air-fuel ratio control in which an air-fuel ratio of the exhaust gas discharged from the internal combustion engine and flowing into the NO_x storage reduction catalyst is controlled to be a rich air-fuel ratio that is richer than a stoichiometric air-fuel ratio, thereby to generate ammonia by means of the NO_x storage reduction catalyst;
- an abnormality determination unit that makes an abnormality determination of the NO_x sensor based on an output integrated quantity which is an integrated quantity of detected values of the NO_x sensor in a predetermined detection time period which includes at least a first detection time period of the NO_x sensor corresponding to a time period in which the predetermined air-fuel ratio control is being executed by the air-fuel ratio control unit;
- an acquisition unit that acquires a degree of deterioration of the NO_x storage reduction catalyst based on a predetermined deterioration parameter other than an output of the NO_x sensor; and
- an adjustment unit that decides a predetermined execution parameter with respect to the predetermined air-fuel ratio control based on the degree of deterioration of the NO_x storage reduction catalyst, and executes the predetermined air-fuel ratio control according to the predetermined execution parameter thus decided, thereby to adjust a generation amount of ammonia generated by the NO_x storage reduction catalyst such that the output integrated quantity falls within a predetermined allowable range irrespective of the degree of deterioration of the NO_x storage reduction catalyst.

[Claim 2]

The abnormality determination device for a NO_x sensor as set forth in claim 1, wherein

the predetermined allowable range is a range which is substantially equivalent to the output integrated quantity which is assumed when the

NOx storage reduction catalyst is at a maximum degree of deterioration.

[Claim 3]

The abnormality determination device for a NOx sensor as set forth in claim 1 or 2, wherein

the predetermined execution parameter of the predetermined air-fuel ratio control is at least any one of a storage amount of NOx stored in the NOx storage reduction catalyst at a time point at which the predetermined air-fuel ratio control is started, a value of the rich air-fuel ratio that is reached in the predetermined air-fuel ratio control, and a control time period in which the rich air-fuel ratio is continued in the predetermined air-fuel ratio control.

[Claim 4]

The abnormality determination device for a NOx sensor as set forth in claim 3, wherein

the abnormality determination unit executes the abnormality determination of the NOx sensor based on an integrated quantity of detected values of the NOx sensor in the predetermined detection time period by using the first detection time period as the predetermined detection time period; and

the generation amount of ammonia in a case where the adjustment by the adjustment unit has been executed is an amount that is decreased in comparison with the generation amount of ammonia in a case where adjustment by the adjustment unit has not been executed, and a range of decrease of the generation amount of ammonia in a case of the degree of deterioration of the NOx storage reduction catalyst being small is set larger than a range of decrease of the generation amount of ammonia in a case of the degree of deterioration of the NOx storage reduction catalyst being large.

[Claim 5]

The abnormality determination device for a NOx sensor as set forth in claim 4, wherein

when the storage amount of NOx is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the storage amount of NOx smaller in a case where the degree of deterioration of the NOx storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large.

[Claim 6]

The abnormality determination device for a NOx sensor as set forth in claim 4, wherein

when the value of the rich air-fuel ratio is included as the prede-

terminated execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the value of the rich air-fuel ratio larger in a case where the degree of deterioration of the NO_x storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large.

[Claim 7]

The abnormality determination device for a NO_x sensor as set forth in claim 4, wherein

when the control time period is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the control time period shorter in a case where the degree of deterioration of the NO_x storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large.

[Claim 8]

The abnormality determination device for a NO_x sensor as set forth in claim 3, wherein

the abnormality determination unit makes the abnormality determination of the NO_x sensor based on an integrated quantity of detected values of the NO_x sensor in the predetermined detection time period, by using both of the first detection time period and a second detection time period as the predetermined detection time period, wherein the second detection time period is a time period before the first detection time period and corresponds to a time period in which the air-fuel ratio of the exhaust gas flowing into the NO_x storage reduction catalyst is controlled to be a lean air-fuel ratio that is leaner than the stoichiometric air-fuel ratio; and

the generation amount of ammonia in a case where an adjustment by the adjustment unit has been executed is an amount that is increased in comparison with the generation amount of ammonia in a case where an adjustment by the adjustment unit has not been executed, and a range of increase of the generation amount of ammonia in a case of the degree of deterioration of the NO_x storage reduction catalyst being small is set larger than a range of increase of the generation amount of ammonia in a case of the degree of deterioration of the NO_x storage reduction catalyst being large.

[Claim 9]

The abnormality determination device for a NO_x sensor as set forth in claim 8, wherein

when the storage amount of NO_x is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the ad-

justment unit makes the storage amount of NO_x larger in a case where the degree of deterioration of the NO_x storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large.

[Claim 10]

The abnormality determination device for a NO_x sensor as set forth in claim 8, wherein

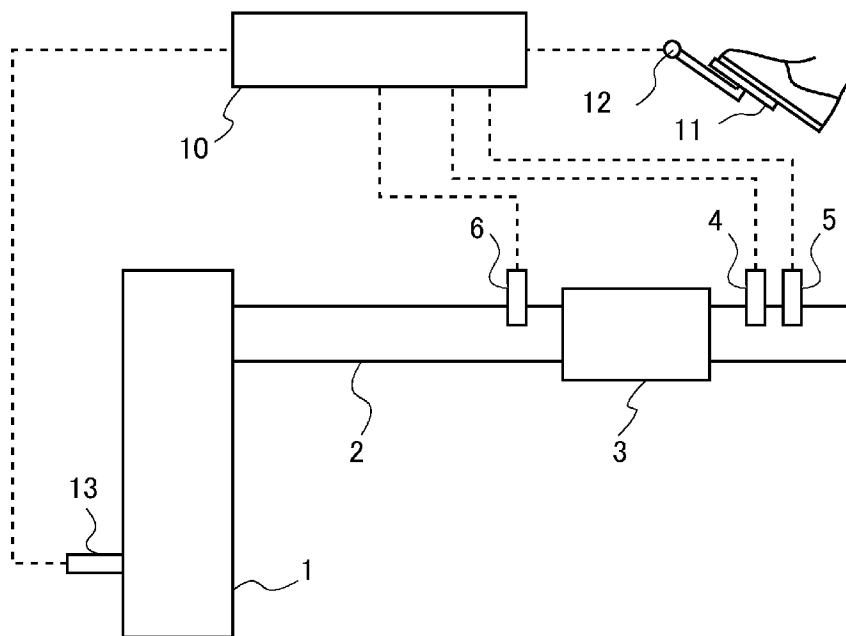
when the value of the rich air-fuel ratio is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the value of the rich air-fuel ratio smaller in a case where the degree of deterioration of the NO_x storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large.

[Claim 11]

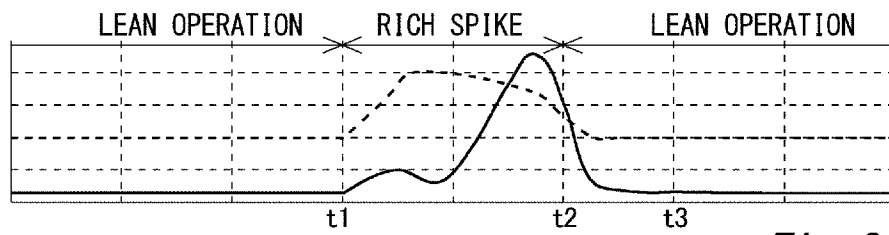
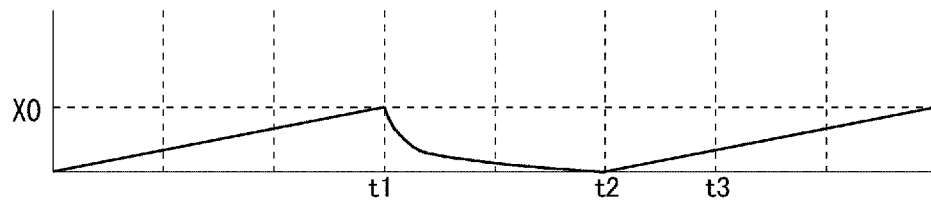
The abnormality determination device for a NO_x sensor as set forth in claim 8, wherein

when the control time period is included as the predetermined execution parameter of the predetermined air-fuel ratio control, the adjustment unit makes the control time period longer in a case where the degree of deterioration of the NO_x storage reduction catalyst is small, in comparison with a case where the degree of deterioration thereof is large.

