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(54) EXHAUST GAS RECIRCULATION DEVICE FOR INTERNAL COMBUSTION ENGINE

(57) In an exhaust gas recirculation apparatus of an internal combustion engine, a technique is provided which reduces a pressure loss in a cyclone type collection device. The apparatus includes a turbocharger (5), a low pressure EGR passage (31), a cyclone type collection device (11) that is arranged in the low pressure EGR passage (31) and collects foreign matters in a low pressure EGR gas, a flow rate regulating passage (12) that causes the low pressure EGR gas to flow from a foreign matter collection part of the cyclone type collection device (11) into an exhaust passage (4) downstream of a connection part thereof with the low pressure EGR passage (31), a flow rate regulating valve (13) that is arranged in the flow rate regulating passage (12) and regulates the flow rate of the low pressure EGR gas flowing through the flow rate regulating passage (12), and a ECU (14) that performs the opening and closing control of the flow rate regulating valve in accordance with a pressure loss occurring at the time when the low pressure EGR gas flowing through the low pressure EGR passage (31) passes through the cyclone type collection device (11).

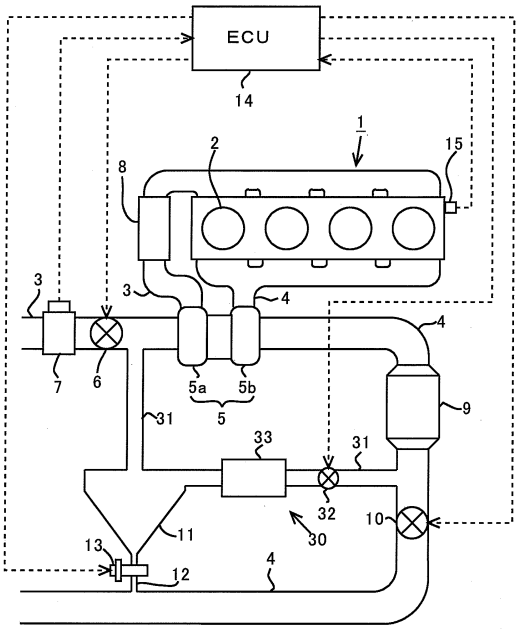


FIG.1

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Description

[Technical Field]

[0001] The present invention relates to an exhaust gas recirculation apparatus of an internal combustion engine.

[Background Art]

[0002] There has been disclosed a technique in which part of an exhaust gas is taken from an exhaust passage of an internal combustion engine as an EGR gas, which is recirculated to an intake passage of the internal combustion engine by way of an EGR passage in which a cyclone type collection device for collecting foreign matters in the EGR gas is arranged (see, for example, a first patent document).

[First Patent Document] Japanese patent application laid-open No. 2002-130058
[Second Patent Document] Japanese patent application laid-open No. 2000-170608
[Third Patent Document] Japanese patent application laid-open No. 2005-155559
[Fourth Patent Document] Japanese patent application laid-open No. H07-158420

[Disclosure of the Invention]

[Problem to be solved by the Invention]

[0003] The cyclone type collection device arranged in the EGR passage can also collect foreign matters of smaller particle sizes as the flow rate of the EGR gas increases and the flow speed of the EGR gas becomes faster. However, in cases where the EGR gas flow rate increases, a pressure loss at the time of the EGR gas passing through the cyclone type collection device becomes larger. As this pressure loss becomes larger, a desired amount of EGR gas will no longer be supplied to the internal combustion engine, so the EGR gas will be insufficient, thereby inducing the deterioration of exhaust emissions. Thus, when the pressure loss in the cyclone type collection device is large, there has been a case where various adverse or harmful effects are caused.

[0004] The present invention has been made in view of the above-mentioned circumstances, and has for its object to provide a technique of reducing a pressure loss in a cyclone type collection device in an exhaust gas recirculation apparatus of an internal combustion engine.

