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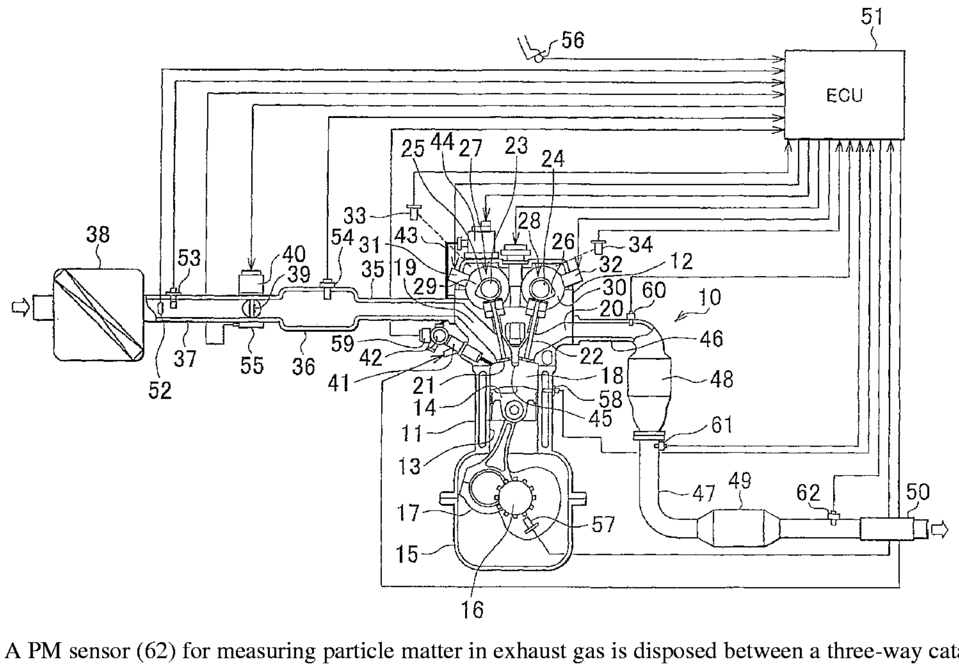
(54) Title: EXHAUST PARTICULATE MATTER MEASURING APPARATUS



(57) Abstract: A PM sensor (62) for measuring particle matter in exhaust gas is disposed between a three-way catalyst (49) and a muffler (5) in an exhaust pipe (47), and has an oxidation catalyst (71) and an electrical heater (72) that are stacked together, and a temperature sensor (73) that measures a temperature of the oxidation catalyst (71) interposed between the oxidation catalyst (71) and the electrical heater (72). The oxidation catalyst (71) carries a ceria as an oxygen-storing agent that occludes oxygen in the exhaust gas, and a ECU (51) calculates a sediment amount of the exhaust particulate matter based on an amount of temperature rise when the electrical heater (72) heats the oxidation catalyst (71) and an accumulated value of an intake air amount.

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EXHAUST PARTICULATE MATTER MEASURING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an exhaust particulate matter measuring apparatus that measures the amount of particulate matter present in exhaust gas.

2. Description of the Related Art

A conventional direct-injection type of internal combustion engine is known in which fuel is injected directly into a combustion chamber, rather than into an intake port. In this direct-injection type internal combustion engine, when the intake valve is open, air is drawn into the combustion chamber from the intake port and compressed by a piston, an injector directly injecting fuel to this high-pressure air. The high-pressure air in the combustion chamber and the fuel mist are mixed, and the resulting air-fuel mixture is ignited by a spark plug to cause an explosion to generate driving power. When the exhaust valve is open, the exhaust gas after combustion is discharged from an exhaust port.

In an internal combustion engine as mentioned above, because the exhaust gas discharged from the combustion chamber includes harmful substances such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx), a three-way catalyst is provided in the exhaust passage to purify the harmful substances. In the above-noted direct-injection type of internal combustion engine, fuel is directly injected into the air in the combustion chamber, which reaches a high temperature by high compression, and ignited. Because a large amount of fuel is injected into the combustion chamber in particular in order to raise the engine output at a high load, the combustion chamber could become oxygen-deficient and particulate matter (PM) such as black smoke might be included in the exhaust gas.

The Japanese Patent Application Publication No. JP-A-2001-221759 describes the following art for measuring the amount of such exhaust particulate matter contained in the exhaust gas in this manner. In this disclosure, a sensor for determining the soot concentration forms a soot sensor is a soot sensor in which an electrical heating member and an electrical temperature probe are provided in a porous molded member, wherein the electrical heating member combusts soot particles that have settled onto the molded member, and the generation of heat caused by the combustion is measured by the electrical temperature probe, the temperature rise being evaluated as a direct criterion using the combustion amount of the soot particles and the soot amount being determined from that evaluation.

This disclosure in the foregoing Japanese Patent Application Publication No. JP-A-2001-221759 describes the combustion of soot particles settling on a molded member using an electrical heating member, using an electrical temperature probe to measure the temperature rise when this is done, and determining the soot amount based on the temperature rise. In this case, in order to combust the soot particles that have settled on the molded member using the electrical heating member, a sufficient amount of surrounding oxygen is required. In a general internal combustion engine, however, the fuel injection amount is determined to keep the air-fuel ratio at a constant value, based on the intake air amount, and the air-fuel ratio is usually controlled to be the stoichiometric air-fuel ratio. For this reason, the problem arises that, when there is not a sufficient amount of oxygen in the area surrounding the soot sensor, even if the molded member is heated by the electrical heating member, it is not possible to properly combust the soot particles settled on the molded member, making it impossible to measure the soot amount with high accuracy.

SUMMARY OF THE INVENTION

The present invention provides an exhaust particulate matter measuring apparatus that accurately measures that amount of particulate matter present in exhaust gas.

An aspect of the present invention relates to an exhaust particulate matter measuring apparatus. The exhaust particulate matter measuring apparatus has an oxidation catalyst, disposed in an exhaust passage of an internal combustion engine; a heating means for heating the oxidation catalyst; a temperature sensor for measuring a temperature of the oxidation catalyst; and a sediment amount calculation means for calculating a sediment amount of exhaust particulate matter in response to a degree of temperature rise when the heating means heats the oxidation catalyst.

In the foregoing exhaust particulate matter measuring apparatus, the oxidation catalyst may carry an oxygen-storing agent.

According to the exhaust particulate matter measuring apparatus noted above, by carrying an oxygen-storing agent on an oxidation catalyst disposed in the exhaust passage of the internal combustion engine and providing a heating means to heat the oxidation catalyst, a temperature sensor to measure the temperature of the oxidation catalyst, and a sediment amount calculation means for calculating a sediment amount of exhaust particulate matter in response to the degree of temperature rise when the heating means heats the oxidation catalyst, the following effect is achieved. Although the oxygen-storing agent of the oxidation catalyst occludes oxygen that usually exists in the exhaust gas, when the oxidation catalyst is heated by the heating means the exhaust particulate matter captured by the oxidation catalyst is properly combusted, along with the oxygen occluded by the oxygen-storing agent, and the sediment amount calculation means can accurately calculate the sediment amount of exhaust particulate matter, in accordance with the degree of temperature rise at that time.

In the foregoing exhaust particulate matter measuring apparatus, the oxidation catalyst may be disposed downstream in an exhaust gas flow direction from a three-way catalyst disposed in the exhaust passage and upstream from a muffler disposed in the exhaust passage.

In the foregoing exhaust particulate matter measuring apparatus, the sediment amount calculation means may estimate an amount of oxygen occluded by the oxygen-storing agent based on a fuel cut control duration time of the internal combustion engine and an intake air amount, and when the amount of oxygen occluded reaches or exceeds a prescribed value, the heating means may heat the oxygen catalyst to calculate a sediment amount of exhaust particulate matter.

In the foregoing exhaust particulate matter measuring apparatus, an oxidation sensor may be disposed in the vicinity of the oxidation catalyst in the exhaust passage, the sediment amount calculation means estimates an amount of oxygen occluded by the oxygen-storing agent based on a detected result of the oxidation sensor, and when the amount of oxygen occluded reaches or exceeds a prescribed value, the heating means may heat the oxygen catalyst to calculate the sediment amount of exhaust particulate matter.

In the foregoing exhaust particulate matter measuring apparatus, the sediment amount calculation means may heat the oxidation catalyst by the heating means to calculate the sediment amount of the exhaust particulate matter when the internal combustion engine executes a fuel cut control.

In the foregoing exhaust particulate matter measuring apparatus, the sediment amount calculation means may heat the oxidation catalyst using the heating means to combust the exhaust particle matter, and when the temperature of the oxidation catalyst is as low as or lower than the temperature at which the exhaust particulate matter cannot be combusted, accumulation of the intake air amount may be started, and when the accumulated amount of intake air is larger than a prescribed value, the sediment amount calculation means may heat the oxidation catalyst using the heating means to calculate the sediment amount of the exhaust particulate matter.

The foregoing exhaust particulate matter measuring apparatus may further include an exhaust temperature sensor disposed in a vicinity of the oxidation catalyst, wherein the sediment amount calculation means, when the exhaust gas temperature reaches at least a combustion temperature at which it is possible for the exhaust particulate matter to be combusted, cancels the accumulated value of intake air amount and restarts the calculation of the intake air amount.

In the foregoing exhaust particulate matter measuring apparatus, the sediment amount calculation means prohibits rich operation of the internal combustion engine during heating the oxidation catalyst using the heating means to calculate the sediment amount of the exhaust particulate matter.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 1 is a drawing showing the general configuration of an internal combustion engine to which an exhaust particulate matter measuring apparatus according to a first embodiment of the present invention is applied;

FIG. 2 is a simplified drawing showing the exhaust particulate matter measuring apparatus according to the first embodiment;

FIG. 3 is a graph showing the relationship between the ceria additive amount and the sensor surface area in the exhaust particulate matter measuring apparatus according to the first embodiment;

FIG. 4 is graph showing the relationship between the ceria additive amount and the exhaust amount in the exhaust particulate matter measuring apparatus according to the first embodiment;

FIG. 5 is a graph showing the relationship between the heater temperature and the sensor temperature in the exhaust particulate matter measuring apparatus according to the first embodiment;

FIG. 6 is a flowchart showing the measurement control in the exhaust particulate matter measuring apparatus according to the first embodiment;

FIG. 7 is a drawing showing the general configuration of an internal combustion engine to which an exhaust particulate matter measuring apparatus according to a second embodiment of the present invention is applied;

FIG. 8 is a flowchart showing the measurement control in the exhaust particulate matter measuring apparatus according to the second embodiment of the present invention;

FIG. 9A and 9B are a flowchart showing the measurement control in an exhaust particulate matter measuring apparatus according to a third embodiment of the present invention;

FIG. 10 is a flowchart showing the measurement control in an exhaust particulate matter measuring apparatus according to a fourth embodiment of the present invention; and

FIG. 11 is a flowchart showing the measurement control in an exhaust particulate matter measuring apparatus according to a fifth embodiment of the present invention.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

Embodiments of an exhaust particulate matter measuring apparatus according to the present invention are described in detail below, making reference to accompanying drawings. It will be understood that these embodiments do not restrict the present invention.

FIG. 1 is a drawing showing the general configuration of an internal combustion engine to which an exhaust particulate matter measuring apparatus according to a first embodiment of the present invention is applied. FIG. 2 is a simplified drawing showing the exhaust particulate matter measuring apparatus according to the first embodiment. FIG. 3 is a graph showing the relationship between the ceria additive amount and the sensor surface area in the exhaust particulate matter measuring apparatus according to the first embodiment. FIG. 4 is graph showing the relationship between the ceria additive amount and the exhaust amount in the exhaust particulate matter measuring apparatus according to the first embodiment. FIG. 5 is a graph showing the relationship between the heater temperature and the sensor temperature in the exhaust particulate matter measuring apparatus according to the first embodiment. FIG. 6 is a flowchart showing the measurement control in the exhaust particulate matter measuring apparatus according to the first embodiment.

In an internal combustion engine to which the exhaust particulate matter measuring apparatus of the first embodiment is applied, as shown in FIG. 1, the engine 10 may be a four-cylinder direct-injection type engine, in which a cylinder head 12 is fitted tightly onto a cylinder block 11, wherein a pistons 14 are fitted into a plurality of cylinder bores

13 formed in the cylinder block 11 to enable up-and-down movement within the cylinder block 11. A crankcase 15 is fitted tightly to the bottom of the cylinder block 11. A crankshaft 16 is rotatably supported inside the crankcase 15, and each of the pistons 14 is linked to the crankshaft 16 via a connecting rod 17. In FIG. 1, only one cylinder and cylinder bore of four cylinders is shown.

A combustion chamber 18 is formed by the wall surface of the cylinder bore 13 of the cylinder block 11, the lower surface of the cylinder head 12, and the upper surface of the piston 14. This combustion chamber 18 is a pent-roof shaped, in which an upper part (lower surface of the cylinder head 12) is inclined so that the center part thereof is high. An intake port 19 and an exhaust port 20 are formed in the upper part of the combustion chamber 18, that is, in the lower surface of the cylinder head 12, and the lower end parts of an intake valve 21 and an exhaust valve 22 are provided at the lower ends of the intake port 19 and the exhaust port 20, respectively. The intake valve 21 and the exhaust valve 22 are supported to enable free movement along the axial direction of the cylinder head 12, and urged in the direction such that the intake port 19 and the exhaust port 20 are blocked (upward in FIG. 1). An intake camshaft 23 and an exhaust camshaft 24 are rotatably supported in the cylinder head 12, and an intake cam 25 and an exhaust cam 26 make contact with the upper end parts of the intake valve 21 and the exhaust valve 22, respectively.

Although not illustrated, an timing chain is wound around the crankshaft sprocket fixed to the crankshaft 16 and camshaft sprockets fixed, respectively, to the intake camshaft 23 and the exhaust camshaft 24, enabling the camshaft 16 to move in concert with the intake camshaft 23 and the exhaust camshaft 24.