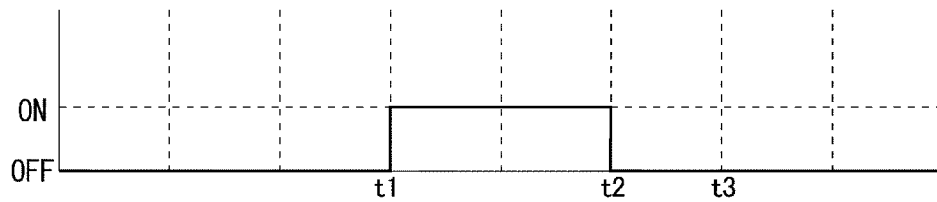
[Fig. 1]

*Fig. 1*

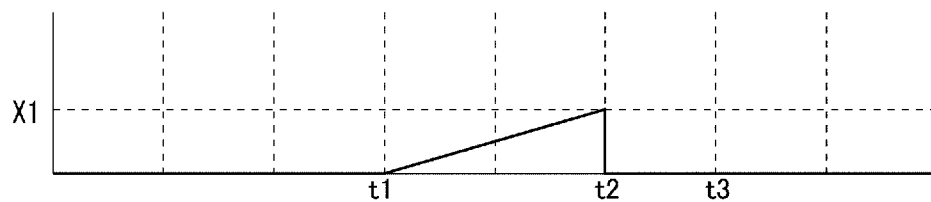
[Fig. 2]

OUTPUT OF NO_x SENSOR*Fig. 2A*STORAGE AMOUNT OF NO_x*Fig. 2B*

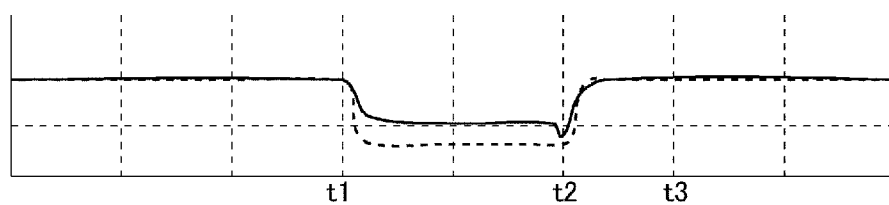
RICH SPIKE FLAG

*Fig. 2C*

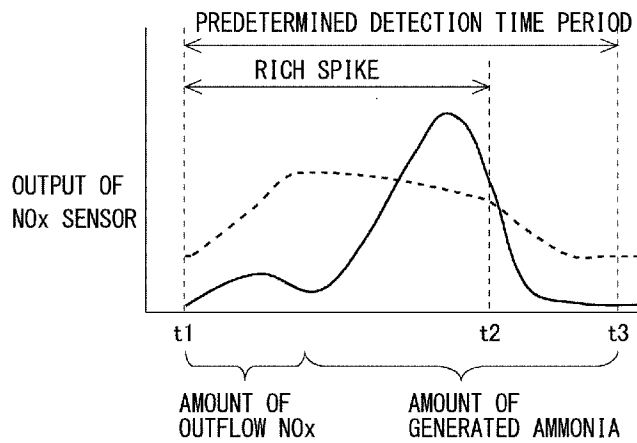
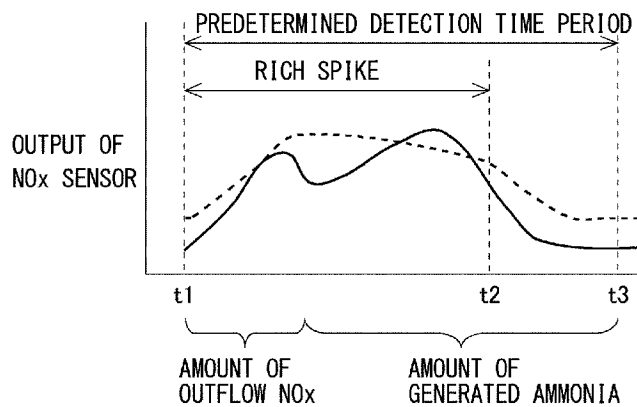
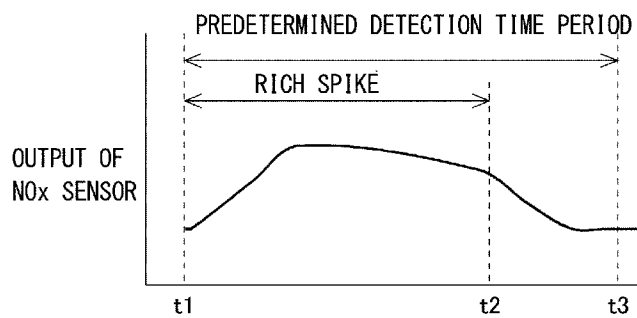
ACCUMULATED AMOUNT OF SUPPLY OF REDUCING AGENT

*Fig. 2D*

AIR-FUEL RATIO
(LEAN SIDE)
STOICHIOMETRIC
AIR-FUEL RATIO
(RICH SIDE)

*Fig. 2E*

[Fig. 3]

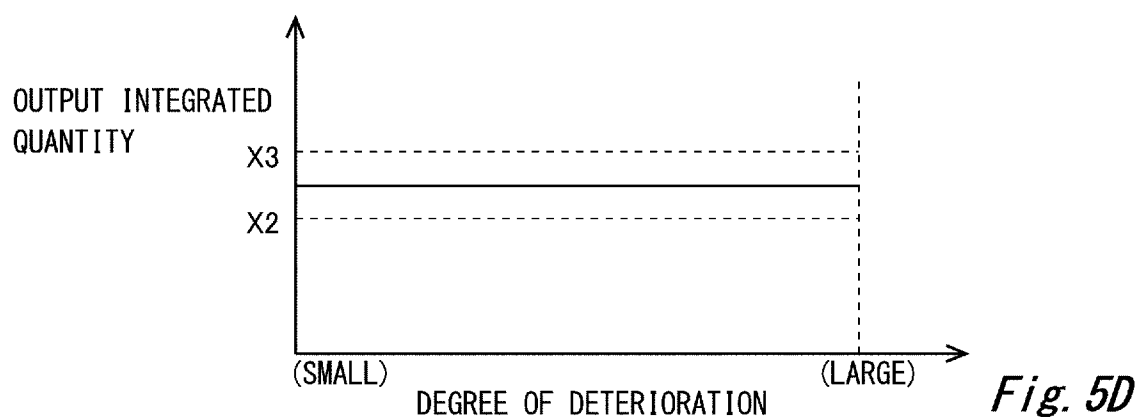
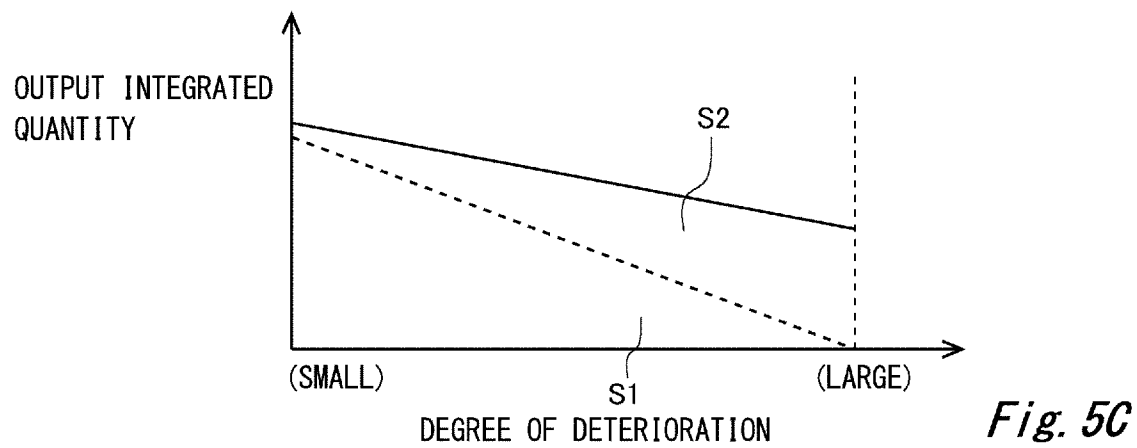
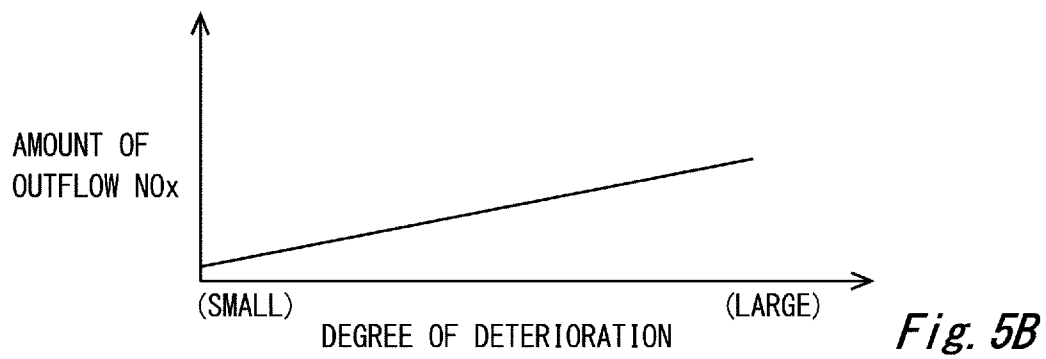
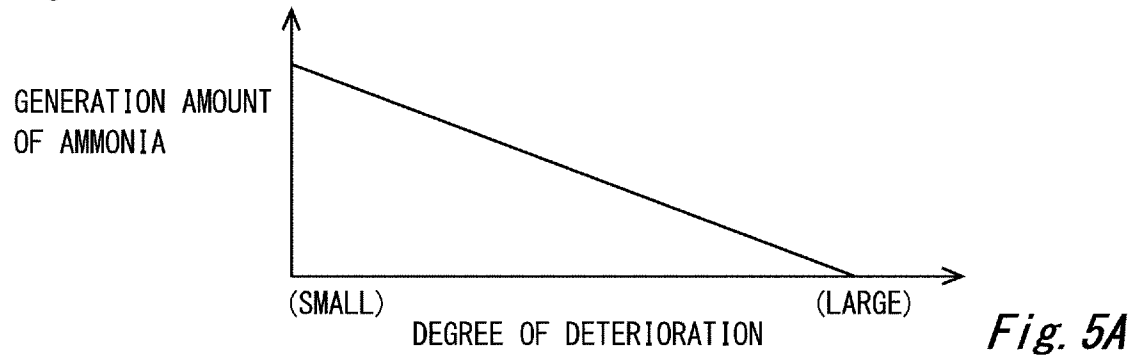
AT THE TIME OF NORMAL NO_x CATALYST (MINIMUM DEGREE OF DETERIORATION)*Fig. 3A*AT THE TIME OF DETERIORATION OF NO_x CATALYST (MEDIUM DEGREE OF DETERIORATION)*Fig. 3B*AT THE TIME OF DETERIORATION OF NO_x CATALYST (MAXIMUM DEGREE OF DETERIORATION)*Fig. 3C*