[Means for Solving the Problems]

[0005] The present invention adopts the following construction. That is, the present invention resides in an exhaust gas recirculation apparatus of an internal combustion engine, which is characterized by comprising:

a turbocharger that has a turbine arranged in an exhaust passage of said internal combustion engine and a compressor arranged in an intake passage of said internal combustion engine;
a low pressure EGR passage that takes in a part of an exhaust gas as a low pressure EGR gas from said exhaust passage downstream of said turbine, and recirculates the low pressure EGR gas to said intake passage upstream of said compressor;
a cyclone type collection device that is arranged in said low pressure EGR passage and collects foreign matters in said low pressure EGR gas;
a flow rate regulating passage that causes said low pressure EGR gas to flow from a foreign matter collection part of said cyclone type collection device into said exhaust passage downstream of a connection part thereof with said low pressure EGR passage;
a flow rate regulating valve that is arranged in said flow rate regulating passage and regulates the flow rate of the low pressure EGR gas flowing through said flow rate regulating passage; and
a first control means that performs the opening and closing control of said flow rate regulating valve in accordance with a pressure loss occurring at the time when the low pressure EGR gas flowing through said low pressure EGR passage passes through said cyclone type collection device.

[0006] The cyclone type collection device arranged in the low pressure EGR passage can also collect foreign matters of smaller particle sizes as the flow rate of the low pressure EGR gas increases and the flow speed of the low pressure EGR gas becomes faster. However, in cases where the flow rate of the low pressure EGR gas increases, a pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device becomes larger. As this pressure loss becomes larger, a desired amount of the low pressure EGR gas will no longer be supplied to the internal combustion engine, so the low pressure EGR gas will be insufficient, thereby inducing the deterioration of exhaust emissions.

[0007] According to the present invention, the flow rate regulating valve is controlled to be opened and closed in accordance with the pressure loss at the time when the low pressure EGR gas passes through the cyclone type collection device. Therefore, in cases where the pressure loss becomes larger, i.e., in cases where the flow rate of the low pressure EGR gas increases, the flow rate regulating valve can be opened. By this, the low pressure EGR gas is caused to pass from the cyclone type collection device to the flow rate regulating passage, so that the low pressure EGR gas remaining in the cyclone type collection device can be decreased. Thus, the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device becomes smaller, so a desired amount of low pressure EGR gas can be supplied to the internal combustion engine, and the deterioration of exhaust emissions resulting from a

shortage of the low pressure EGR gas can be suppressed.

[0008] In addition, when the low pressure EGR gas is caused to pass from the cyclone type collection device to the flow rate regulating passage as in the present invention, the flow speed of the low pressure EGR gas passing through the cyclone type collection device becomes slower, and the cyclone type collection device becomes unable to collect foreign matters of small particle sizes. However, even in this case, what is necessary is just to be able to collect foreign matters of particle sizes equal to or larger than a particle size which affects the intake system of the internal combustion engine. Thus, if foreign matters of particle sizes equal to or larger than the particle size which affects the intake system of the internal combustion engine can be collected by the cyclone type collection device, the inclusion of the foreign matters will not influence the intake system of the internal combustion engine.

[0009] Preferably, said first control means closes said flow rate regulating valve in cases where the flow rate of the low pressure EGR gas flowing through said low pressure EGR passage is less than a first predetermined flow rate used as a threshold which gives priority to reducing the pressure loss at the time of said low pressure EGR gas passing through said cyclone type collection device rather than collecting foreign matters by said cyclone type collection device, and opens said flow rate regulating valve at a degree of opening in a range in which said cyclone type collection device is able to collect foreign matters of particle sizes equal to or larger than the particle size which affects said intake system of the internal combustion engine in cases where the flow rate of the low pressure EGR gas flowing through said low pressure EGR passage becomes equal to or more than said first predetermined flow rate.