Therefore, when the intake camshaft 23 and the exhaust camshaft 24 rotate in synchronization with the rotation of the crankshaft 16, the intake cam 25 and the exhaust cam 26 move the intake valve 21 and the exhaust valve 22 up and down with a prescribed timing to open and close the intake port 19 and the exhaust port 20. Thus, the intake port 19 communicates with the combustion chamber 18, and the combustion chamber 18 communicates with the exhaust port 20. In this case, the intake camshaft 23 and the exhaust camshaft 24 are set to make one rotation (360°) during two rotations (720°) of the crankshaft 16. For this reason, the engine 10 executes the four strokes of intake stroke, compression stroke, expansion stroke, and exhaust stroke during two rotations of the crankshaft 16, during which the intake camshaft 23 and the exhaust camshaft 24 rotate one time.

The variable-valve mechanisms of the engine 10 are intake/exhaust variable valve timing-intelligent mechanisms (hereinafter VVT mechanisms) 27, 28 that control the intake valve 21 and the exhaust valve 22 with the optimum timing, in response to an operating condition. The intake and exhaust variable valve timing mechanisms 27, 28 have VVT controllers 29, 30 on the shaft end parts of the intake camshaft 23 and the exhaust camshaft 24. Hydraulic pressure from oil control valves 31, 32 is caused to act on an advance angle chamber and a retard angle chamber (not shown) of the VVT controllers 29, 30 to change the phase of the camshafts 23, 24 with respect to the cam sprocket, thereby enabling advancing angle or retarding angle of the timing of opening and closing the intake valve 21 and the exhaust valve 22. In this case, the intake and exhaust variable valve timing mechanisms 27, 28 advance or retard the timing of opening and closing to keep the operating angle (opening time period) of the intake valve 21 and the exhaust valve 22 constant. Cam position sensors 33, 34 are provided on the intake camshaft 23 and exhaust camshaft 24 to detect the rotational phase thereof.

A surge tank 36 is connected to the intake port 19 via an intake manifold 35, and an intake pipe 37 is connected to the surge tank 36. An air cleaner 38 is mounted to an air intake port of the intake pipe 37. An electronic throttle apparatus 40 having a throttle valve 39 is provided downstream from the air cleaner 38. An injector 41 that injects fuel directly into the combustion chamber 18 is attached to the cylinder head 12, the injector 41 being positioned on the intake port 19 side and disposed at a prescribed inclination angle with respect to the up-down direction. The injectors 41 attached to each cylinder are linked to a delivery pipe 42, and a high-pressure fuel pump 44 is connected to the delivery pipe 42 via a high-pressure fuel supply pipe 43. Additionally, a spark plug 45 that ignites the air-fuel mixture is provided at the top of the combustion chamber 18 in the cylinder head 12.

An exhaust pipe (exhaust passage) 47 is connected to the exhaust port 20 via an exhaust manifold 46. Three-way catalysts 48, 49, which purify harmful substances such as HC, CO, and NOx contained in the exhaust gas, are attached to the exhaust pipe 47, and a muffler 50 is also attached to the exhaust pipe 47 further downstream from the three-way catalyst 49.

An electronic control unit 51 (hereinafter, ECU 51) that controls, for example, the injector 41 and the spark plug 45 is mounted aboard the vehicle, and an air flow sensor 52 and intake temperature sensor 53 are provided in an upstream-side of the intake pipe (intake passage) 37. An intake pressure sensor 54 is also provided in the surge tank 36, and the measured intake air amount, intake temperature, and intake pressure (intake pipe negative pressure) are output to the ECU 51. A throttle position sensor 55 is attached to the electronic throttle apparatus 40 and outputs the current throttle opening amount to the ECU 51, and an accelerator sensor 56 outputs the current accelerator depression amount to the ECU 51. Additionally, a crank angle sensor 57 outputs the detected crank angles of each cylinder to the ECU 51, and the ECU 51 distinguishes the intake stroke, the compression stroke, the expansion stroke, and the exhaust stroke in the cylinders from the detected crank angle, and also calculates the engine speed. A coolant temperature sensor 58 that detects the engine coolant temperature is provided in the cylinder block 11 and outputs the detected engine coolant temperature to the ECU 51. Also, a fuel pressure sensor 59 that detects the fuel pressure is provided in the delivery pipe 42 that communicates with the injectors 41, and outputs the detected fuel pressure to the ECU 51. Oxygen sensors 60, 61 that detect oxygen concentration of the exhaust gas are provide upstream and downstream from the three-way catalyst 48 in the exhaust pipe 47, and output the detected oxygen concentrations to the ECU 51.

The ECU 51, therefore, drives the high-pressure pump 44 to achieve a prescribed fuel pressure based on the detected fuel pressure, determines such items as the fuel injection amount (fuel injection time), the fuel injection timing, and the ignition timing, based on the engine operating conditions such as the detected intake air amount, intake air temperature, intake air pressure, throttle opening amount, accelerator depression amount, engine speed, and engine coolant temperature, and drives the injector 41 and spark plug 45 to execute fuel injection and ignition. The ECU 51 executes a feedback control based on the oxygen concentration of the detected exhaust gas so as to correct the fuel injection amount to achieve a stoichiometric air-fuel ratio.

The ECU 51 controls the intake and exhaust variable valve timing mechanisms 27, 28 based on the engine operating condition. Specifically, when the engine is started at a low temperature, and during idling or light-load operation, by eliminating overlap between the period of time the exhaust valve 22 is closed and the period of time the intake valve 21 is open, it is possible to reduce the amount of blowback of exhaust gas to intake port 19 or the combustion chamber 18 and to improve combustion stability and fuel economy. At a medium load, by making this overlap large, the internal EGR ratio is increased and the exhaust gas purification efficiency is improved, and it is also possible to reduce the pumping loss and improve the fuel economy. Additionally, at a high load and low-speed to mid-speed, by advancing the closing time of the intake valve 21, the amount of blowback of the intake to the intake port 19 is reduced, and the volumetric efficiency is improved. At a high load and high-speed, by retarding the closing timing of the intake valve 21 in accordance with the engine speed, the volumetric efficiency is improved, with timing adjusted to the momentum force of the intake air.

In the engine 10 of this embodiment, a PM (particulate matter) sensor 62 that measures the amount of particulate matter in the exhaust gas, specifically the amount of particulate matter such as black smoke, is provided between the three-way catalyst 49 and the muffler 50 in the exhaust pipe 47. The PM sensor 62, as shown in FIG. 2, is box-shaped, and has an oxidation catalyst 71 and an electrical heater 72 that heats the oxidation catalyst 71, the oxidation catalyst 71 and electrical heater 72 that are stacked together. A temperature sensor 73 that measures the temperature of the oxidation catalyst 71 is interposed between the oxidation catalyst 71 and the electrical heater 72.

The oxidation catalyst 71 has formed in it, for example, a large number of exhaust flow passages by making a ceramic porous, wherein a metal such as platinum or palladium is carried as the catalytic metal of the oxidation catalyst 71. The oxidation catalyst 71 carries ceria as an oxygen-storing agent that occludes oxygen contained in the exhaust gas. In this case, the amount of ceria additive, as shown in FIG. 3, is set in accordance with the surface area of the PM sensor 62 (oxidation catalyst 71) and, as shown in FIG. 4, is set in accordance with the displacement of the engine 10.

The PM sensor 62, therefore, converts HC and CO components in the exhaust gas by oxidation (reaction with oxygen) to CO_2 and H_2O and, by passing the exhaust gas through the porous member, and captures particulate matter, and in particular smoke particles in the exhaust gas. Because the oxidation catalyst 71 carries ceria, it can occlude oxygen in the exhaust gas. With exhaust particulate matter captured by the PM sensor 62 and settled up to a prescribed amount and also when the occluded oxygen amount in the oxidation catalyst 71 is sufficient, when the electrical heater 72 is electrically powered to heat the oxidation catalyst 71, the exhaust particulate matter sediment is combusted using the oxygen that is occluded in the ceria, the ECU 51, as a sediment amount calculation means, calculates the sediment amount of the exhaust particulate matter in accordance with the degree of temperature rise at that time.

That is, because the oxidation catalyst 71 is heated when the electrical heater 72 is electrically powered, with an increase in temperature of the heater, the temperature of the oxidation catalyst 71 detected by the temperature sensor (sensor temperature) increases proportionately, as indicated by the solid line in FIG. 5. When this occurs, if exhaust particulate matter has settled in the oxidation catalyst 71, by combusting the exhaust particulate matter at the point at which the temperature of the oxidation catalyst 71 rises to a temperature at which it is possible to combust the exhaust particulate matter, the temperature of the oxidation catalyst 71 detected by the temperature sensor (sensor temperature) rises suddenly, as shown by the single-dot-dash line in FIG. 5. Then, when all of the exhaust particulate matter in the oxidation catalyst 71 is combusted, the sensor temperature drops suddenly. Therefore, a prescribed map based on the intake air amount during the period of time of capture of exhaust particulate matter by the oxidation catalyst 71 of the PM sensor 62 and the amount of temperature rise at that time can be used to calculate the sediment amount of exhaust particulate matter.

The PM sensor 62 is disposed downstream from three-way catalyst 49 disposed in the exhaust pipe 47 in the exhaust gas flow direction and also upstream from the muffler 50 in the exhaust gas flow direction. In this case, when the engine 10 is operating under a high load, because the exhaust gas temperature rises to 650 °C or greater, at which the exhaust particulate matter is combusted, even the exhaust particulate matter settled in the PM sensor 62 is combusted by the high-temperature exhaust gas, making it impossible to measure the sediment amount. Given this, the PM sensor 62 is disposed at a downstream location a prescribed distance from three-way catalyst 49 in the exhaust gas flow direction, at which the exhaust gas temperature is reduced to a temperature, for example 600 °C, at which the exhaust particulate matter can not be combusted. Because the downstream portion of the exhaust pipe 47 is exposed to the atmosphere, condensed water may come in contact with the PM sensor 62 when the engine 10 is cold-started and damage the sensor. Thus, the PM sensor 62 is disposed at prescribed distance upstream from the muffler 50 attached to the end part of the exhaust pipe 47 in the exhaust gas flow direction.

The method of measuring the exhaust particulate matter with the exhaust particulate matter measuring apparatus according to this embodiment is described in detail below, with reference being made to the flowchart of FIG. 6.

At step S11, the ECU 51 determines whether the engine 10 is warmed-up. That is, the ECU 51 determines whether the engine coolant temperature detected by the coolant temperature sensor 58 has reached at least a prescribed engine warm-up coolant temperature. At this point, if the determination is made that the engine coolant temperature has not reached the engine warm-up coolant temperature, nothing is done and the routine ends. If, however, the determination is made that the engine coolant temperature has reached at least the engine warm-up coolant temperature, the process then proceeds to step S12.

At step S12, the ECU 51 electrically powers the electrical heater 72 in the PM sensor 62 to heat the oxidation catalyst 71, thereby combusting the exhaust particulate matter settled in the oxidation catalyst 71. Then, at step S13 a determination is made of whether the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted. In this case, although when electrical heater 72 is electrically powered, the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 is combusted, and the temperature of the oxidation catalyst 71 (sensor temperature) rises suddenly indicated by the single-dot-dash line in FIG. 5, when all of the exhaust particulate matter is combusted, the sensor temperature drops suddenly, and returns to the change indicated by the solid line in FIG. 5. The ECU 51 determines whether the exhaust particulate matter has been completed combusted, based on this change in the sensor temperature. The processing of steps S12 and S13 is repeated until the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 is determined at step S13 to have been completed combusted.

If the determination is made at step S13 that the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted, at step S14 the ECU 51 stops the electrical power to the electrical heater 72 in the PM sensor 62. Then, at step S15 the temperature sensor 73 measures the temperature of the oxidation catalyst 71, and at step S16 a determination is made as to whether the temperature t_{PM} of the oxidation catalyst 71 measured by the temperature sensor 73 is as low as or lower than the temperature t_A at which the exhaust particulate matter cannot be combusted. The processing of steps S15 and S16 is repeated until a determination is made at step S16 that the temperature t_{PM} of the oxidation catalyst 71 has decreased to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted.

If the determination is made at step S16 that the temperature t_{PM} of the oxidation catalyst 71 has decreased to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted, at step S17 accumulation of the intake air amount is started. In this case, the intake air amount detected by the air flow sensor 52 is accumulated from the point at which the temperature t_{PM} of the oxidation catalyst 71 has decreased to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted. At step S18, a determination is made of whether the accumulated amount of intake air Σga is larger than a prescribed value A. The processing of steps S17 and S18 is repeated until the determination is made at step S18 that the accumulated amount of intake air Σga has become greater than the prescribed value A.

If the determination is made at step S18 that the accumulated amount of intake air Σga has become greater than the prescribed value A, at step S19 the ECU 51 determines whether oxygen is present in the area surrounding the PM sensor 62. In this embodiment, because ceria is carried by the oxidation catalyst 71 of the PM sensor 62, after the temperature t_{PM} of the oxidation catalyst 71 decreases to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted, during a prescribed air amount accumulation time period after the start of accumulation of the intake air amount detected by the air flow sensor 52, a determination is made of whether the environment surrounding the ceria of the oxidation catalyst 71 is one that enables the occlusion of oxygen. That is, during this air amount accumulation time period, the oxygen occlusion amount of the ceria is estimated by determining whether the fuel cut control duration time or accumulation time has reached or exceeded a prescribed time and also the accumulated intake air amount has reached or exceeded a prescribed accumulated value.

If, at step S19, if the fuel cut control duration time or accumulation time has not reached or exceeded a prescribed time or the accumulated intake air amount has not reached or exceeded a prescribed accumulated value, the determination is made that the ceria of the oxidation catalyst 71 has not occluded a sufficient amount of oxygen, and the processing of steps S17 to S19 is repeated. If, however, at step 19, the fuel cut control duration time or accumulation time has reached or exceeded a prescribed time and also the accumulated intake air amount has reached or exceeded a prescribed accumulated value, the determination is made that the ceria of the oxidation catalyst 71 has occluded a sufficient amount of oxygen, and processing proceeds to step S20.