[Fig. 4]

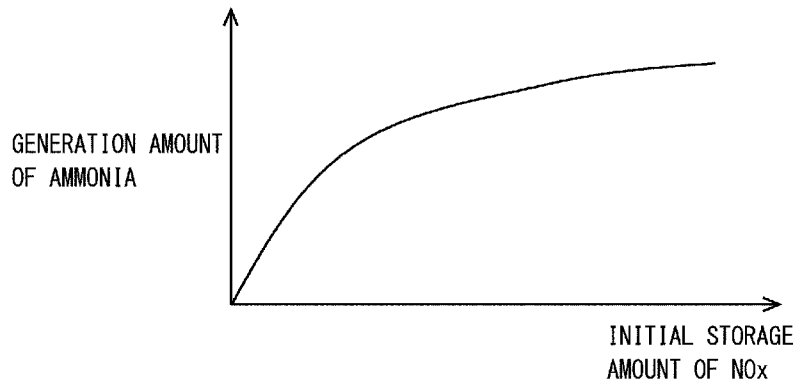
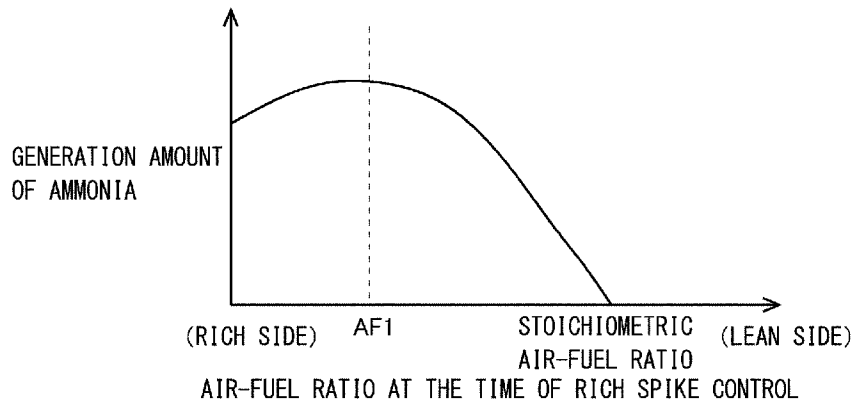
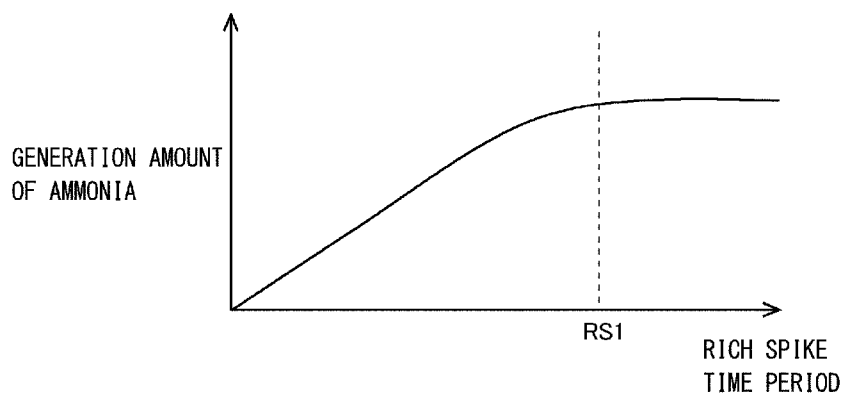
COMPONENTS	MINIMUM DEGREE OF DETERIORATION		MAXIMUM DEGREE OF DETERIORATION	
	FLOWING INTO CATALYST	FLOWING OUT OF CATALYST	FLOWING INTO CATALYST	FLOWING OUT OF CATALYST
NOx DURING LEAN OPERATION	100mol	0mol	100mol	100mol
NOx DURING RICH SPIKE CONTROL	50mol	10mol	50mol	50mol
NITROGEN DURING RICH SPIKE CONTROL	---	60mol	---	0mol
AMMONIA DURING RICH SPIKE CONTROL	---	80mol	---	0mol
OUTPUT INTEGRATED QUANTITY OF NOx SENSOR	---	90mol	---	50mol

Fig. 4

[Fig. 5]



[Fig. 6]

*Fig. 6A**Fig. 6B**Fig. 6C*

[Fig. 7]