[0010] Here, the first predetermined flow rate is a flow rate of the low pressure EGR gas that is used as a threshold which gives priority to reducing the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device rather than collecting foreign matters by the cyclone type collection device, when the flow rate of the low pressure EGR gas is equal to or larger than the threshold.

[0011] According to the present invention, in cases where the flow rate of the low pressure EGR gas increases more than the first predetermined flow rate, the flow rate regulating valve is opened so that the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device can be reduced. In addition, when the flow rate regulating valve is opened, the cyclone type collection device is able to collect foreign matters of particle sizes larger than the particle size which affects the intake system of the internal combustion engine.

[0012] The present invention also adopts the following construction. That is, the present invention resides in an exhaust gas recirculation apparatus of an internal combustion engine, which is characterized by comprising:

a turbocharger that has a turbine arranged in an exhaust passage of said internal combustion engine and a compressor arranged in an intake passage of said internal combustion engine;

a catalyst that is arranged in said exhaust passage downstream of said turbine and becomes a high temperature when activated;

a cyclone type collection device that is arranged in said exhaust passage immediately downstream of said catalyst and collects foreign matters in an exhaust gas;

a low pressure EGR passage that takes in a part of an exhaust gas as a low pressure EGR gas from said exhaust passage downstream of said cyclone type collection device, and recirculates the low pressure EGR gas to said intake passage upstream of said compressor;

a flow rate regulating passage that causes the exhaust gas to flow from a foreign matter collection part of said cyclone type collection device into said exhaust passage downstream of a connection part thereof with said low pressure EGR passage;

a flow rate regulating valve that is arranged in said flow rate regulating passage and regulates the flow rate of the exhaust gas flowing through said flow rate regulating passage; and

a second control means that performs the opening and closing control of said flow rate regulating valve in accordance with a pressure loss occurring at the time when the exhaust gas flowing through said exhaust passage passes through said cyclone type collection device.

[0013] The cyclone type collection device arranged in the exhaust passage can also collect foreign matters of smaller particle sizes as the flow rate of the exhaust gas increases and the flow speed of the exhaust gas becomes faster. However, in cases where the exhaust gas flow rate increases, a pressure loss at the time of the exhaust gas passing through the cyclone type collection device becomes larger. As this pressure loss becomes larger, the reduction in the output of the internal combustion engine and the deterioration of the fuel consumption thereof will be caused.

[0014] According to the present invention, the degree of opening of the flow rate regulating valve is controlled in accordance with the pressure loss at the time when the exhaust gas passes through the cyclone type collection device. Therefore, in cases where the pressure loss becomes larger, i.e., in cases where the flow rate of the exhaust gas increases, the flow rate regulating valve can be opened. By this, the exhaust gas is caused to pass from the cyclone type collection device to the flow rate regulating passage, so that the exhaust gas stagnating in the cyclone type collection device can be decreased. Thus, the pressure loss at the time of the exhaust gas

passing through the cyclone type collection device becomes smaller, so it is possible to suppress the reduction in the output of the internal combustion engine and the deterioration of fuel consumption thereof.

[0015] In addition, when the exhaust gas is caused to pass from the cyclone type collection device to the flow rate regulating passage as in the present invention, the flow speed of the exhaust gas passing through the cyclone type collection device becomes slower, and the cyclone type collection device becomes unable to collect foreign matters of small particle sizes. However, even in this case, what is necessary is just to be able to collect foreign matters of particle sizes equal to or larger than a particle size which affects the intake system of the internal combustion engine. Thus, if foreign matters of particle sizes equal to or larger than the particle size which affects the intake system of the internal combustion engine can be collected by the cyclone type collection device, the inclusion of the foreign matters will not influence the intake system of the internal combustion engine.