Then, at step S20, the ECU 51 electrically powers the electrical heater 72 in the PM sensor 62 to heat the oxidation catalyst 71, thereby combusting the exhaust particulate matter settled in the oxidation catalyst 71. At step S21, the sediment amount of the exhaust particulate matter is calculated in accordance with the degree of temperature rise in the oxidation catalyst 71 at that time. That is, the sediment amount of the exhaust particulate matter is calculated using a prescribed map based on the accumulated intake air amount measured during the above-noted period of time of accumulation of intake air amount and the amount of temperature rise in the oxidation catalyst 71 detected by the temperature sensor 73.

At step S22, a determination is made of whether, by completely combusting the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62, the calculation of the sediment amount of the exhaust particulate matter has ended. In this case, the determination of ending is made by the decrease of the temperature (sensor temperature) of the oxidation catalyst 71 that had risen suddenly by the combustion of exhaust particulate matter settled in the oxidation catalyst 71, and return to the change indicated by the solid line in FIG. 5. The processing of steps S20 to S22 is repeated until the determination is made at step S22 that the processing to calculate the sediment amount of the exhaust particulate matter has ended.

Therefore, when the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 is combusted and the sediment amount of exhaust particulate matter is calculated based on the change in temperature at that time, even if oxygen is not present in the exhaust gas flowing around the oxidation catalyst 71, it is possible to use the oxygen occluded by the ceria to reliably combust the exhaust particulate matter, thereby enabling proper calculation of the sediment amount of the exhaust particulate matter.

After the above, when the determination is made at step S22 that the calculation of the sediment amount of exhaust particulate matter has ended, at step S23 the ECU 51 stops electrical power to the electrical heater 72 in the PM sensor 62, and all processing is ended.

In this manner, the exhaust particulate matter measuring apparatus of the first embodiment is configured to provide, between the three-way catalyst 49 and the muffler 50 in the exhaust pipe 47, a PM sensor 62 that measures the amount of particulate matter in the exhaust gas, the PM sensor 62 being fixed by stacking the oxidation catalyst 71 and the electrical heater 72 together, and a temperature sensor 73 that measures the temperature of the oxidation catalyst 71 being interposed between the oxidation catalyst 71 and the electrical heater 72. The oxidation catalyst 71 carries ceria as an oxygen-storing agent that occludes oxygen in the exhaust gas, and the ECU 51 calculates the sediment amount of the exhaust particulate matter based on the amount of temperature rise when the electrical heater 72 heats the oxidation catalyst 71, and the accumulated intake air amount.

Therefore, the ceria in the oxidation catalyst 71 constantly occludes oxygen present in the exhaust gas and, when the oxidation catalyst 71 is heated by the electrical heater 72, the exhaust particulate matter settled in the oxidation catalyst 71 can be properly combusted with the oxygen occluded in the ceria, and the ECU 51 accurately calculates the sediment amount of exhaust particulate matter, based on the amount of temperature rise at this time and the accumulate value of intake air amount. As a result, even if the engine 10 is operating at a stoichiometric air-fuel ratio (theoretical air-fuel ratio), because the ceria of the oxidation catalyst 71 reliably occludes oxygen mixed with the exhaust gas during fuel cut control, for example, it is possible to reliably calculate the sediment amount of the exhaust particulate matter.

By the ECU 51 electrically powering the electrical heater 72 in the PM sensor 62 to heat the oxidation catalyst 71, if the temperature t_{PM} of the oxidation catalyst 71 decreases to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted, the processing to accumulate the intake air amount detected by the exhaust air flow sensor 52 is started. It is therefore possible before measurement to combust the exhaust particulate matter settled in the oxidation catalyst 71, and also possible to reduce measurement error by decreasing the temperature of the oxidation catalyst 71 to a temperature at which the exhaust particulate matter is not combusted.

Additionally, by determining whether the fuel cut control duration time or accumulation time has reached or exceeded a prescribed time and also whether the accumulated intake air amount has reached or exceeded a prescribed accumulated value, during the prescribed intake air amount accumulation time after the start of accumulation of intake air amount detected by the air flow sensor 52, the ECU 51 estimates the amount of oxygen occluded by the ceria. Therefore, estimation of the amount of oxygen occluded by the ceria based on the fuel cut control and intake air amount, makes it possible to properly execute the calculation of the sediment amount of exhaust particulate matter.

In this embodiment, the PM sensor 62 is disposed downstream from three-way catalyst 49 disposed in the exhaust pipe 47 in the exhaust gas flow direction and also upstream from the muffler 50 in the exhaust gas flow direction. Therefore, even if the engine 10 is operated at a high load and the exhaust gas temperature rises to 650 °C or greater, at which the exhaust particulate matter is combusted, before the exhaust gas reaches the PM sensor 62 the temperature thereof decreases to a temperature at which exhaust particulate matter cannot be combusted, thereby enabling proper calculation of the sediment amount of exhaust particulate matter. Also, even if the engine 10 is cold started, condensed water does not reach the PM sensor 62, thereby preventing damage thereto.

FIG. 7 is a drawing showing the general configuration of an internal combustion engine to which an exhaust particulate matter measuring apparatus according to the second embodiment of the present invention is applied and FIG. 8 is a flowchart showing the measurement control in the exhaust particulate matter measuring apparatus according to the second embodiment of the present invention. Members of the second embodiment having the same function as members described with regard to the first embodiment are referred to by the same numerals and are not repeatedly herein.

In the exhaust particulate matter measuring apparatus of the second embodiment, as shown in FIG. 7, because the basic configuration of the engine 10 is substantially the same as in the above-described first embodiment, the description thereof will be omitted. In this embodiment, the PM sensor 62 that measures the amount of particulate matter in the exhaust gas is provided between the three-way catalyst 49 and the muffler 50 in the exhaust pipe 47. This PM sensor 62, as shown in FIG. 2, has an oxidation catalyst 71 and an electrical heater 72, and a temperature sensor 73, and the oxidation catalyst 71 carries ceria, which occludes oxygen in the exhaust gas. In this embodiment, an oxygen sensor (O_2 sensor) 63 is disposed in the vicinity of the PM sensor 62.

The PM sensor 62, therefore, can capture particulate matter, particularly particles of soot, in the exhaust gas that flows through the exhaust pipe 47, and the oxidation catalyst 71 carries ceria, which can occlude the oxygen in the exhaust gas. With exhaust particulate matter captured by the PM sensor 62 and settled up to a prescribed amount and also when the occluded oxygen amount in the oxidation catalyst 71 is sufficient, based on the detection result of the oxygen sensor 63, when the electrical heater 72 is electrically powered to heat the oxidation catalyst 71, the exhaust particulate matter sediment is combusted using the oxygen that is occluded in the ceria by heating the oxidation catalyst 71, the ECU 51, as a sediment amount calculation means, calculates the sediment amount of the exhaust particulate matter in accordance with the degree of temperature rise at that time.

The method of measuring the exhaust particulate matter with the exhaust particulate matter measuring apparatus according to the second embodiment is described in detail below, with reference being made to the flowchart of FIG. 8.

At step S31, a determination is made of whether the engine 10 is completed warmed-up, that is, whether the engine coolant temperature detected by the coolant temperature sensor 58 is at least a prescribed engine warm-up coolant temperature. At this point, if the determination is made that the engine coolant temperature has reached the engine warm-up coolant temperature, at step S32, the electrical heater 72 in the PM sensor 62 is electrically powered to heat the oxidation catalyst 71, thereby combusting the exhaust particulate matter settled in the oxidation catalyst 71. Then, at step S33, a determination is made of whether the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted, based on the temperature change of the oxidation catalyst 71.

If the determination is made at step S33 that the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted, at step S34 the electrical power to the electrical heater 72 in the PM sensor 62 is stopped. Then, at step S35 the temperature sensor 73 measures the temperature of the oxidation catalyst 71, and, at step S36, a determination is made as to whether the temperature t_{PM} of the oxidation catalyst 71 measured by the temperature sensor 73 is as low as or lower than the temperature t_A at which the exhaust particulate matter cannot be combusted. If the determination is made that the temperature t_{PM} of the oxidation catalyst 71 has decreased to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted, at step S37 accumulation of the intake air amount is started. Then, at step S38, a determination is made of whether the accumulated amount of intake air Σga is larger than a prescribed value A.

If the determination is made at step S38 that the accumulated amount of intake air Σga has become greater than the prescribed value A, at step S39 a determination is made of whether oxygen is present in the area surrounding the PM sensor 62. In this embodiment, because the oxidation catalyst 71 of the PM sensor 62 carries ceria, after the temperature t_{PM} of the oxidation catalyst 71 decreases to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted, during a prescribed air amount accumulation time period after the start of accumulation of the intake air amount detected by the air flow sensor 52, a determination is made of whether the environment surrounding the ceria of the oxidation catalyst 71 is one that enables the occlusion of oxygen. That is, during this air amount accumulation time period, the amount of oxygen occluded by the ceria is estimated based on the history of the oxygen sensor 63 detecting oxygen.

In general, an oxygen sensor 63 detects the oxygen concentration based on an electromotive force generated in response to the oxygen concentration in the exhaust gas. That is, when exhaust gas is introduced into the internal detection element, a difference in oxygen concentration occurs between the inside platinum electrode and the outside platinum electrode, and oxygen ions flow from the inside platinum electrode, which has a high oxygen concentration, through a solid-state zirconia electrolyte, to the outside platinum electrode, which has a low oxygen concentration, thereby generating an electromotive force. In this case, if combustion is done with a rich air-fuel mixture, because the amount of oxygen remaining in the exhaust gas is small, by the catalytic action of the outside platinum electrode a very small amount of oxygen reacts with carbon monoxide and hydrocarbons in the exhaust gas, thereby removing almost all the oxygen from the surface of the outside platinum electrode, the oxygen concentration difference between the outside platinum electrode and the inside platinum electrode becoming large, and a large electromotive force being generated. In contrast, if combustion is done with a lean air-fuel mixture, because a large amount of oxygen remains in the exhaust gas, by the catalytic action of the outside platinum electrode a large amount of oxygen reacts a very small amount of carbon monoxide and hydrocarbons in the exhaust gas, resulting in excess oxygen remaining at the surface of the outside platinum electrode, the oxygen concentration difference between the outside platinum electrode and the inside platinum electrode becoming small, so that almost no electromotive force is generated. For this reason, there is a great change in the size of the generated electromotive force occurring at the stoichiometric air-fuel ratio as a boundary, and the oxygen concentration can be detected by using this electromotive force.

Therefore, at step S39, if, in the air amount accumulation time, based on the electromotive force generated at the oxygen sensor 63, the time during which the exhaust gas is in the lean condition has reached at least a prescribed period of time, the determination is made that the ceria of the oxidation catalyst 71 has occluded a sufficient amount of oxygen. When the determination is made that the ceria of the oxidation catalyst 71 has occluded a sufficient amount of oxygen, based on the detection result from the oxygen sensor 63, processing proceeds to step S40.

Then, at step S40, the electrical heater 72 in the PM sensor 62 is electrically powered to heat the oxidation catalyst 71, thereby combusting the exhaust particulate matter settled in the oxidation catalyst 71. Then, at step S41, the sediment amount of the exhaust particulate matter is calculated in accordance with the degree of temperature rise in the oxidation catalyst 71 at that time. That is, the sediment amount of the exhaust particulate matter is calculated using a map of the accumulated intake air amount measured during the above-noted period of time of accumulation of intake air amount and the amount of temperature rise in the oxidation catalyst 71 detected by the temperature sensor 73. At step S42, a determination is made of whether, by completely combusting the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62, the calculation of the sediment amount of the exhaust particulate matter has ended.

Therefore, when the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 is combusted and the sediment amount of exhaust particulate matter is calculated based on the change in temperature at that time, even if oxygen is not present in the exhaust gas flowing in the area around the oxidation catalyst 71, the oxygen occluded by the ceria can be used to reliably combust the exhaust particulate matter, thereby enabling proper calculation of the sediment amount of the exhaust particulate matter.

After the above, when the determination is made at step S42 that the calculation of the sediment amount of exhaust particulate matter has ended, at step S43 the electrical power to the electrical heater 72 in the PM sensor 62 is stopped, and all processing is ended.

In this manner, the exhaust particulate matter measuring apparatus of the second embodiment is configured to provide, in the exhaust pipe 47, a PM sensor 62 that measures the amount of particulate matter in the exhaust gas, the PM sensor 62 being fixed by stacking the oxidation catalyst 71 and the electrical heater 72 together, and a temperature sensor 73 that measures the temperature of the oxidation catalyst 71 being interposed between the oxidation catalyst 71 and the electrical heater 72. The oxidation catalyst 71 carries ceria as an oxygen-storing agent that occludes oxygen in the exhaust gas, and the ECU 51 determines, based on the detection result from the oxygen sensor 63, whether the ceria has occluded a sufficient amount of oxygen and, when the determination is made that the ceria has occluded a sufficient amount of oxygen, the ECU 51 calculates the sediment amount of the exhaust particulate matter based on the amount of temperature rise when the oxidation catalyst 71 is heated by the electrical heater 72, and the accumulated intake air amount.

Therefore, the ceria in the oxidation catalyst 71 constantly occludes oxygen present in the exhaust gas and verification can be made, based on the detection result from the oxygen sensor 63, of whether the ceria has occluded a sufficient amount of oxygen. When this is done, when the oxidation catalyst 71 is heated by the electrical heater 72, the exhaust particulate matter settled in the oxidation catalyst 71 can be properly combusted with the oxygen occluded in the ceria, and the ECU 51 accurately calculates the sediment amount of exhaust particulate matter, based on the amount of temperature rise at this time and the accumulate value of intake air amount. As a result, even if the engine 10 is operating at a stoichiometric air-fuel ratio (theoretical air-fuel ratio), because oxygen mixed with the exhaust gas is reliably occluded by the ceria of the oxidation catalyst 71 during fuel cut control, for example, it is possible to reliably calculate the sediment amount of the exhaust particulate matter.