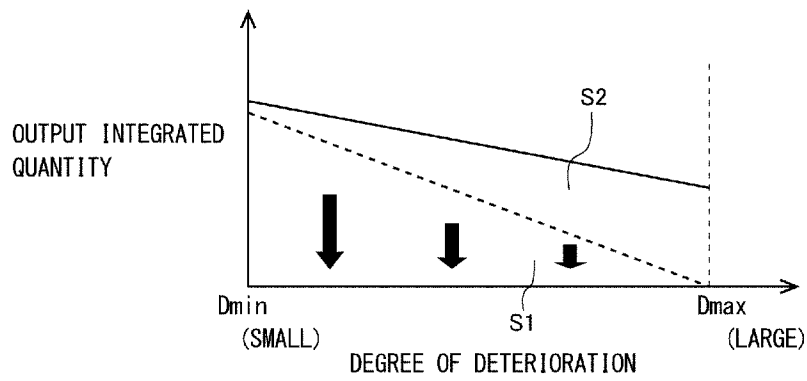


Fig. 7A

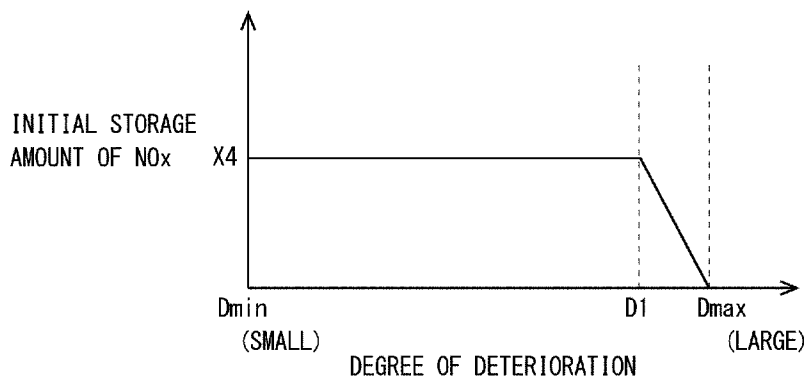


Fig. 7B

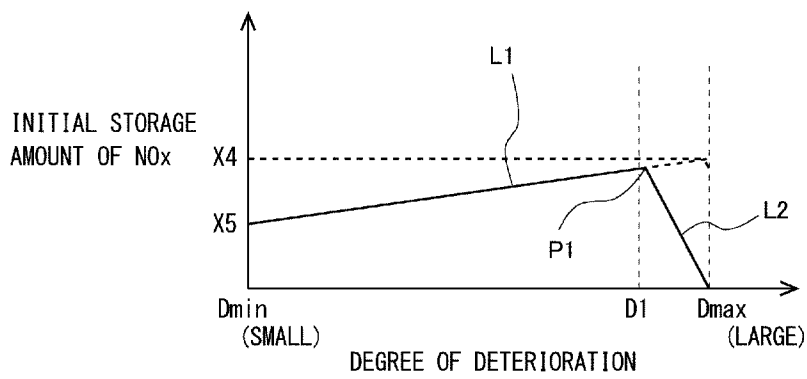
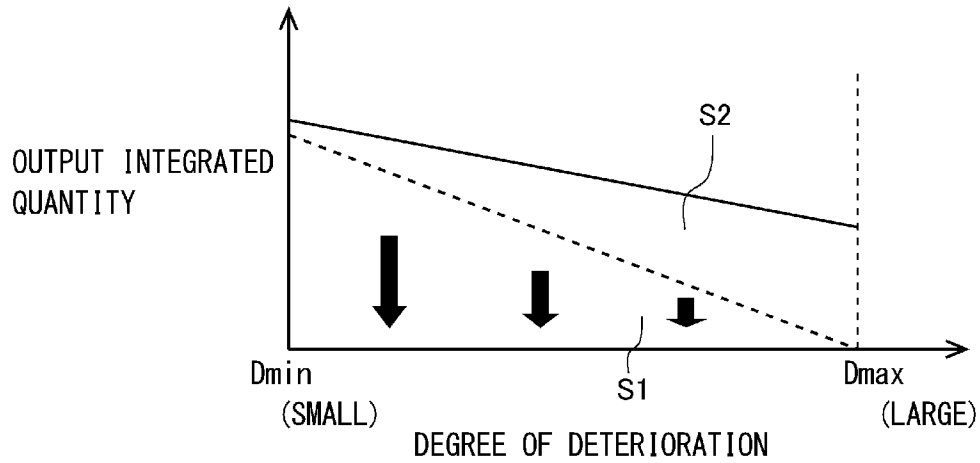
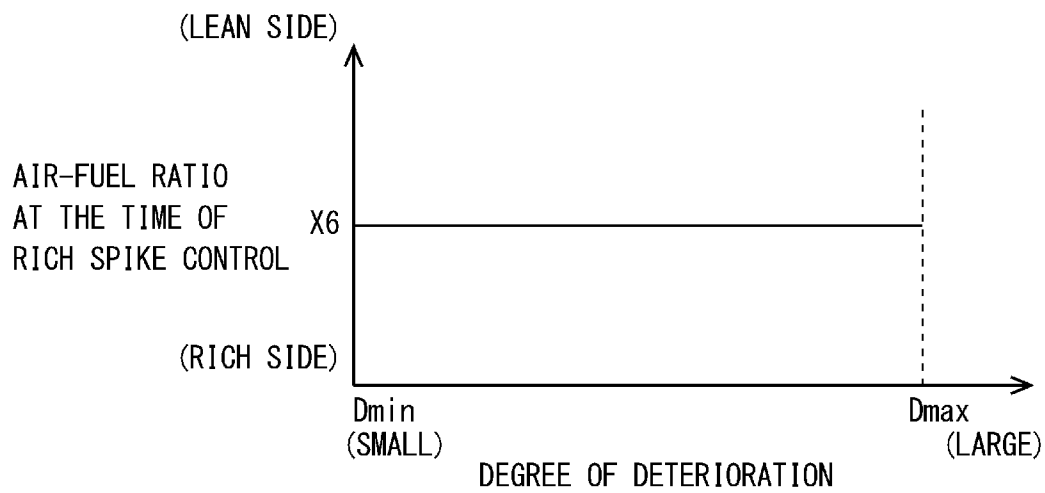
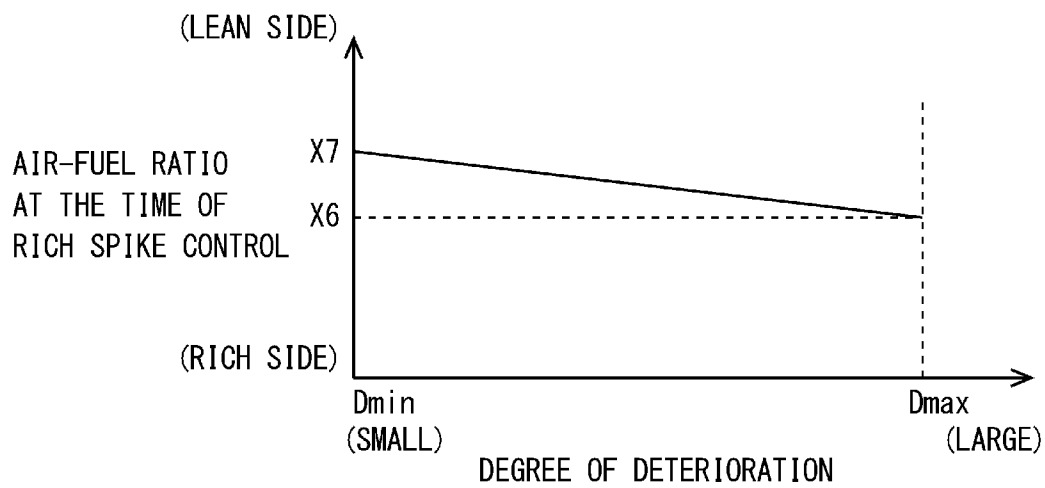
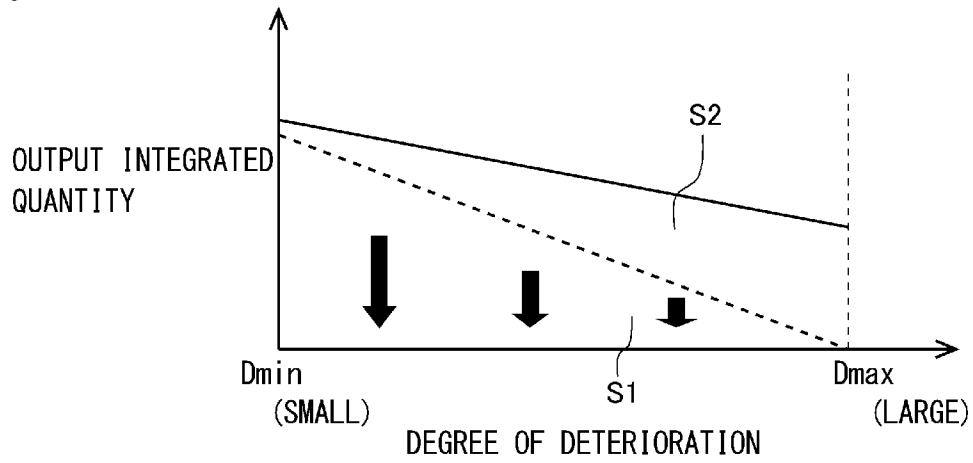
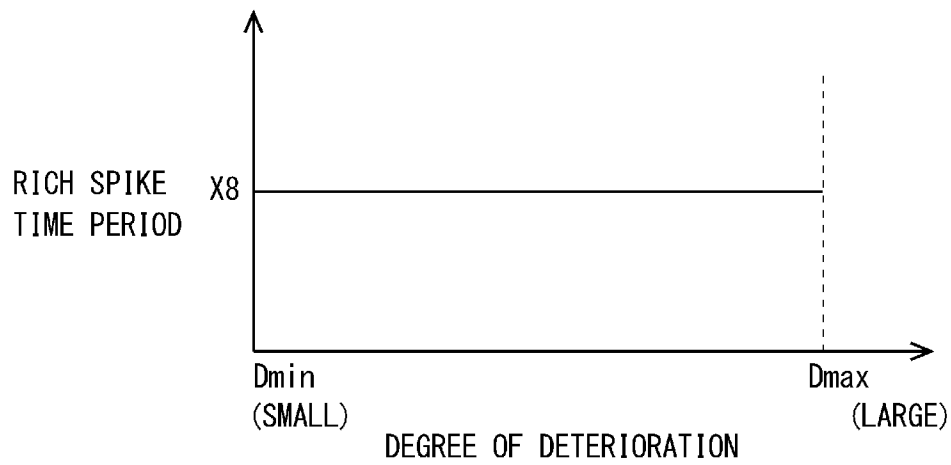
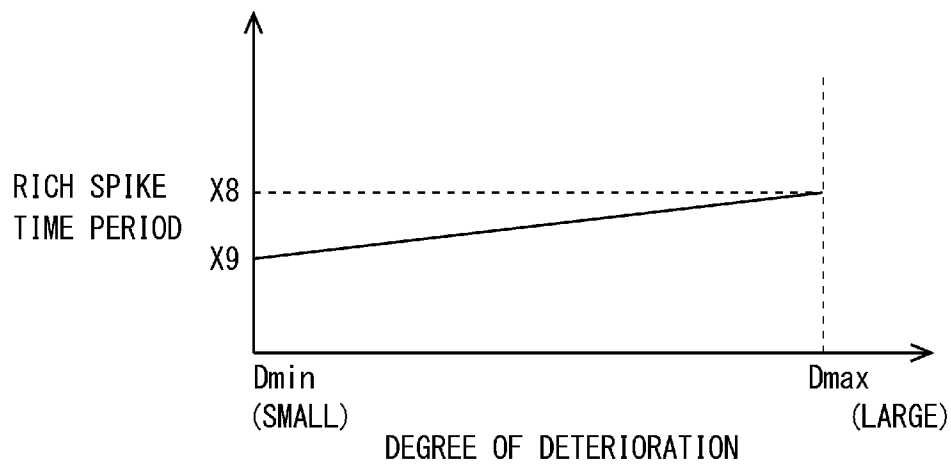