[0016] Moreover, in cases where the cyclone type collection device is arranged at a location immediately downstream of the catalyst, the exhaust gas carries away an amount of heat from the catalyst which has become high temperature at the time of activation thereof, and the exhaust gas in a warmed state flows into the cyclone type collection device. For this reason, the exhaust gas is at high temperature in the cyclone type collection device, so the amount of saturated steam of the exhaust gas does not decrease, thus making it possible to suppress the generation of condensate from the exhaust gas in the cyclone type collection device. Accordingly, it is possible to suppress the corrosion reliability of intake and exhaust piping from being affected resulting from the generation of condensate.

[0017] Preferably, said second control means closes said flow rate regulating valve in cases where the flow rate of the exhaust gas flowing through said exhaust passage is less than a second predetermined flow rate used as a threshold which gives priority to reducing the pressure loss at the time of the exhaust gas passing through said cyclone type collection device rather than collecting foreign matters by said cyclone type collection device, and opens said flow rate regulating valve at a degree of opening in a range in which said cyclone type collection device is able to collect foreign matters of particle sizes equal to or larger than the particle size which affects said intake system of the internal combustion engine in cases where the flow rate of the exhaust gas flowing through said exhaust passage becomes equal to or more than said second predetermined flow rate.

[0018] Here, the second predetermined flow rate is a flow rate of the exhaust gas that is used as a threshold which gives priority to reducing the pressure loss at the time of the exhaust gas passing through the cyclone type collection device rather than collecting foreign matters by the cyclone type collection device, when the flow rate of the exhaust gas is equal to or larger than the threshold.

[0019] According to the present invention, in cases where the flow rate of the exhaust gas increases more than the second predetermined flow rate, the flow rate regulating valve is opened so that the pressure loss at the time of the exhaust gas passing through the cyclone type collection device can be reduced. In addition, when the flow rate regulating valve is opened, the cyclone type collection device is able to collect foreign matters of particle sizes equal to or larger than the particle size which affects the intake system of the internal combustion engine.

[0020] The present invention further adopts the following construction. That is, the present invention resides in an exhaust gas recirculation apparatus of an internal combustion engine, which is characterized by comprising:

a turbocharger that has a turbine arranged in an exhaust passage of said internal combustion engine and a compressor arranged in an intake passage of said internal combustion engine;

a low pressure EGR passage that takes in a part of an exhaust gas as a low pressure EGR gas from said exhaust passage downstream of said turbine, and recirculates the low pressure EGR gas to said intake passage upstream of said compressor;

a cyclone type collection device that is arranged in said low pressure EGR passage and collects foreign matters in said low pressure EGR gas;

a bypass passage that serves to cause said low pressure EGR gas to bypass said cyclone type collection device in said low pressure EGR passage;

a bypass valve that opens and closes said bypass passage; and

a third control means that opens said bypass valve in cases where the flow rate of the low pressure EGR gas flowing through said low pressure EGR passage is less than a third predetermined flow rate that is a threshold which does not allow foreign matters to reach said compressor, and in cases where the number of revolutions per unit time of said turbocharger is lower than a predetermined number of revolutions per unit time that is a threshold with which said compressor will not be damaged even if foreign matters of small particle sizes unable to be collected by said cyclone type collection device reach said compressor.

[0021] Here, the third predetermined flow rate means a flow rate of the low pressure EGR gas that is a threshold below which foreign matters are unable to reach the compressor. In addition, the predetermined number of revolutions per unit time means a number of revolutions of the turbocharger that is a threshold below which foreign matters of small particle sizes unable to be collected by the cyclone type collection device, even if reach the compressor, will not damage the compressor.