FIG. 9A and 9B are a flowchart of the measurement control of the exhaust particulate matter measuring apparatus according to the third embodiment of the present invention. The overall constitution of the exhaust particulate matter measuring apparatus of the third embodiment is substantially the same as that of the above-described embodiments. The third embodiment will be described using FIG. 1 and FIG. 2, and members having the same function as those members of the first and second embodiments already are referred to by the same numerals and are not repeatedly described herein.

In the exhaust particulate matter measuring apparatus of the third embodiment, as shown in FIG. 1 and FIG. 2, because the basic configuration of the engine 10 is substantially the same as in the above-described first embodiment, the description thereof will be omitted. In this embodiment, the PM sensor 62 that measures the amount of particulate matter in the exhaust gas is provided between the three-way catalyst 49 and the muffler 50 in the exhaust pipe 47. This PM sensor 62, as shown in FIG. 2, has an oxidation catalyst 71 and an electrical heater 72, and the temperature sensor 73, and the oxidation catalyst 71 carries ceria, which occludes oxygen in the exhaust gas. In this embodiment, a temperature sensor 73 that detects the temperature within the PM sensor 62 is applied as an exhaust temperature sensor to measure the exhaust gas temperature.

Therefore, the PM sensor 62 can capture particulate matter, and particularly soot particles, in the exhaust gas flowing through the exhaust pipe 47, and the ceria carried by the oxidation catalyst 71 can occlude oxygen in the exhaust gas. With exhaust particulate matter captured by the PM sensor 62 and settled up to a prescribed amount and also a sufficient amount of oxygen occluded in the oxidation catalyst 71, when the electrical heater 72 is electrically powered to heat the oxidation catalyst 71, the exhaust particulate matter sediment is combusted using the oxygen that is occluded in the ceria, the ECU 51, as a sediment amount calculation means, calculates the sediment amount of the exhaust particulate matter in accordance with the degree of temperature rise at that time. This embodiment cancels the accumulated amount of air intake and re-starts the accumulation of the intake air amount when the temperature of the exhaust gas detected by the temperature sensor 73 reaches at least the combustion temperature at which the exhaust particulate matter can be combusted.

The method of measuring the exhaust particulate matter with the exhaust particulate matter measuring apparatus according to the third embodiment is described in detail below, with reference being made to the flowchart of FIG. 9A and 9B.

At step S51, a determination is made of whether the engine 10 is completed warmed-up, that is, whether the engine coolant temperature detected by the coolant temperature sensor 58 is at least a prescribed engine warm-up coolant temperature. At this point, if the engine coolant temperature has reached the engine warm-up coolant temperature, at step S52, the electrical heater 72 in the PM sensor 62 is electrically powered to heat the oxidation catalyst 71, thereby combusting the exhaust particulate matter settled in the oxidation catalyst 71. Then, at step S53, a determination is made of whether the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted, based on the temperature change in the oxidation catalyst 71.

If the determination is made at step S53 that the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted, at step S54 the electrical power to the electrical heater 72 in the PM sensor 62 is stopped. Then, at step S55 the temperature sensor 73 measures the temperature of the oxidation catalyst 71, and, at step S56, a determination is made as to whether the temperature t_{PM} of the oxidation catalyst 71 measured by the temperature sensor 73 is as low as or lower than the temperature t_A at which the exhaust particulate matter cannot be combusted. If the determination is made at this point that the temperature t_{PM} of the oxidation catalyst 71 has decreased to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted, at step S57 accumulation of the intake air amount is started. Then, at step S58, a determination is made of whether the accumulated amount of intake air Σga is larger than a prescribed value A.

If the determination is made at step S58 that the accumulated amount of intake air Σga has become greater than the prescribed value A, at step S59 a determination is made of whether oxygen is present in the area surrounding the PM sensor 62. In this embodiment, after the temperature t_{PM} of the oxidation catalyst 71 decreases to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted, during a prescribed air amount accumulation time period after the start of accumulation of the intake air amount detected by the air flow sensor 52, a determination is made of whether the fuel cut control duration time or accumulation time has reached or exceeded a prescribed time and also the accumulated amount of intake air has reached or exceeded a prescribed amount, thereby estimating the amount of oxygen occluded by the ceria.

At step S59, when the fuel cut control duration time or accumulation time reaches or exceeds a prescribed time and also the accumulated value of intake air amount reaches or exceeds a prescribed value, the determination is made that the ceria of the oxidation catalyst 71 has occluded a sufficient amount of oxygen, and processing proceeds to step S60. At step S60, a determination is made of whether the exhaust gas temperature detected by the temperature sensor 73 is at least a prescribed value and also the temperature of the gas flowing in the region of the PM sensor 62 is at least the temperature at which the exhaust particulate matter settled in the oxidation catalyst 71 can be combusted. At this point, if the temperature of the exhaust gas passing through the region surrounding the PM sensor 62 that is detected by the temperature sensor 73 is determined to be at least the combustion temperature at which it is possible to combust the exhaust particulate matter, at step S61 the accumulated value of intake air amount calculated by the processing of step S57 is canceled, return is made to step S55, and the processing of step S55 and thereafter is performed to again accumulate the intake air amount.

That is, when the exhaust gas temperate detected by the temperature sensor 73 is at least the combustion temperature at which the exhaust particulate matter can be combusted, the exhaust particulate matter settled in the operating angle is combusted by the high-temperature exhaust gas, so that there is a mismatch between the accumulated value of intake air amount and the sediment amount of exhaust particulate matter, making it impossible to accurately measure the sediment amount of exhaust particulate matter. For this reason, when this occurs, the accumulated value of intake air amount that is held is canceled, and the accumulation of intake air amount is performed again.

However, if at step S60 the temperature of the exhaust gas passing through the region surrounding the PM sensor 62 detected by the temperature sensor 73 is determined to be not as high as the combustion temperature at which the exhaust particulate matter can be combusted, at step S62 the electrical heater 72 of the PM sensor 62 is electrically powered to heat the oxidation catalyst 71 to combust the exhaust particulate matter settled in the oxidation catalyst 71. Then, at step S63, the sediment amount of exhaust particulate matter is calculated in accordance with the degree of temperature rise of the oxidation catalyst 71 at that time. At step S64, a determination is made of whether the processing to calculate the sediment amount of the exhaust particulate matter has ended, by complete combustion of the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62.

Therefore, when the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 is combusted, when the sediment amount of exhaust particulate matter is calculated based on the temperature at that time, if the exhaust gas temperature detected by the temperature sensor 73 is at least as high as the combustion temperature at which the exhaust particulate matter can be combusted, by canceling the already-calculated accumulated value of intake air amount and executing accumulation of the intake air amount anew, a proper calculation is performed of the sediment amount exhaust particulate matter.

After the above, at step S64, if the determination is made that the processing to calculate the sediment amount of the exhaust particulate matter has ended, at step S65 the electrical power to the electrical heater 72 of the PM sensor 62 is stopped, and the ECU 51 ends all processing.

In this manner, the exhaust particulate matter measuring apparatus according to the third embodiment is configured to provide in the exhaust pipe 47 a PM sensor 62 that measures the amount of particulate matter in the exhaust gas, the PM sensor 62 being fixed by stacking the oxidation catalyst 71 and the electrical heater 72 together, and a temperature sensor 73 that measures the temperature of the oxidation catalyst 71 being interposed between the oxidation catalyst 71 and the electrical heater 72. The oxidation catalyst 71 carries ceria as an oxygen-storing agent that occludes oxygen in the exhaust gas. When the ceria occludes a sufficient amount of oxygen and also the exhaust gas temperature has not reached the combustion temperature at which the exhaust particulate matter can be combusted, the ECU 51 heats the oxidation catalyst 71 using the electrical heater 72 and calculates the sediment amount of exhaust particulate matter based on the amount of temperature rise at that time and the accumulated value of the intake air amount.

Therefore, the ceria in the oxidation catalyst 71 constantly occludes oxygen present in the exhaust gas. When verification is made that the ceria has occluded a sufficient amount of oxygen and the temperature of the exhaust gas passing through the region surrounding the oxidation catalyst 71 is verified as not having reached the combustion temperature at which the exhaust particulate matter can be combusted, the oxidation catalyst 71 is heated by the electrical heater 72, the exhaust particulate matter settled in the oxidation catalyst 71 can be properly combusted with the oxygen occluded in the ceria, and the ECU 51 accurately calculates the sediment amount of exhaust particulate matter, based on the amount of temperature rise at this time and the accumulate value of intake air amount. However, if the temperature of the exhaust gas flowing through the region surrounding the oxidation catalyst 71 is at least the combustion temperature at which the exhaust particulate matter can be combusted, the held accumulated value of intake air amount is canceled, and the accumulation of the intake air amount is redone, thereby enabling a proper determination of the sediment amount of exhaust particulate matter with respect to the accumulated value of intake air amount. As a result, even if the engine 10 is operating at a stoichiometric air-fuel ratio (theoretical air-fuel ratio), because oxygen mixed with the exhaust gas is reliably occluded by the ceria of the oxidation catalyst 71 during fuel cut control, for example, it is possible to reliably calculate the sediment amount of the exhaust particulate matter.

FIG. 10 is a flowchart of the measurement control of the exhaust particulate matter measuring apparatus according to the fourth embodiment of the present invention. The overall constitution of the exhaust particulate matter measuring apparatus of the fourth embodiment is substantially the same as that of the first embodiment. The fourth embodiment will be described using FIG. 1 and FIG. 2, and members having the same function as those members of embodiments already described are referred to by the same numerals and are not repeatedly described herein.

In the exhaust particulate matter measuring apparatus of the fourth embodiment, as shown in FIG. 1 and FIG. 2, because the basic configuration of the engine 10 is substantially the same as in the above-described first embodiment, the description thereof will be omitted. In this embodiment, the PM sensor 62 that measures the amount of particulate matter in the exhaust gas is provided between the three-way catalyst 49 and the muffler 50 in the exhaust pipe 47. The PM sensor 62, as shown in FIG. 2, has an oxidation catalyst 71 and an electrical heater 72, although the oxidation catalyst 71 does not carry ceria.

Therefore, the PM sensor 62 can capture particulate matter, and particularly soot particles, in the exhaust gas flowing through the exhaust pipe 47. With exhaust particulate matter captured by the PM sensor 62 and settled up to a prescribed amount and also a sufficient amount of oxygen included in the exhaust gas, when the electrical heater 72 is electrically powered to heat the oxidation catalyst 71, the settled exhaust particulate matter sediment is combusted using the oxygen that is included in the exhaust gas, the ECU 51 calculates the sediment amount of the exhaust particulate matter in accordance with the degree of temperature rise at that time.

The method of measuring the exhaust particulate matter with the exhaust particulate matter measuring apparatus according to the fourth embodiment is described in detail below, with reference being made to the flowchart of FIG. 10.

At step S71, a determination is made of whether the engine 10 is completely warmed-up, that is, whether the engine coolant temperature detected by the coolant temperature sensor 58 is at least a prescribed engine warm-up coolant temperature. At this point, if the engine coolant temperature has reached the engine warm-up coolant temperature, at step S72, the electrical heater 72 in the PM sensor 62 is electrically powered to heat the oxidation catalyst 71, thereby combusting the exhaust particulate matter settled in the oxidation catalyst 71. Then, at step S73, a determination is made of whether the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted, based on the temperature change in the oxidation catalyst 71.

If the determination is made at step S73 that the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted, at step S74 the electrical power to the electrical heater 72 in the PM sensor 62 is stopped. Then, at step S75 the temperature sensor 73 measures the temperature of the oxidation catalyst 71, and, at step S76, a determination is made as to whether the temperature t_{PM} of the oxidation catalyst 71 measured by the temperature sensor 73 is as low as or lower than the temperature t_A at which the exhaust particulate matter cannot be combusted. If the determination is made at this point that the temperature t_{PM} of the oxidation catalyst 71 has decreased to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted, at step S77 accumulation of the intake air amount is started. Then, at step S78, a determination is made of whether the accumulated amount of intake air Σga is larger than a prescribed value A.

If the determination is made at step S78 that the accumulated amount of intake air Σga has become greater than the prescribed value A, at step S79 a determination is made of whether oxygen is present in the area surrounding the PM sensor 62. In this embodiment, a determination is made as to whether fuel cut control is in progress to estimate whether oxygen is present in the exhaust gas.

If execution of fuel cut control is in progress at step S79, the determination is made that sufficient oxygen is present in the area surrounding the oxidation catalyst 71, and processing proceeds to step S80. At step S80, the electrical heater 72 in the PM sensor 62 is electrically powered to heat the oxidation catalyst 71, thereby combusting the exhaust particulate matter settled in the oxidation catalyst 71. Then, at step S81, the sediment amount of exhaust particulate matter is calculated in accordance with the degree of temperature rise of the oxidation catalyst 71 at this time. At step S82, a determination is made of whether the processing to calculate the sediment amount of the exhaust particulate matter has ended, by complete combustion of the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62.

Therefore, when the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 is combusted, when the sediment amount of exhaust particulate matter is calculated based on the temperature change at that time, it is possible to reliably combust the exhaust particulate matter using the oxygen present in the exhaust gas itself, the sediment amount of exhaust particulate matter being properly calculated.

After the above, at step S82, if the determination is made that the processing to calculate the sediment amount of the exhaust particulate matter has ended, at step S83 the electrical power to the electrical heater 72 of the PM sensor 62 is stopped, and the ECU 51 ends all processing.