Fig. 7C

[Fig. 8]

*Fig. 8A**Fig. 8B**Fig. 8C*

[Fig. 9]

*Fig. 9A**Fig. 9B**Fig. 9C*

[Fig. 10]

	INITIAL STORAGE AMOUNT OF NO _x		AIR-FUEL RATIO AT THE TIME OF RICH SPIKE CONTROL		RICH SPIKE TIME PERIOD	
	INCREASED	DECREASED	MADE RICH	MADE LEAN	MADE LONG	MADE SHORT
AMMONIA DURING RICH SPIKE CONTROL	INCREASES	DECREASES	INCREASES	DECREASES	INCREASES	DECREASES
NO _x FLOWING INTO CATALYST DURING RICH SPIKE CONTROL	----	----	DECREASES	INCREASES	INCREASES	DECREASES
NO _x FLOWING INTO CATALYST DURING LEAN OPERATION	INCREASES	DECREASES	----	----	----	----

Fig. 10

[Fig. 11]

NO ADJUSTMENT OF EXECUTION PARAMETER

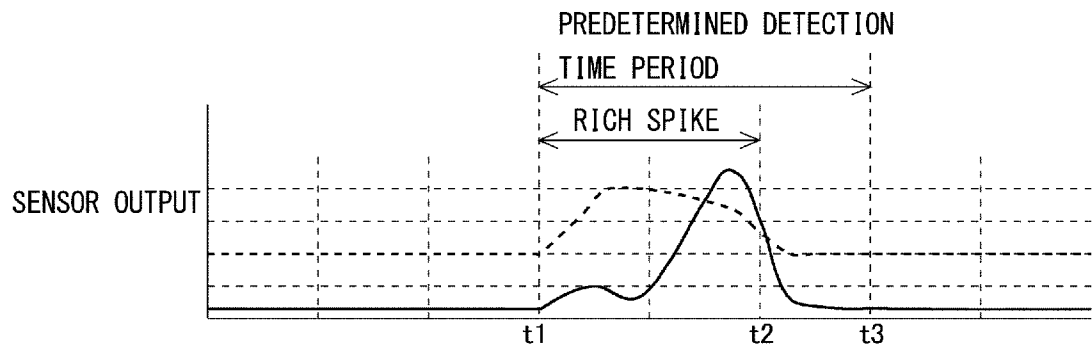


Fig. 11A

DECRESING ADJUSTMENT OF INITIAL STORAGE AMOUNT OF NO_x

PREDETERMINED DETECTION

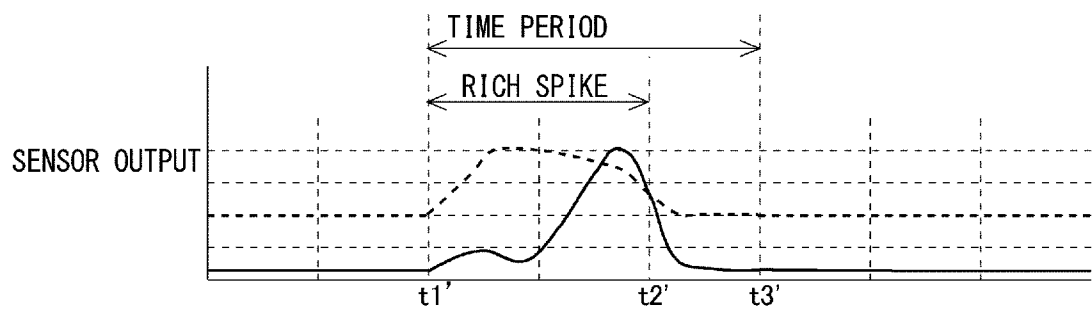


Fig. 11B

LEAN ADJUSTMENT OF AIR-FUEL RATIO AT THE TIME OF RICH SPIKE CONTROL

PREDETERMINED DETECTION

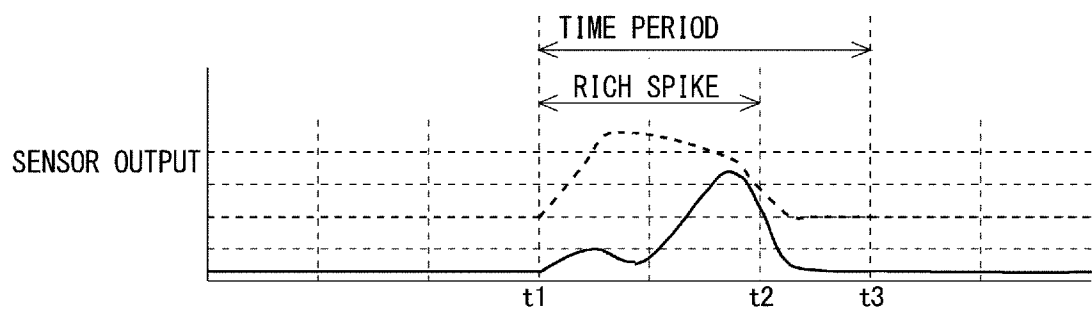


Fig. 11C

SHORTENING ADJUSTMENT OF RICH SPIKE TIME PERIOD

PREDETERMINED DETECTION

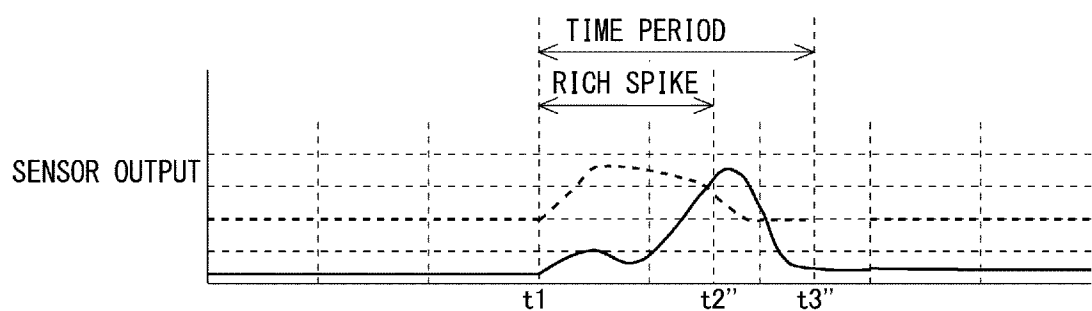
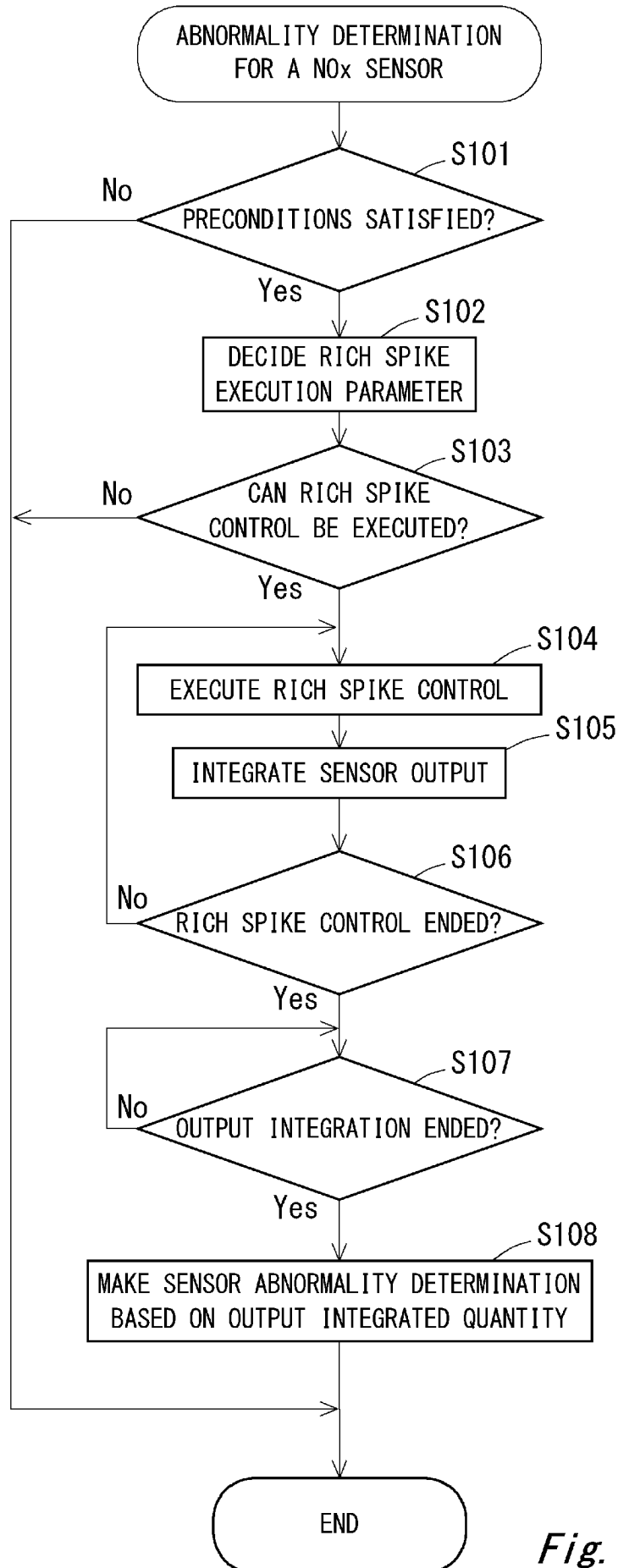