[0022] According to the present invention, the bypass

valve is opened in cases where the flow rate of the low pressure EGR gas flowing through the low pressure EGR passage is less than the third predetermined flow rate that does not allow foreign matters to reach the compressor, and in cases where the number of revolutions per unit time of the turbocharger is lower than the predetermined number of revolutions per unit time with which the compressor will not be damaged even if foreign matters of small particle sizes unable to be collected by the cyclone type collection device reaches the compressor. With this, the low pressure EGR gas flowing through the low pressure EGR passage is caused to bypass the cyclone type collection device, so that the low pressure EGR gas flows through the bypass passage. For this reason, there will be no pressure loss generated at the time of the low pressure EGR gas passing through the cyclone type collection device. Accordingly, the pressure loss on the route of the low pressure EGR passage becomes smaller, so a desired amount of low pressure EGR gas can be supplied to the internal combustion engine, and the deterioration of exhaust emissions resulting from a shortage of the low pressure EGR gas can be suppressed.

[Effect of the Invention]

[0023] According to the present invention, in an exhaust gas recirculation apparatus of an internal combustion engine, it is possible to reduce a pressure loss in a cyclone type collection device.

[Brief Description of the Drawings]

[0024]

[Fig. 1] is a view showing the schematic construction of an internal combustion engine and its intake and exhaust systems according to a first embodiment of the present invention.

[Fig. 2] is a view showing the flow rate of a low pressure EGR gas which is required in accordance with an operating state of the internal combustion engine according to the first embodiment.

[Fig. 3] is a view showing the relation between the flow rate of the low pressure EGR gas flowing into a cyclone type collection device and the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device according to the first embodiment.

[Fig. 4] is a view showing the relation between the particle sizes of foreign matters and the foreign matter collection efficiency in the cyclone type collection device according to the first embodiment.

[Fig. 5] is a flow chart showing a control routine for the flow rate of the low pressure EGR gas according to the first embodiment.

[Fig. 6] is a view showing the schematic construction of an internal combustion engine and its intake and exhaust systems according to a second embodiment of the present invention.

[Fig. 7] is a view showing the states which a three-way valve can take according to the second embodiment.

[Fig. 8] is a view showing the characteristics of the temperature of an exhaust gas and the amount of water vapor according to the second embodiment.

[Fig. 9] is a flow chart showing a control routine for the flow rate of the exhaust gas according to the second embodiment.

[Fig. 10] is a view showing the schematic construction of an internal combustion engine and its intake and exhaust systems according to a third embodiment of the present invention.

[Fig. 11] is a view showing a region in which a bypass valve is opened in accordance with the operating state of the internal combustion engine according to the third embodiment.

[Fig. 12] is a view showing the relation between the flow rate of the low pressure EGR gas and the pressure loss on the route of a low pressure EGR passage according to the third embodiment.

[Fig. 13] is a flow chart showing a control routine for the bypass valve according to the third embodiment.

[Explanation of Reference Numerals and Characters]

[0025]

1	an internal combustion engine
2	cylinders
3	an intake passage
4	an exhaust passage
5	a turbocharger
5a	a compressor
5b	a turbine
6	a throttle valve
7	an air flow meter
8	an intercooler
9	an exhaust gas purification device
10	an exhaust throttle valve
11	a cyclone type collection device
12	a flow rate regulating passage
13	a flow rate regulating valve
14	an ECU
15	a crank position sensor
16	a three-way valve
17	a bypass passage
18	a bypass valve
30	a low pressure EGR system
31	a low pressure EGR passage
32	a low pressure EGR valve
33	a low pressure EGR cooler

[Best Mode for Carrying out the Invention]

[0026] In the following, specific embodiments of the

present invention will be described.

<First Embodiment>

[0027] Fig. 1 is a view showing the schematic construction of an internal combustion engine and its intake and exhaust systems to which an exhaust gas recirculation apparatus of an internal combustion engine according to this embodiment of the present invention is applied. The internal combustion engine 1 illustrated in Fig. 1 is a four-stroke cycle diesel engine of a water cooled type having four cylinders 2 each of which cooperates with a piston to form a combustion chamber. The internal combustion engine 1 is installed on a vehicle. An intake passage 3 and an exhaust passage 4 are connected to the internal combustion engine 1.