In this manner, the exhaust particulate matter measuring apparatus according to the fourth embodiment is configured to provide in the exhaust pipe 47 the PM sensor 62 that measures the amount of particulate matter in the exhaust gas, the PM sensor 62 being fixed by stacking the oxidation catalyst 71 and the electrical heater 72 together, and a temperature sensor 73 that measures the temperature of the oxidation catalyst 71 being interposed between the oxidation catalyst 71 and the electrical heater 72. When execution of fuel cut control is in progress and sufficient oxygen is present in the exhaust gas, the ECU 51 heats the oxidation catalyst 71 using the electrical heater 72 and calculates the sediment amount of exhaust particulate matter based on the amount of temperature rise at that time and the accumulated value of the intake air amount.

Therefore, during execution of fuel cut control, the exhaust gas is lean and sufficient oxygen is present in the exhaust gas. In this condition, when the oxidation catalyst 71 is heated by the electrical heater 72, the exhaust particulate matter captured by the oxidation catalyst 71 can be properly combusted along with the oxygen in the exhaust gas, and the ECU 51 accurately calculates the sediment amount of exhaust particulate matter, based on the amount of temperature rise at this time and the accumulate value of intake air amount.

FIG. 11 is a flowchart of the measurement control of the exhaust particulate matter measuring apparatus according to the fifth embodiment of the present invention. The overall constitution of the exhaust particulate matter measuring apparatus of the fifth embodiment is substantially the same as that of the first embodiment. The fifth embodiment will be described using FIG. 1 and FIG. 2, and members having the same function as those members of embodiments already described are referred to by the same numerals and are not repeatedly described herein.

In the exhaust particulate matter measuring apparatus of the fifth embodiment, as shown in FIG. 1 and FIG. 2, because the basic configuration of the engine 10 is substantially the same as in the above-described first embodiment, the description thereof will be omitted. In this embodiment, the PM sensor 62 that measures the amount of particulate matter in the exhaust gas is provided between the three-way catalyst 49 and the muffler 50 in the exhaust pipe 47. The PM sensor 62, as shown in FIG. 2, has an oxidation catalyst 71, an electrical heater 72, and a temperature sensor 73.

Therefore, the PM sensor 62 can capture particulate matter, and particularly soot particles, in the exhaust gas flowing through the exhaust pipe 47. With exhaust particulate matter captured by the PM sensor 62 and settled up to a prescribed amount and also a sufficient amount of oxygen present in the area surrounding the PM sensor 62, when the electrical heater 72 is electrically powered to heat the oxidation catalyst 71, the settled exhaust particulate matter sediment is combusted using the oxygen present in the surrounding area, and the ECU 51 calculates the sediment amount of the exhaust particulate matter in accordance with the degree of temperature rise at that time. According to this embodiment, the rich operation of the engine 10 is prohibited during calculation of the sediment amount of exhaust particulate matter.

The method of measuring the exhaust particulate matter with the exhaust particulate matter measuring apparatus according to the fifth embodiment is described in detail below, with reference being made to the flowchart of FIG. 11.

At step S91, a determination is made of whether the engine 10 is completely warmed-up, that is, whether the engine coolant temperature detected by the coolant temperature sensor 58 is at least a prescribed engine warm-up coolant temperature. At this point, if the engine coolant temperature has reached the engine warm-up coolant temperature, at step S92, the electrical heater 72 in the PM sensor 62 is electrically powered to heat the oxidation catalyst 71, thereby combusting the exhaust particulate matter settled in the oxidation catalyst 71. Then, at step S93, a determination is made of whether the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted, based on the temperature change in the oxidation catalyst 71.

If the determination is made at step S93 that the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 has been completely combusted, at step S94 the electrical power to the electrical heater 72 in the PM sensor 62 is stopped. Then, at step S95 the temperature sensor 73 measures the temperature of the oxidation catalyst 71, and, at step S96, a determination is made as to whether the temperature t_{PM} of the oxidation catalyst 71 measured by the temperature sensor 73 is as low as or lower than the temperature t_A at which the exhaust particulate matter cannot be combusted. If the determination is made at this point that the temperature t_{PM} of the oxidation catalyst 71 has decreased to no greater than the temperature t_A at which the exhaust particulate matter cannot be combusted, at step S97 accumulation of the intake air amount is started. Then, at step S98, a determination is made of whether the accumulated amount of intake air Σga is larger than a prescribed value A.

If the determination is made at step S98 that the accumulated amount of intake air Σga has become greater than the prescribed value A, at step S99 a determination is made of whether oxygen is present in the area surrounding the PM sensor 62. At this point, when ceria is carried as an oxygen-storing agent by the oxidation catalyst 71, a determination may be made of whether the ceria of the oxidation catalyst 71 has occluded a sufficient amount of oxygen, based on the fuel cut control duration time or accumulation time, similar to the cases of the first and third embodiments already described. Also, in the case in which an oxygen sensor 63 is provided in the vicinity of the PM sensor 62 in the exhaust pipe 47, a determination may be made of whether the ceria in the oxidation catalyst 71 has occluded a sufficient amount of oxygen, based on the detection result from the oxygen sensor 63, similar to the case of the second embodiment. Also, similar to the case of the fourth embodiment, when ceria is not carried as an oxygen-storing agent by the oxidation catalyst 71, whether execution of fuel cut control is in progress can be determined to estimate whether oxygen is present in the exhaust gas, and to estimate whether oxygen is present in the vicinity of the PM sensor 62.

If the determination is made at step S99 that sufficient oxygen is present in the area surrounding the oxidation catalyst 71, processing proceeds to step S100, at which point the ECU 51 prohibits rich operation of the engine 10. That is, when the PM sensor 62 calculates the sediment amount of exhaust particulate matter, if the engine 10 is operated in the rich condition and the exhaust gas is a rich atmosphere, the oxygen present in the area surrounding the oxidation catalyst 71 is consumed in the oxidation of the rich exhaust gas, thereby reducing the amount of oxygen for combustion of the exhaust particulate matter settled in the oxidation catalyst 71.

Then, after prohibiting rich operation of the engine 10 at step S100, the exhaust particulate matter settled in the oxidation catalyst 71 is combusted by electrically powering the electrical heater 72 in the PM sensor 62 to heat the oxidation catalyst 71 at step S101. Then at step S102, the sediment amount of the exhaust particulate matter is calculated in accordance with the degree of temperature rise of the oxidation catalyst 71 at that time. At step S103 a determination is made of whether the processing to calculate the sediment amount of the exhaust particulate matter has ended, by complete combustion of the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62.

Therefore, when the exhaust particulate matter settled in the oxidation catalyst 71 of the PM sensor 62 is combusted, the sediment amount of exhaust particulate matter is calculated based on the temperature change at that time, the prohibition of rich operation of the engine 10 makes it possible to reliably combust the exhaust particulate matter using the oxygen present in the area surrounding the oxidation catalyst 71, and to properly calculate the sediment amount of the exhaust particulate matter.

After the above, if a determination is made at step S103 that the processing to calculate the sediment amount of the exhaust particulate matter has ended, at step S104 electrical power to the electrical heater 72 in the PM sensor 62 is stopped and, at step S105, the prohibition of rich operation of the engine 10 is removed, the ECU 51 ends the process.

In this manner, the exhaust particulate matter measuring apparatus according to the fifth embodiment is configured to provide in the exhaust pipe 47 a PM sensor 62 that measures the amount of particulate matter in the exhaust gas, the PM sensor 62 is fixed by stacking the oxidation catalyst 71 and the electrical heater 72 together, and a temperature sensor 73 that measures the temperature of the oxidation catalyst 71 being interposed between the oxidation catalyst 71 and the electrical heater 72. When sufficient oxygen is present in the area surrounding the oxidation catalyst 71, the ECU 51 prohibits rich operation of the engine 10, after which it heats the oxidation catalyst 71 using the electrical heater 72 and calculates the sediment amount of exhaust particulate matter based on the amount of temperature rise at that time and the accumulated value of the intake air amount.

Therefore, the ECU 51 may prohibit rich operation of the engine 10 when sufficient oxygen is present in the area surrounding the oxidation catalyst 71, by heating the oxidation catalyst 71 using the electrical heater 72 without consuming the oxygen present in the area surrounding the oxidation catalyst 71 in the oxidation of exhaust particulate matter of the rich exhaust gas, exhaust particulate matter captured by the oxidation catalyst 71 is properly combusted along with the oxygen present in the area surrounding the oxidation catalyst 71, and the ECU 51 accurately calculates the sediment amount of exhaust particulate matter, based on the amount of temperature rise at that time and the accumulated value of intake air amount. Also if ceria is carried by the oxidation catalyst 71, even if the engine 10 is operated at a stoichiometric air-fuel ratio (theoretical air-fuel ratio), because the ceria of the oxidation catalyst 71 reliably occludes the oxygen mixed in the exhaust gas during, for example, execution of the fuel cut control, it is possible to reliably calculate the sediment amount of exhaust particulate matter.

In each of the foregoing embodiments the exhaust particulate matter settled in the oxidation catalyst 71 is combusted by the PM sensor 62 disposed in the exhaust pipe 47 in the internal combustion engine 10 and the discharged amount of the exhaust particulate matter in the exhaust gas is estimated based on the temperature change of the oxidation catalyst 71, and the engine 10 may be controlled to change the fuel injection amount or air-fuel ratio to reduce the discharged amount, based on the estimated amount of discharge of the exhaust particulate matter.

As described above, by achieving a sufficient amount of oxygen and combusting the captured exhaust particulate matter, the exhaust particulate matter measuring apparatus according to the present invention accurately measures the amount of exhaust particulate matter in the exhaust gas based on the temperature change, and may be applied to any type of internal combustion engine. Also, although the above-described first and third embodiments use ceria as an oxygen-storing agent in the oxidation catalyst 71, the present invention is not restricted to these embodiments, and is compatible with oxygen-storing agents other than ceria.

CLAIMS:

1. An exhaust particulate matter measuring apparatus, characterized by comprising:

an oxidation catalyst (71), disposed in an exhaust passage (47) of an internal combustion engine;

heating means (72) for heating the oxidation catalyst (71);

a temperature sensor (73) that detects a temperature of the oxidation catalyst (71); and

sediment amount calculation means (51) for calculating a sediment amount of exhaust particulate matter based on the amount by which the temperature of the oxidation catalyst (71) increases when the heating means (72) heats the oxidation catalyst (71),

wherein the oxidation catalyst (71) is disposed downstream in an exhaust gas flow direction from a three-way catalyst (49) disposed in the exhaust passage (47) and upstream from a muffler (50) disposed in the exhaust passage (47).

2. An exhaust particulate matter measuring apparatus according to claim 1, wherein the oxidation catalyst (71) carries an oxygen-storing agent.

3. The exhaust particulate matter measuring apparatus according to claim 2, wherein:

the sediment amount calculation means (51) estimates an amount of oxygen occluded by the oxygen-storing agent based on a duration time of a fuel cut control executed by the internal combustion engine and an intake air amount; and

when the amount of occluded oxygen reaches or exceeds a prescribed value, the heating means (72) heats the oxygen catalyst (71) to calculate the sediment amount of exhaust particulate matter.

4. The exhaust particulate matter measuring apparatus according to claim 1, wherein:

an oxidation sensor (63) is disposed in the vicinity of the oxidation catalyst (71) in the exhaust passage (47);

the sediment amount calculation means (51) estimates an amount of oxygen occluded by the oxygen-storing agent based on a detected result of the oxidation sensor (63); and when the amount of oxygen occluded reaches or exceeds a prescribed value, the heating means (72) heats the oxygen catalyst (71) to calculate the sediment amount of exhaust particulate matter.

5. An exhaust particulate matter measuring apparatus according to claim 1, wherein the sediment amount calculation means (51) heats the oxidation catalyst (71) by the heating means (72) to calculate the sediment amount of the exhaust particulate matter when the internal combustion engine executes a fuel cut control.

6. The exhaust particulate matter measuring apparatus according to any one of claims 1 to 5, wherein the sediment amount calculation means (51) heats the oxidation catalyst (71) using the heating means (72) to combust the exhaust particle matter when the temperature of the oxidation catalyst (71) is at or below than a temperature at which the exhaust particulate matter cannot be combusted, and accumulation of the intake air amount is started,

wherein when the accumulated amount of intake air exceeds a prescribed value, the sediment amount calculation means (51) heats the oxidation catalyst (71) using the heating means (72) to calculate the sediment amount of the exhaust particulate matter.

7. The exhaust particulate matter measuring apparatus according to claim 6, further comprising an exhaust temperature sensor disposed in a vicinity of the oxidation catalyst (71),

wherein the sediment amount calculation means (51) cancels the accumulated value of intake air amount and restarts the calculation of the intake air amount when the exhaust gas temperature reaches the combustion temperature of the exhaust particulate matter.

8. The exhaust particulate matter measuring apparatus according to any one of claims 1 to 7, wherein the sediment amount calculation means (51) prohibits rich operation of the internal combustion engine when the heating means (72) heats the oxidation catalyst (71)

to calculate the sediment amount of the exhaust particulate matter.

9. The exhaust particulate matter measuring apparatus according to claim 4, wherein the sediment amount calculation means (51) determines whether the exhaust gas is in a lean condition, based on a detection result of the oxygen sensor (63) and, if it is determined that the exhaust gas has been a lean condition for at least a prescribed period of time, heats the oxidation catalyst (71) by the heating means (72) and calculates the sediment amount of the exhaust particulate matter.

10. The exhaust particulate matter measuring apparatus according to claim 6, further comprising an air flow sensor (52) disposed in the intake passage of the internal combustion engine that detects the intake air amount.