Fig. 11D

[Fig. 12]

*Fig. 12*

[Fig. 13]
OUTPUT OF NO_x SENSOR

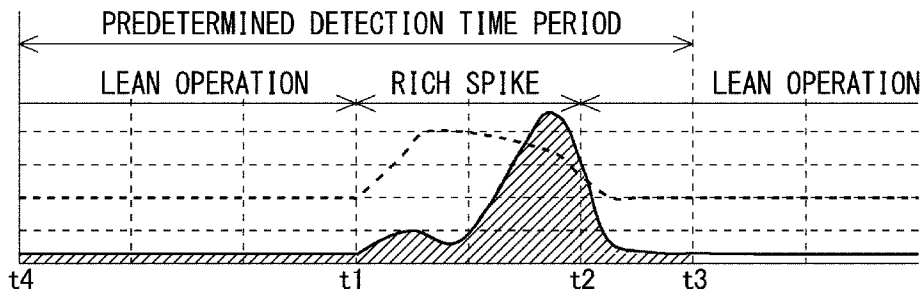


Fig. 13A

OUTPUT OF NO_x SENSOR

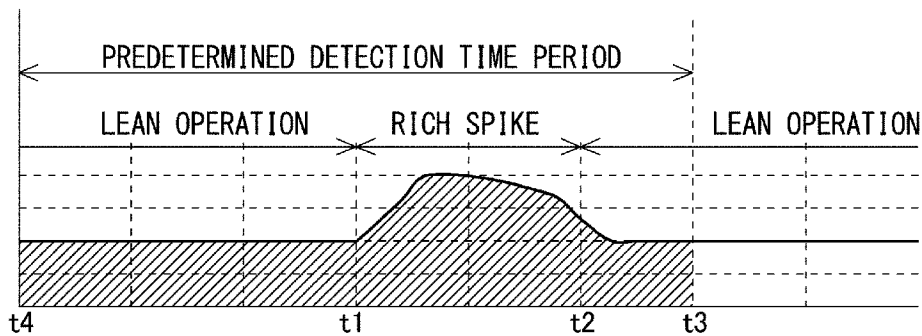


Fig. 13B

COMPONENTS	MINIMUM DEGREEE OF DETERIORATION		MAXIMUM DEGREE OF DETERIORATION	
	FLOWING INTO CATALYST	FLOWING OUT OF CATALYST	FLOWING INTO CATALYST	FLOWING OUT OF CATALYST
NO _x DURING LEAN OPERATION	100mol	0mol	100mol	100mol
NO _x DURING RICH SPIKE CONTROL	50mol	10mol	50mol	50mol
NITROGEN DURING RICH SPIKE CONTROL	---	60mol	---	0mol
AMMONIA DURING RICH SPIKE CONTROL	---	80mol	---	0mol
OUTPUT INTEGRATED QUANTITY OF NO _x SENSOR	---	90mol	---	150mol

Fig. 13C

[Fig. 14]

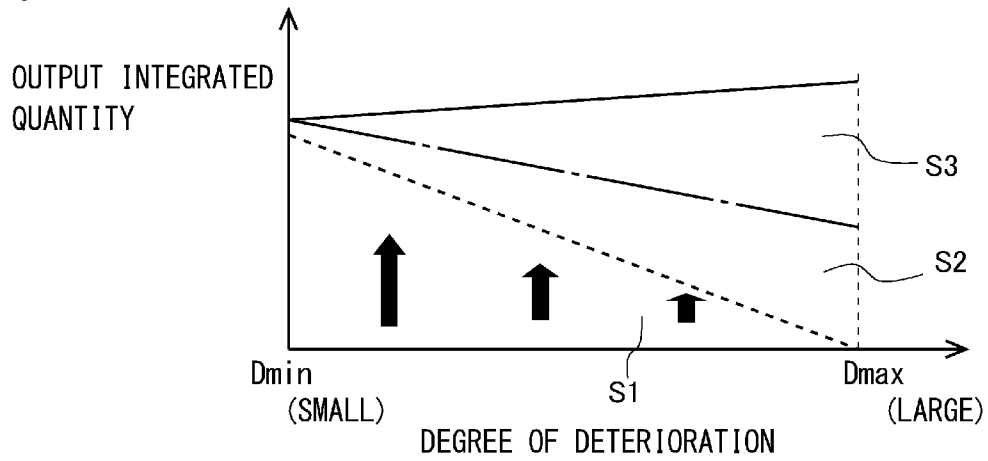


Fig. 14A

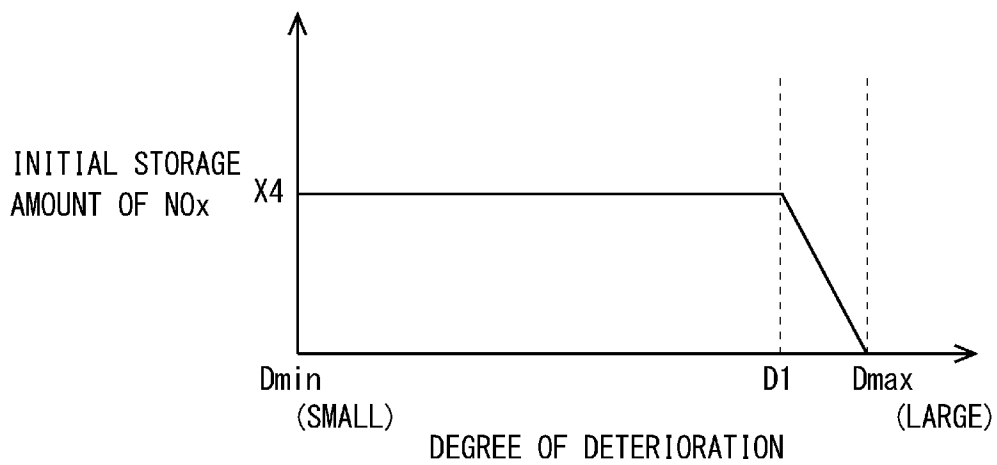


Fig. 14B

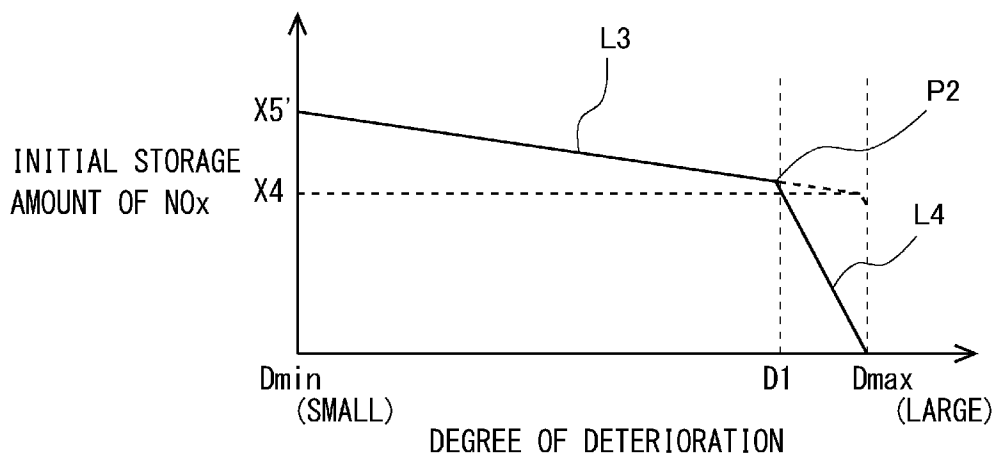
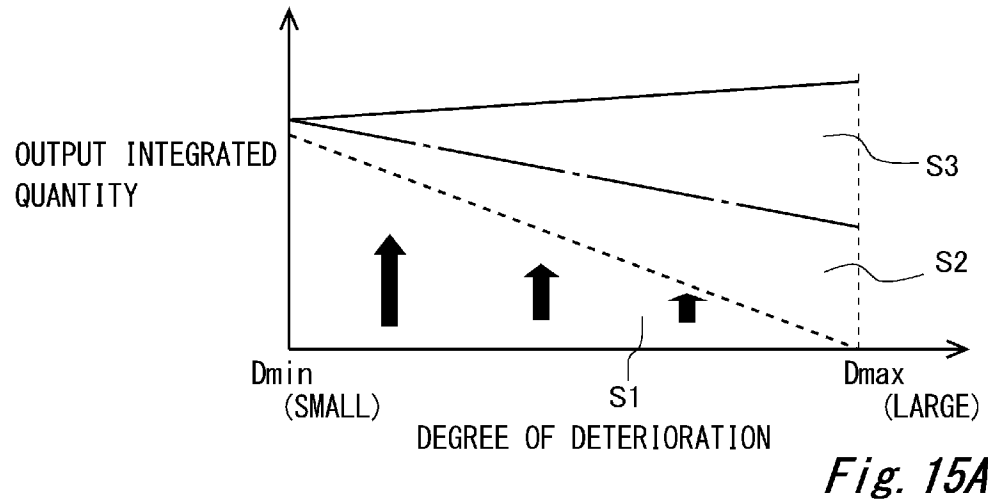
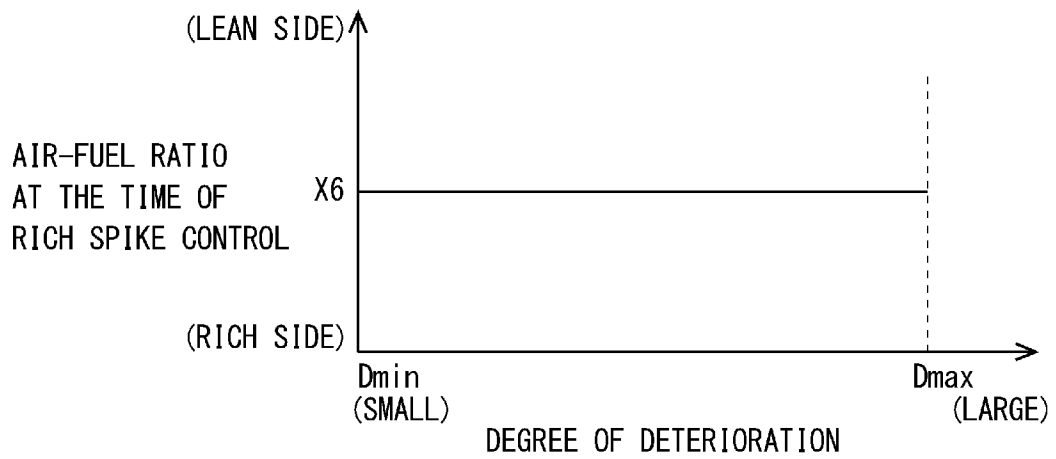
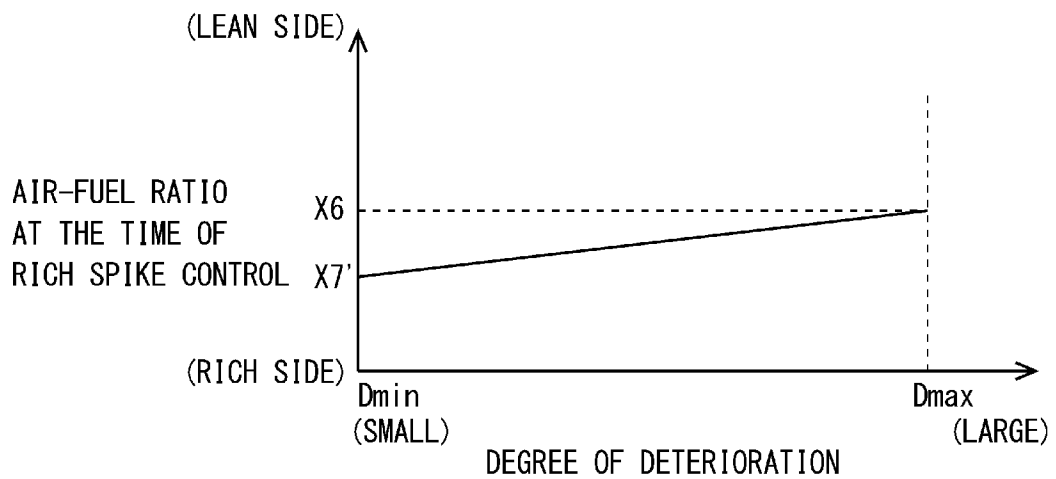
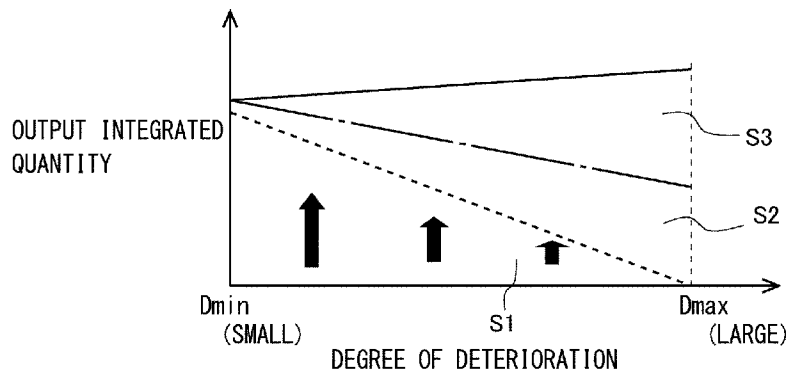
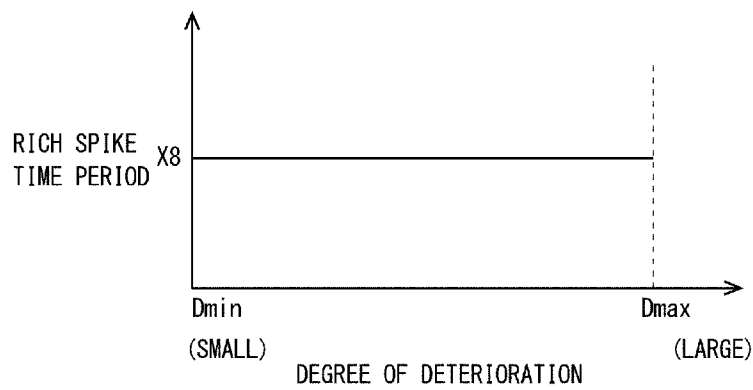
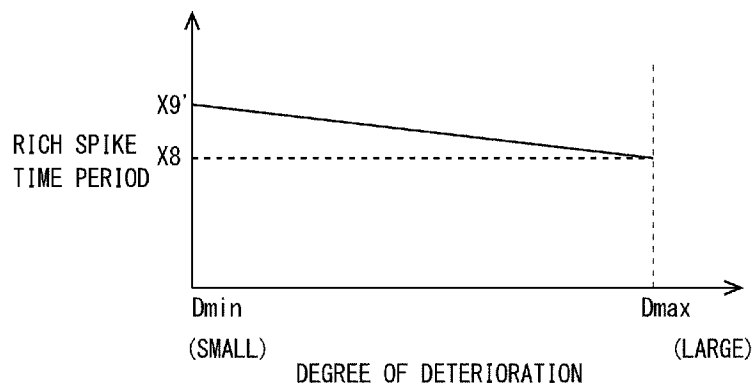