11. An exhaust particulate matter measuring apparatus, characterized by comprising:

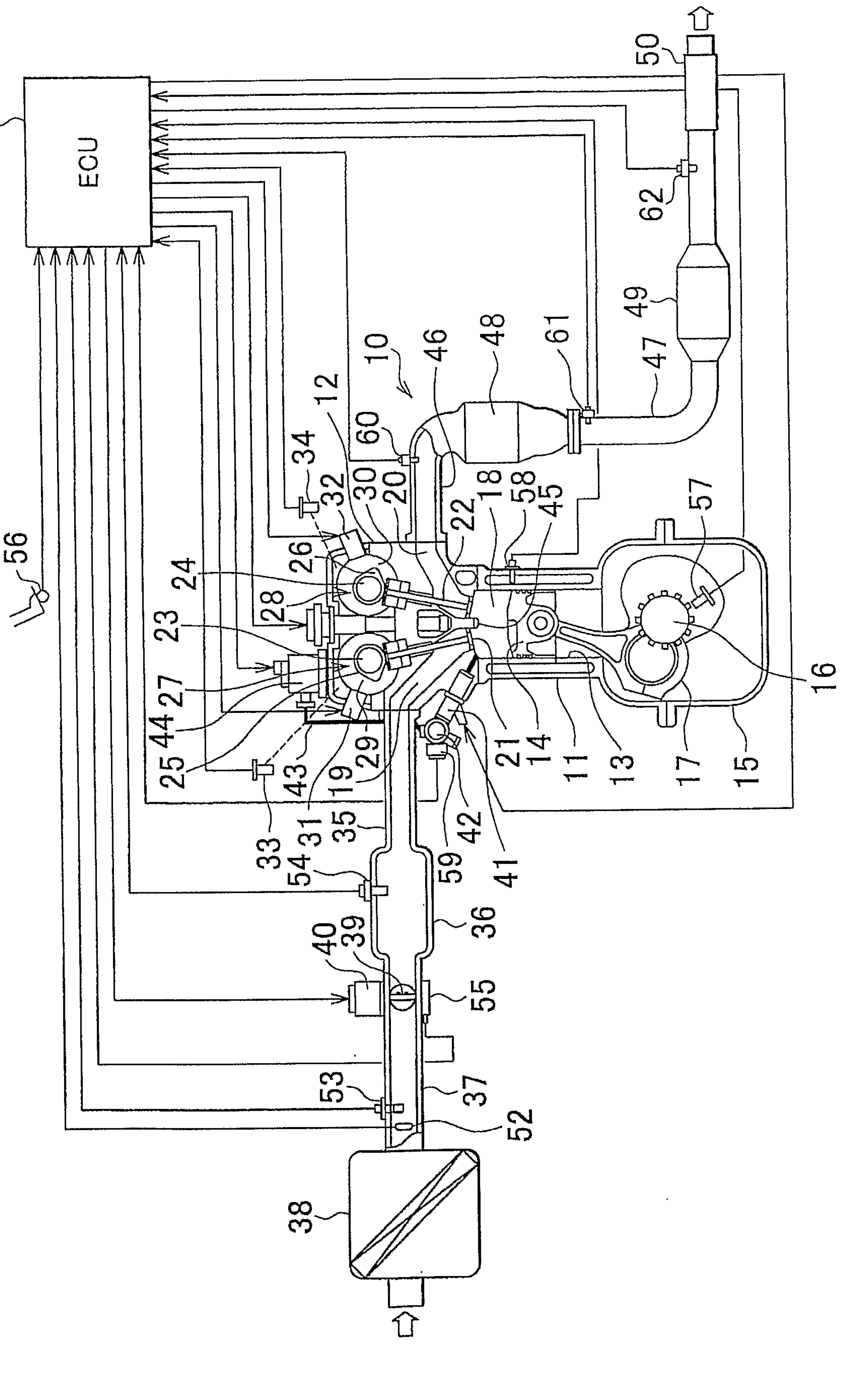
an oxidation catalyst, disposed in an exhaust passage of an internal combustion engine;

a heating device that heats the oxidation catalyst;

a temperature sensor that detects a temperature of the oxidation catalyst; and

a sediment amount calculation device that calculates a sediment amount of exhaust particulate matter based on the amount by which the temperature of the oxidation catalyst increases when the heating device heats the oxidation catalyst,

wherein the oxidation catalyst is disposed downstream in an exhaust gas flow direction from a three-way catalyst disposed in the exhaust passage and upstream from a muffler disposed in the exhaust passage.


ECU
51
50
62
49
47
61
48
46
10
12
60
34
32
30
20
18
58
45
22
57
26
24
28
23
27
44
25
43
19
29
31
33
35
21
14
11
13
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53
37
52
38
56

FIG. 1

FIG. 2

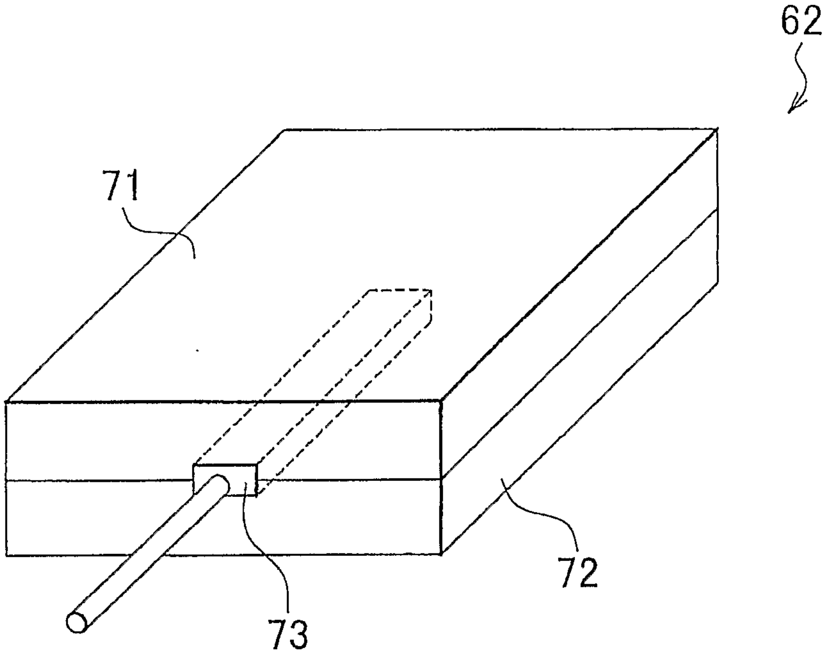


FIG. 3

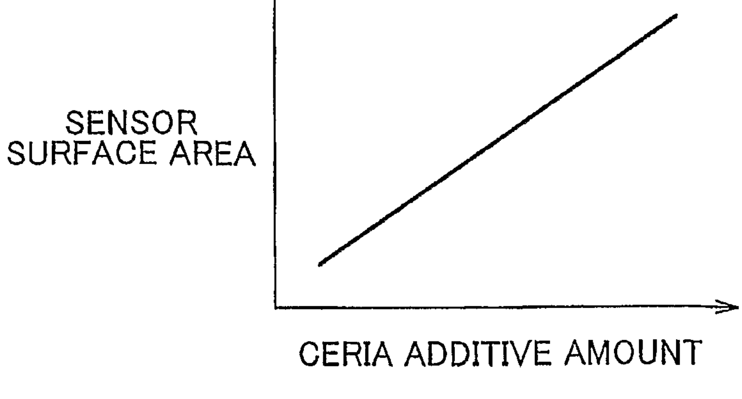


FIG. 4

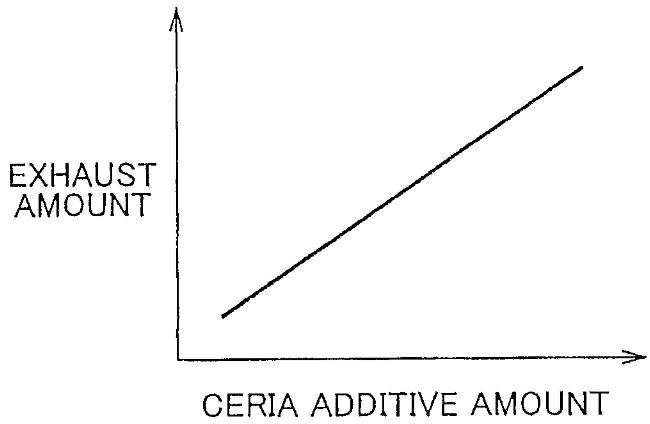
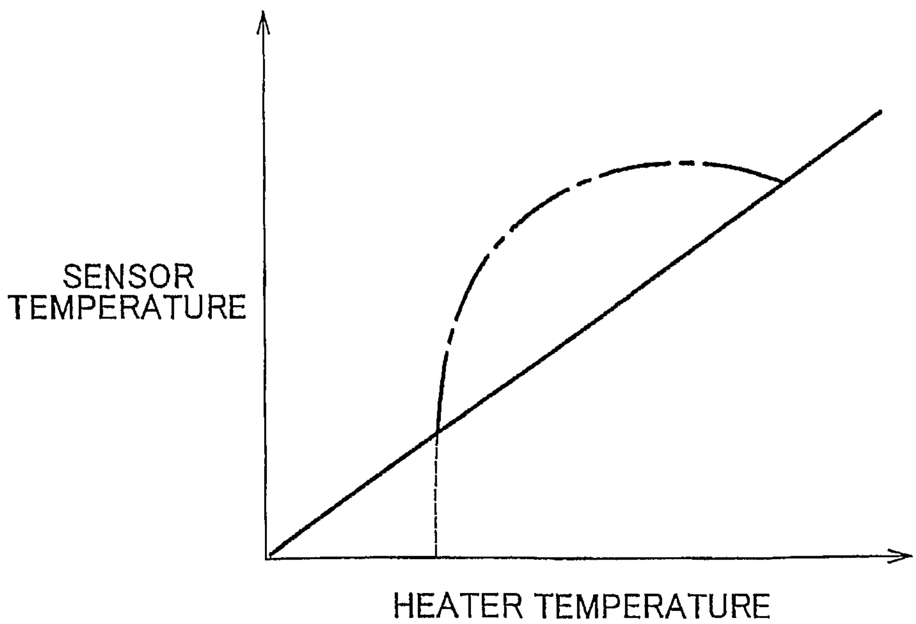

EXHAUST
AMOUNT
CERIA ADDITIVE AMOUNT

FIG. 5


SENSOR
TEMPERATURE
HEATER TEMPERATURE

F I G . 6

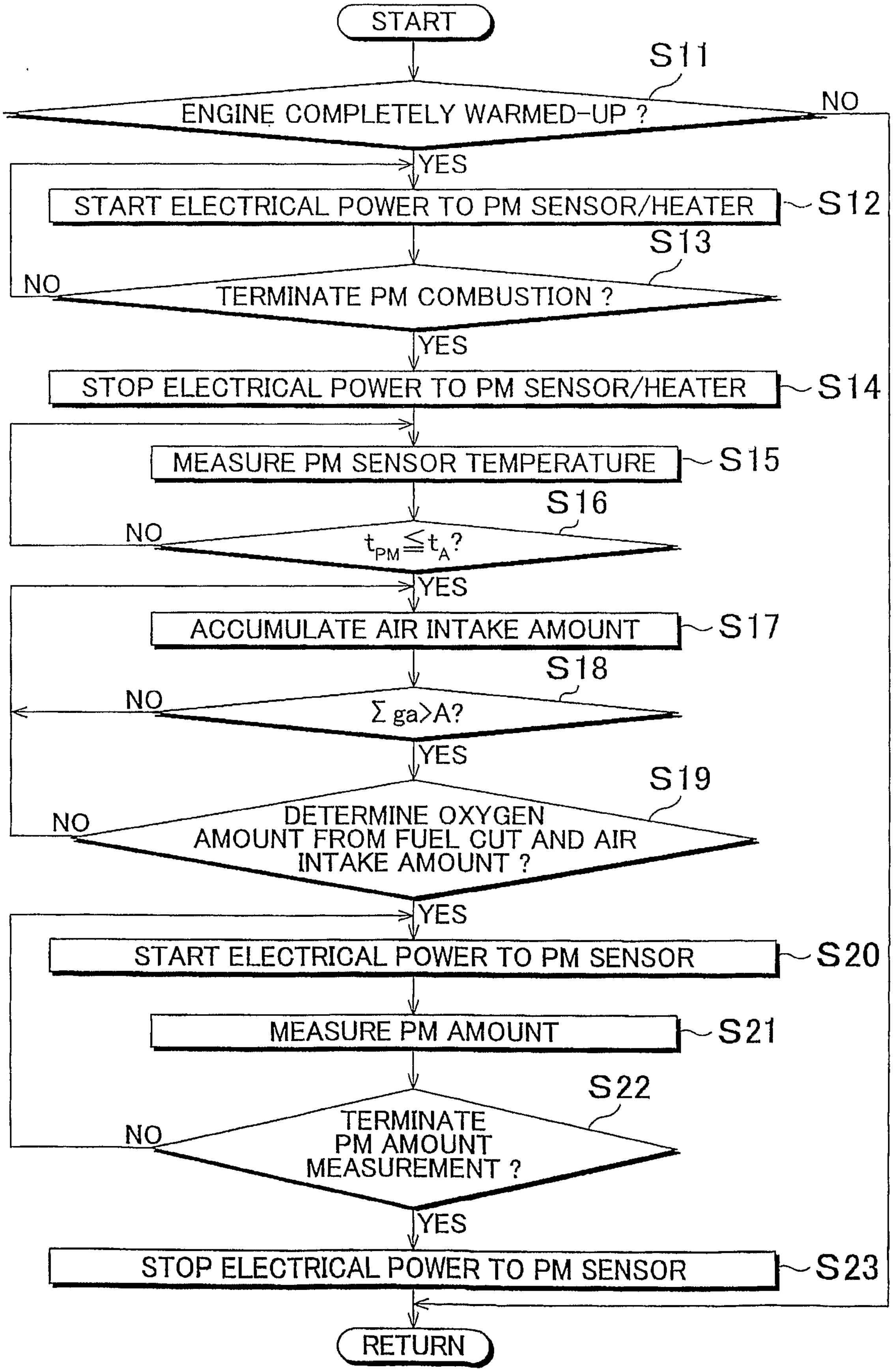
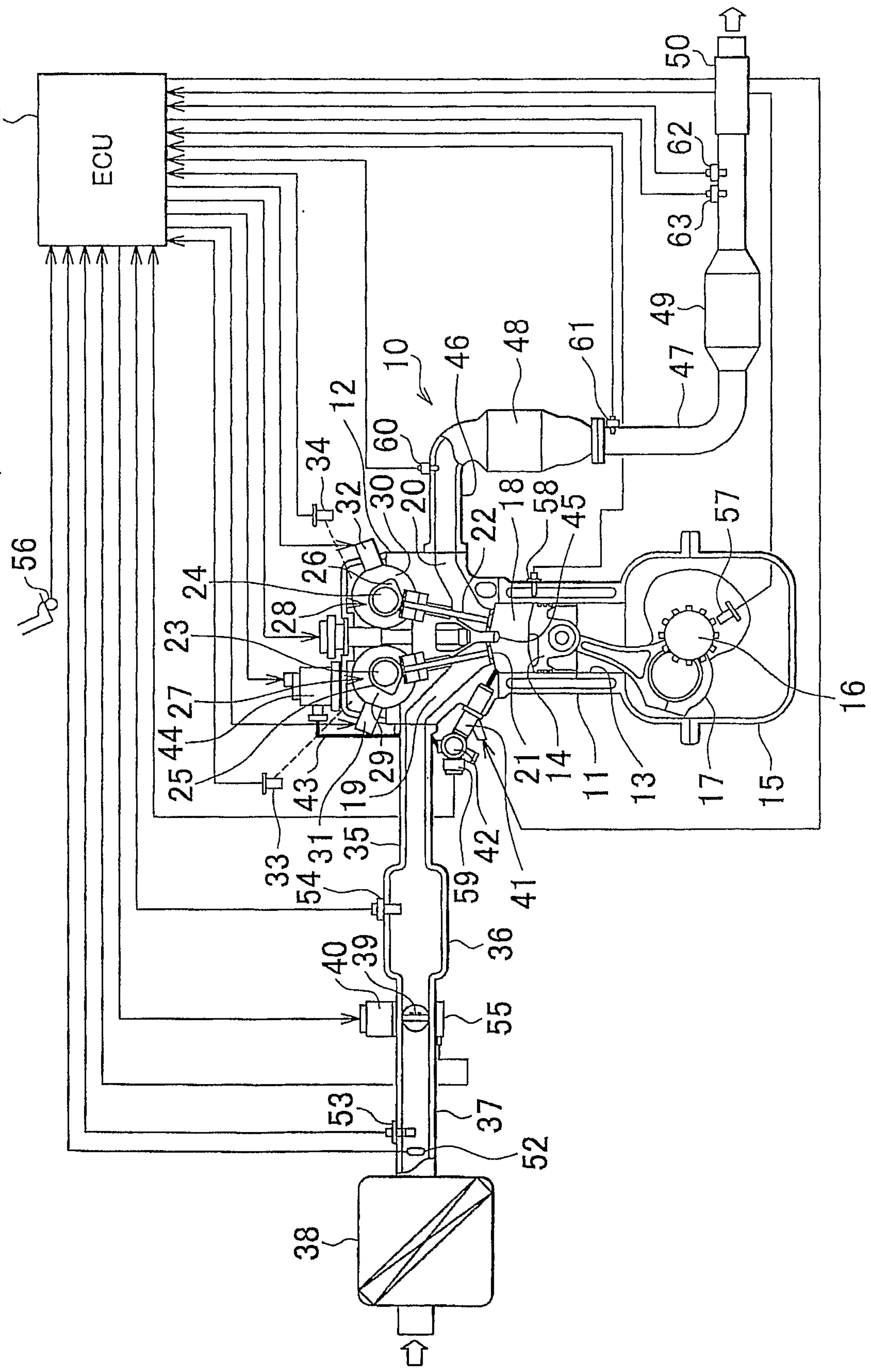