Fig. 14C

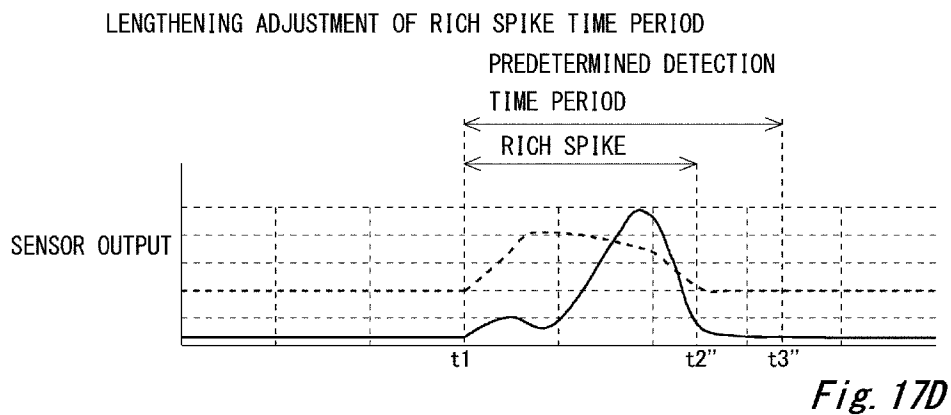
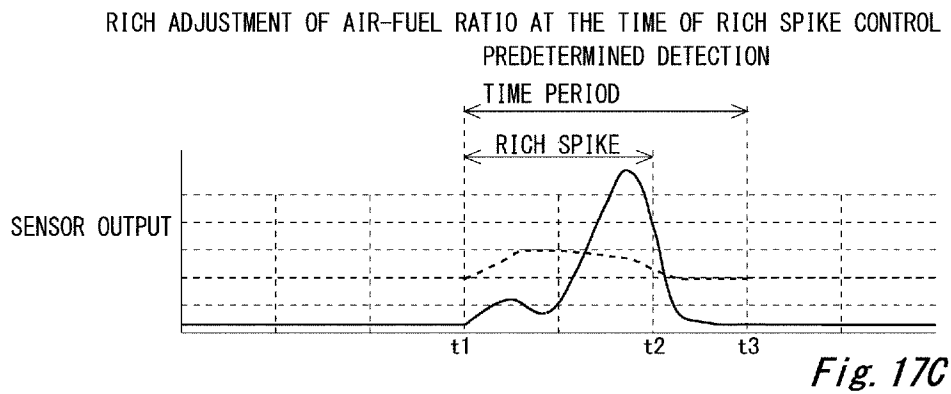
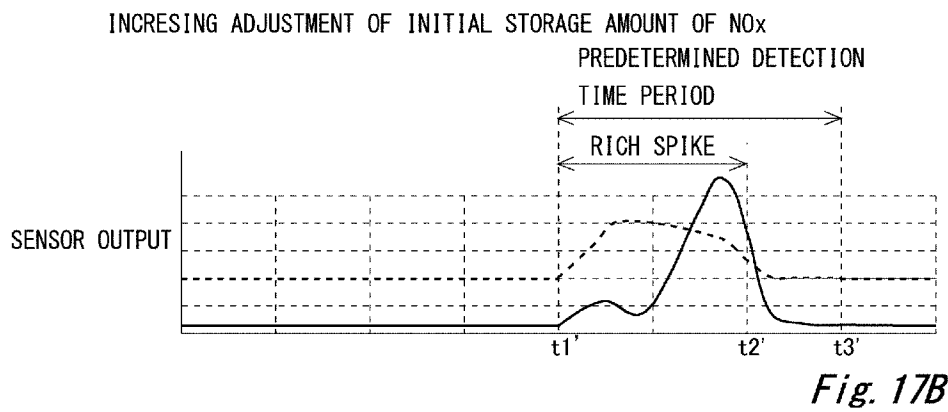
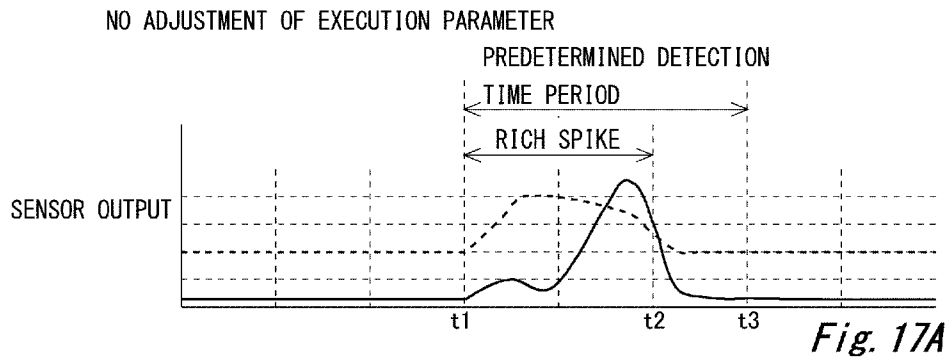
[Fig. 15]

*Fig. 15A**Fig. 15B**Fig. 15C*

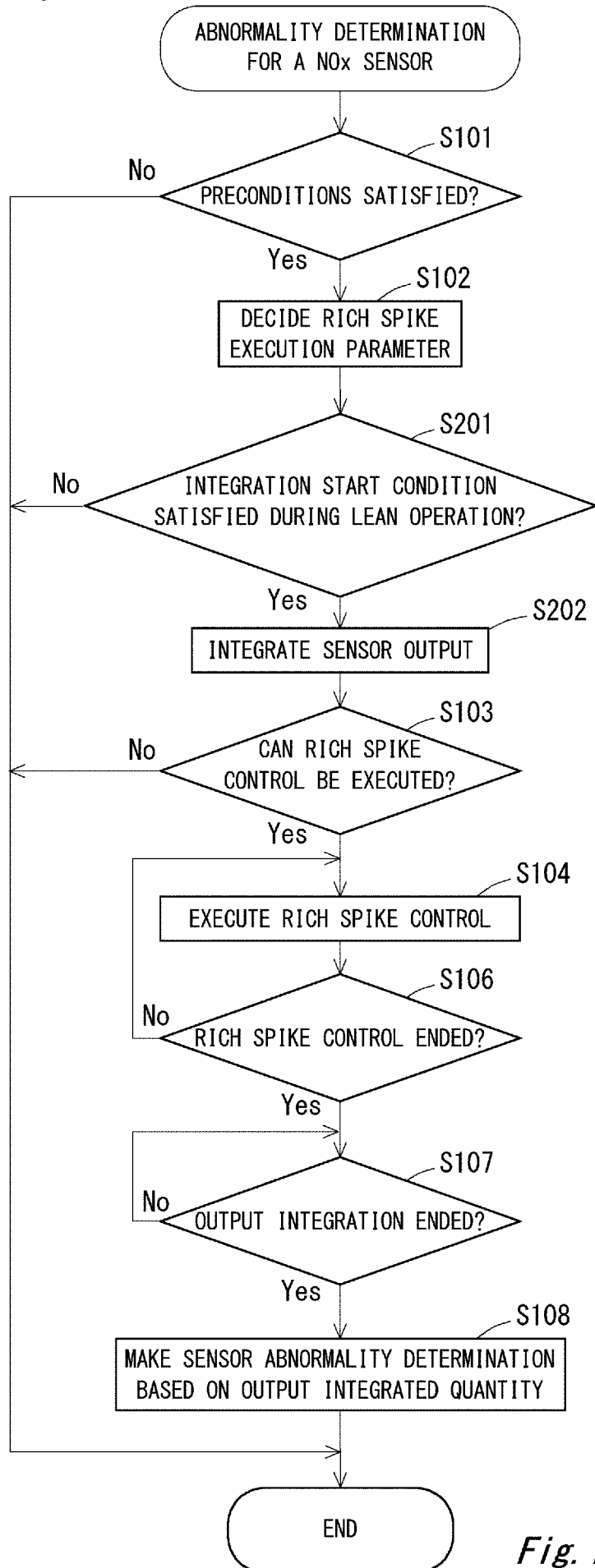
[Fig. 16]

*Fig. 16A**Fig. 16B**Fig. 16C*

[Fig. 17]



[Fig. 18]

*Fig. 18*

INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2015/003705

A. CLASSIFICATION OF SUBJECT MATTER

INV. F02D41/14 F02D41/22 F01N3/20
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F02D F01N

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 188 506 A1 (TOYOTA MOTOR CO LTD [JP]; DENSO CORP [JP]) 26 May 2010 (2010-05-26) cited in the application paragraph [0001] - paragraph [0016]; claims 1,2,10; figures 1-5 paragraph [0024] - paragraph [0026] paragraph [0031] - paragraph [0056] paragraph [0064] - paragraph [0073] paragraph [0080]	1-3
A	FR 2 818 311 A1 (SIEMENS AG [DE]) 21 June 2002 (2002-06-21) the whole document	1-11



Further documents are listed in the continuation of Box C.



See patent family annex.

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

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

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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

"&" document member of the same patent family

Date of the actual completion of the international search

15 October 2015

Date of mailing of the international search report

26/10/2015

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Fax: (+31-70) 340-3016

Authorized officer

Rocabruna Vilardell

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/JP2015/003705

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US 2011202230 A1	18-08-2011
		WO 2009022217 A1	19-02-2009

FR 2818311	A1	21-06-2002	DE 10062289 A1 04-07-2002
		FR 2818311 A1	21-06-2002