START
S11
ENGINE COMPLETELY WARMED-UP ?
NO
YES
START ELECTRICAL POWER TO PM SENSOR/HEATER
S12
S13
NO
TERMINATE PM COMBUSTION ?
YES
STOP ELECTRICAL POWER TO PM SENSOR/HEATER
S14
MEASURE PM SENSOR TEMPERATURE
S15
S16
NO
$t_{PM} \leqq t_A$?
YES
ACCUMULATE AIR INTAKE AMOUNT
S17
S18
NO
Σ ga>A?
YES
S19
NO
DETERMINE OXYGEN AMOUNT FROM FUEL CUT AND AIR INTAKE AMOUNT ?
YES
START ELECTRICAL POWER TO PM SENSOR
S20
MEASURE PM AMOUNT
S21
S22
NO
TERMINATE PM AMOUNT MEASUREMENT ?
YES
STOP ELECTRICAL POWER TO PM SENSOR
S23
RETURN

FIG. 7


ECU
51
56
50
62
63
49
47
61
48
46
10
12
60
34
32
30
20
22
18
58
45
57
16
26
24
28
23
27
44
25
43
19
29
31
33
35
21
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42
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41
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53
37
52
38

FIG. 8

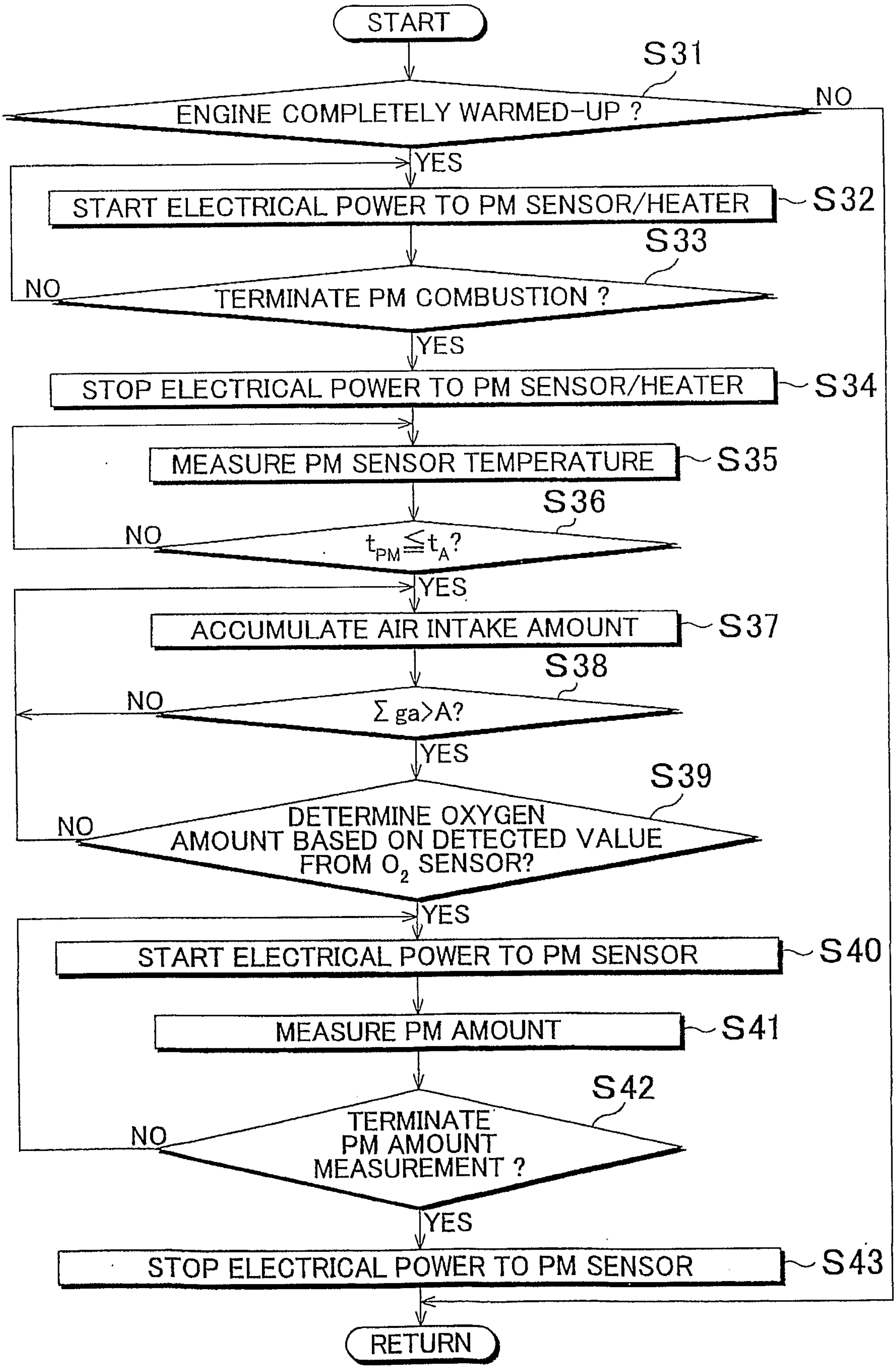
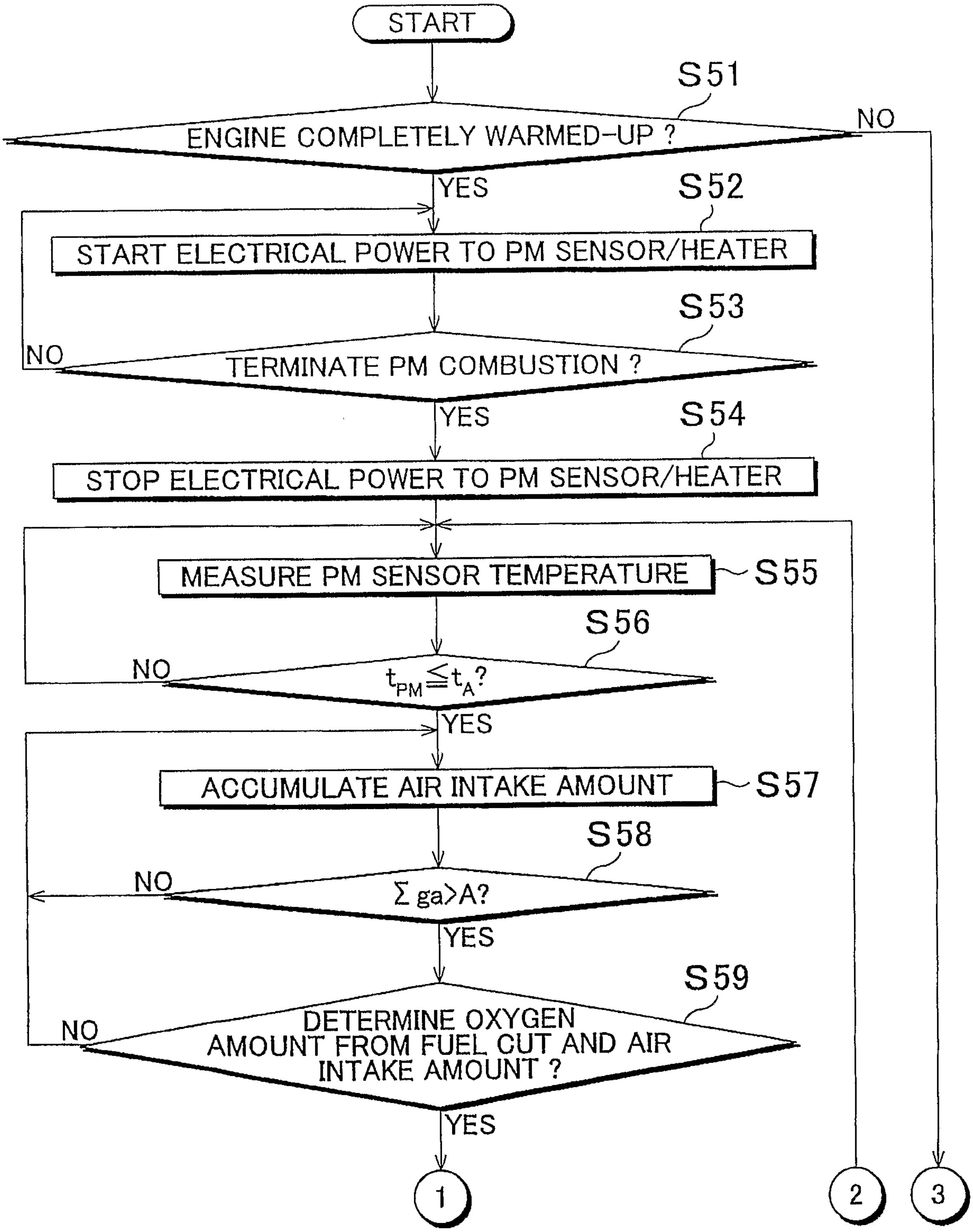

START
S31
ENGINE COMPLETELY WARMED-UP ?
NO
YES
START ELECTRICAL POWER TO PM SENSOR/HEATER
S32
S33
NO
TERMINATE PM COMBUSTION ?
YES
STOP ELECTRICAL POWER TO PM SENSOR/HEATER
S34
MEASURE PM SENSOR TEMPERATURE
S35
S36
NO
$t_{PM} \leqq t_A$?
YES
ACCUMULATE AIR INTAKE AMOUNT
S37
S38
NO
$\Sigma ga > A$?
YES
S39
NO
DETERMINE OXYGEN AMOUNT BASED ON DETECTED VALUE FROM O_2 SENSOR?
YES
START ELECTRICAL POWER TO PM SENSOR
S40
MEASURE PM AMOUNT
S41
S42
NO
TERMINATE PM AMOUNT MEASUREMENT ?
YES
STOP ELECTRICAL POWER TO PM SENSOR
S43
RETURN

FIG. 9A



START
S51
ENGINE COMPLETELY WARMED-UP ?
NO
YES
S52
START ELECTRICAL POWER TO PM SENSOR/HEATER
S53
NO
TERMINATE PM COMBUSTION ?
YES
S54
STOP ELECTRICAL POWER TO PM SENSOR/HEATER
MEASURE PM SENSOR TEMPERATURE
S55
S56
NO
$t_{PM} \leqq t_A$?
YES
ACCUMULATE AIR INTAKE AMOUNT
S57
S58
NO
Σ ga>A?
YES
S59
NO
DETERMINE OXYGEN AMOUNT FROM FUEL CUT AND AIR INTAKE AMOUNT ?
YES
1
2
3

FIG. 9B

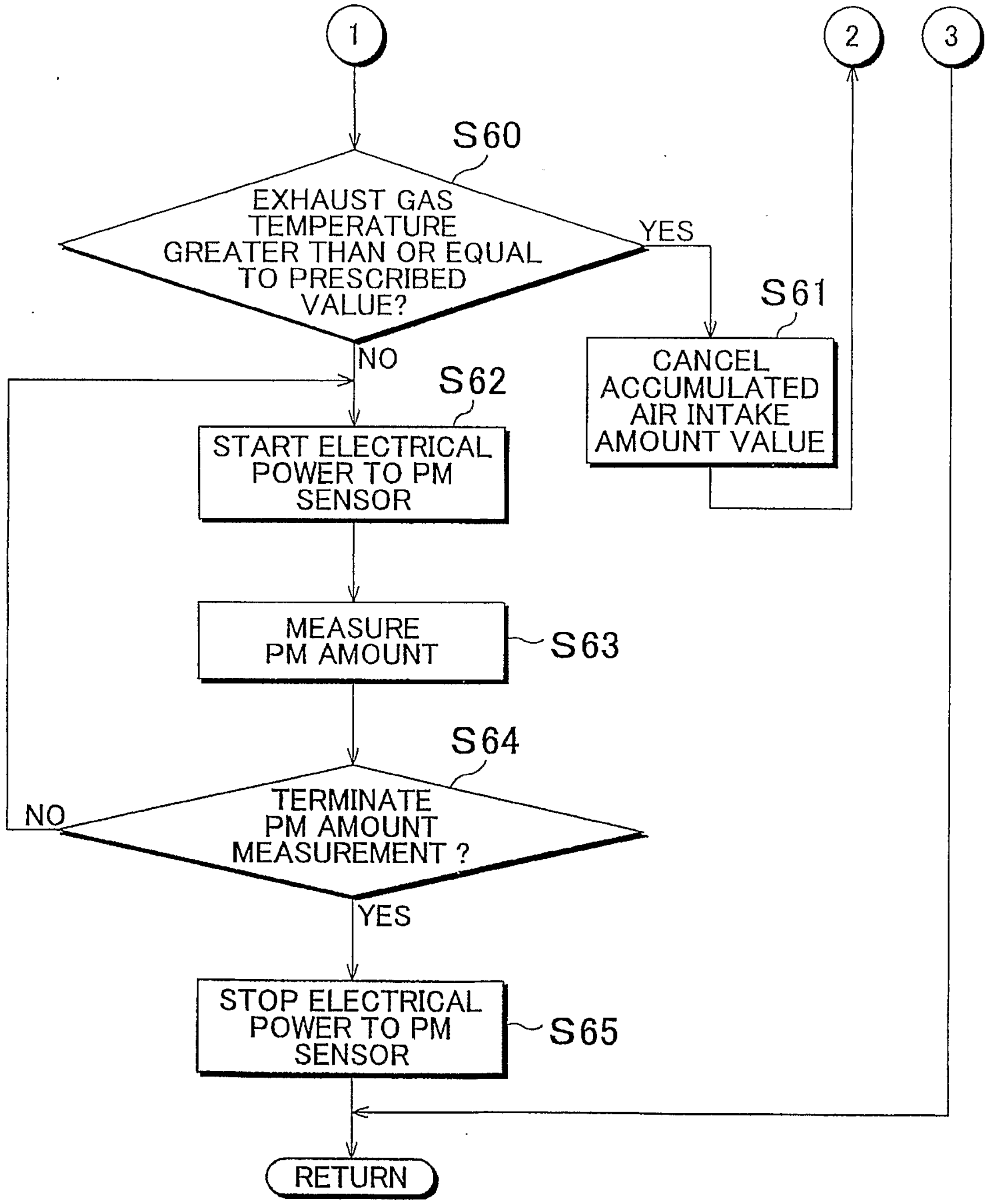

1
2
3
S60
EXHAUST GAS TEMPERATURE GREATER THAN OR EQUAL TO PRESCRIBED VALUE?
YES
NO
S61
CANCEL ACCUMULATED AIR INTAKE AMOUNT VALUE
S62
START ELECTRICAL POWER TO PM SENSOR
MEASURE PM AMOUNT
S63
S64
TERMINATE PM AMOUNT MEASUREMENT ?
NO
YES
STOP ELECTRICAL POWER TO PM SENSOR
S65
RETURN

FIG. 10

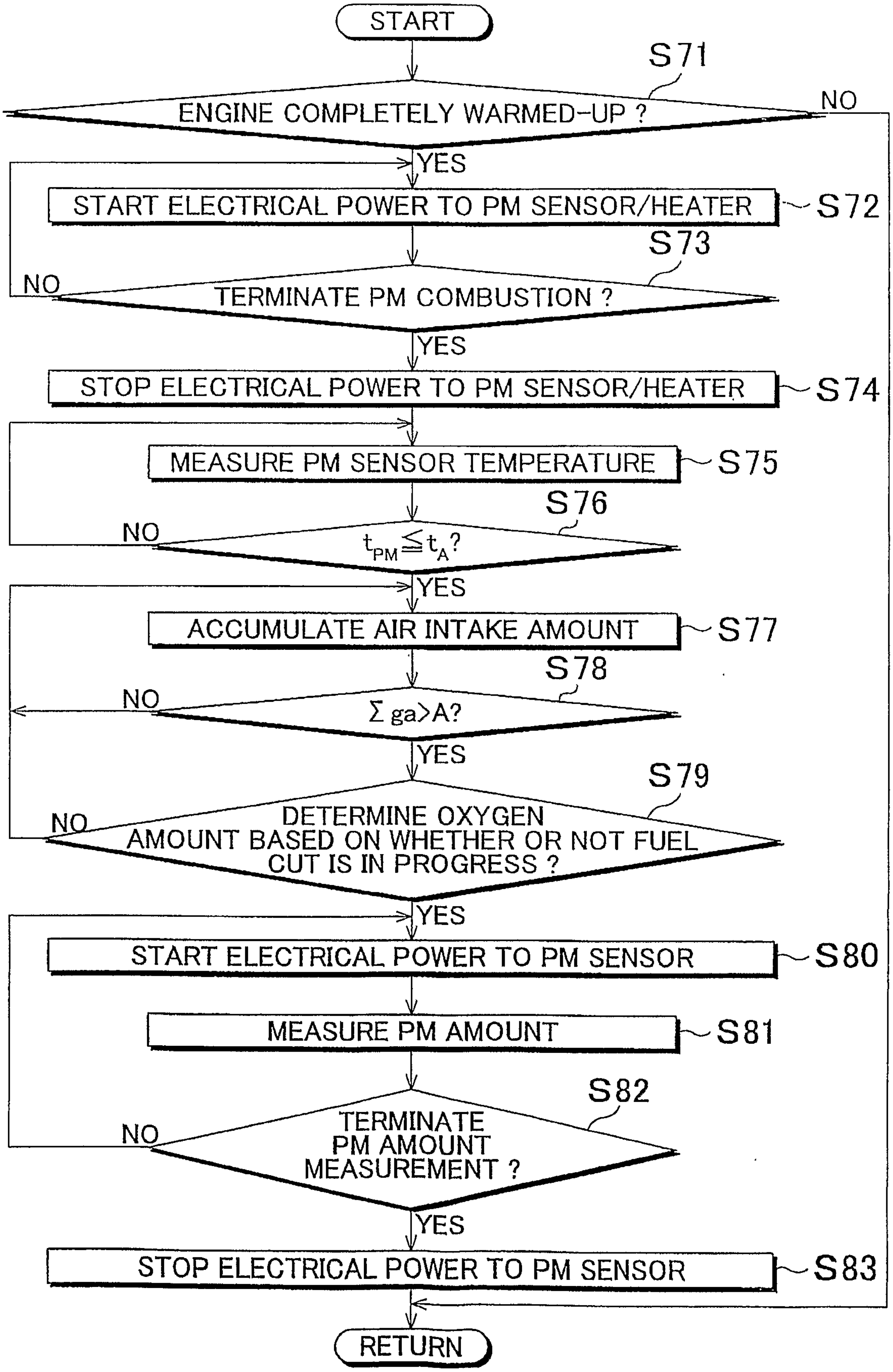
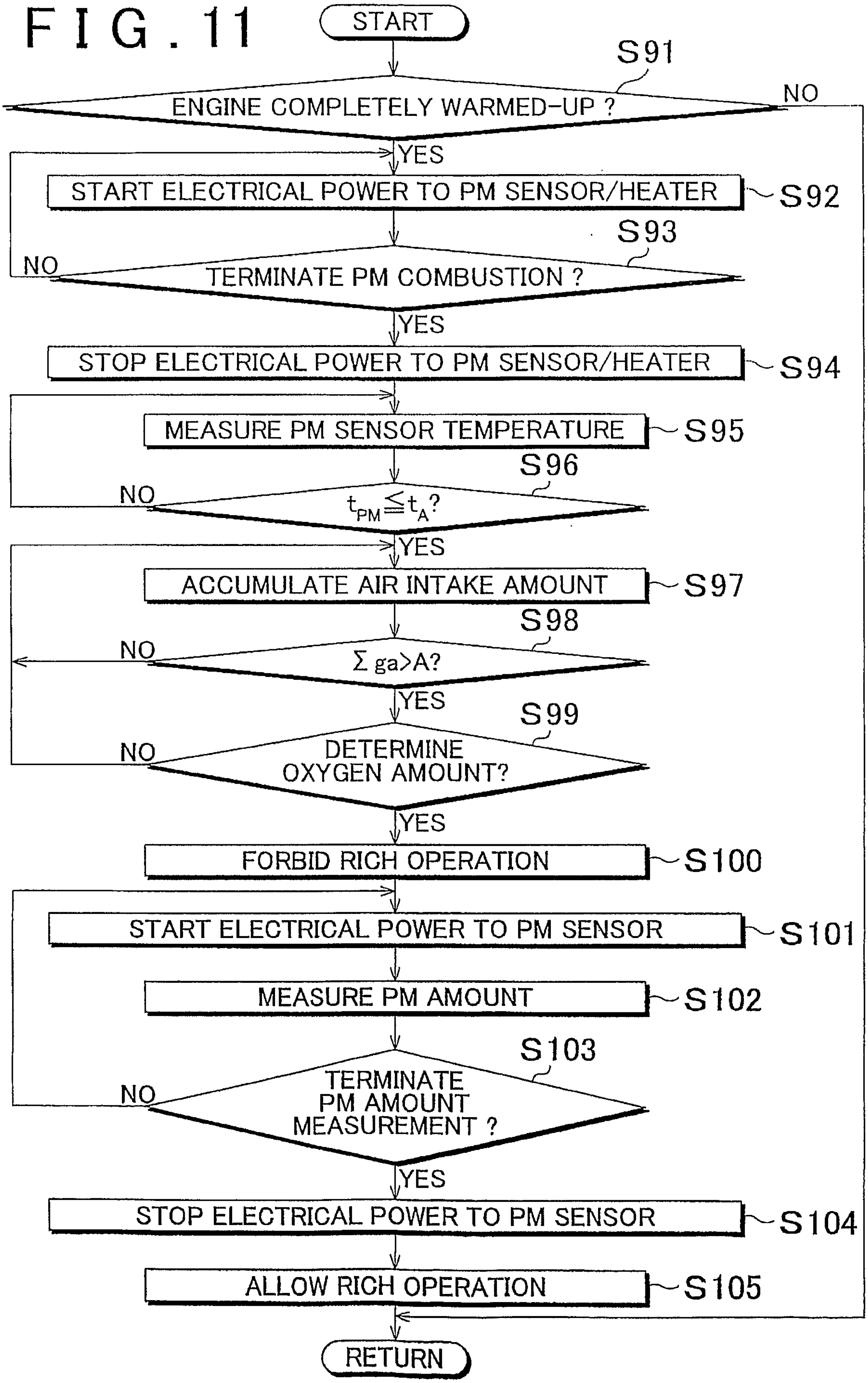

START
S71
ENGINE COMPLETELY WARMED-UP ?
NO
YES
START ELECTRICAL POWER TO PM SENSOR/HEATER
S72
S73
NO
TERMINATE PM COMBUSTION ?
YES
STOP ELECTRICAL POWER TO PM SENSOR/HEATER
S74
MEASURE PM SENSOR TEMPERATURE
S75
S76
NO
$t_{PM} \leqq t_A$?
YES
ACCUMULATE AIR INTAKE AMOUNT
S77
S78
NO
$\Sigma ga > A$?
YES
S79
NO
DETERMINE OXYGEN AMOUNT BASED ON WHETHER OR NOT FUEL CUT IS IN PROGRESS ?
YES
START ELECTRICAL POWER TO PM SENSOR
S80
MEASURE PM AMOUNT
S81
S82
NO
TERMINATE PM AMOUNT MEASUREMENT ?
YES
STOP ELECTRICAL POWER TO PM SENSOR
S83
RETURN

FIG. 11


START
ENGINE COMPLETELY WARMED-UP ?
S91
NO
YES
START ELECTRICAL POWER TO PM SENSOR/HEATER
S92
TERMINATE PM COMBUSTION ?
S93
NO
YES
STOP ELECTRICAL POWER TO PM SENSOR/HEATER
S94
MEASURE PM SENSOR TEMPERATURE
S95
$t_{PM} \leqq t_A$?
S96
NO
YES
ACCUMULATE AIR INTAKE AMOUNT
S97
Σ ga>A?
S98
NO
YES
DETERMINE OXYGEN AMOUNT?
S99
NO
YES
FORBID RICH OPERATION
S100
START ELECTRICAL POWER TO PM SENSOR
S101
MEASURE PM AMOUNT
S102
TERMINATE PM AMOUNT MEASUREMENT ?
S103
NO
YES
STOP ELECTRICAL POWER TO PM SENSOR
S104
ALLOW RICH OPERATION
S105
RETURN