[0028] In the middle of the intake passage 3 connected to the internal combustion engine 1, there is arranged a compressor 5a of a turbocharger 5 that is driven to operate with the use of the energy of an exhaust gas as a driving source.

[0029] In the intake passage 3 at a location upstream of the compressor 5a, there is arranged a throttle valve 6 that serves to adjust the flow rate of intake air flowing through the intake passage 3. This throttle valve 6 is driven to be opened and closed by an electric actuator. In the intake passage 3 at a location upstream of the throttle valve 6, there is arranged an air flow meter 7 that outputs a signal in accordance with the flow rate of fresh air flowing through the intake passage 3. By this air flow meter 7, the amount of intake air (the amount of fresh air) sucked into the internal combustion engine 1 is metered or measured.

[0030] An intercooler 8 for performing heat exchange between intake air and outside air is arranged in the intake passage 3 at a location downstream of the compressor 5a.

[0031] On the other hand, in the middle of the exhaust passage 4 connected to the internal combustion engine 1, there is arranged a turbine 5b of the turbocharger 5. A exhaust gas purification device 9 is arranged in the exhaust passage 4 at a location downstream of the turbine 5b.

[0032] The exhaust gas purification device 9 is constructed to have an oxidation catalyst and a particulate filter (hereinafter referred to simply as a filter) that is arranged at a latter stage (or downstream side) of the oxidation catalyst. Here, note that an occlusion reduction type NOx catalyst (hereinafter simply referred to as a NOx catalyst) may be carried by the filter. The exhaust gas purification device 9 operates such that the oxidation catalyst and the NOx catalyst become high temperature when activated and exhibit their functions. The oxidation catalyst or the NOx catalyst, which are used in the exhaust gas purification device 9, correspond to a catalyst of the present invention.

[0033] In addition, an exhaust throttle valve 10 for adjusting the flow rate of the exhaust gas flowing through the exhaust passage 4 is arranged in the exhaust passage 4 at a location downstream of the exhaust gas purification device 9. This exhaust throttle valve 10 is driven to open and close by an electric actuator.

[0034] The internal combustion engine 1 is equipped with a low pressure EGR system 30 that returns (recirculates) a part of the exhaust gas flowing through the exhaust passage 4 to the intake passage 3 at low pressure. This low pressure EGR system 30 is constructed to be provided with a low pressure EGR passage 31, a low pressure EGR valve 32, and a low pressure EGR cooler 33.

[0035] The low pressure EGR passage 31 serves to connect between a portion of the exhaust passage 4 at a downstream side of the exhaust gas purification device 9 and at an upstream side of the exhaust throttle valve 10 and a portion of the intake passage 3 at an upstream side of the compressor 5a and at a downstream side of the throttle valve 6. The exhaust gas is sent into the internal combustion engine 1 through this low pressure EGR passage 31 at low pressure. In this embodiment, the exhaust gas being returned while flowing through the low pressure EGR passage 31 is called a low pressure EGR gas.

[0036] By regulating the passage sectional area of the low pressure EGR passage 31, the low pressure EGR valve 32 adjusts the amount of the low pressure EGR gas flowing through the low pressure EGR passage 31. This low pressure EGR valve 32 is driven to open and close by an electric actuator. Here, note that the regulation of the amount of the low pressure EGR gas can also be carried out by means of methods other than the adjustment of the degree of opening of the low pressure EGR valve 32. For example, by regulating the degree of opening of the throttle valve 6 or by adjusting the degree of opening of the exhaust throttle valve 10, the difference in pressure between an upstream side of the low pressure EGR passage 31 and a downstream side thereof can be changed, thereby making it possible to adjust the amount of the low pressure EGR gas.

[0037] The low pressure EGR cooler 33 performs heat exchange with the low pressure EGR gas passing through the low pressure EGR cooler 33 and engine cooling water of the internal combustion engine 1, whereby the temperature of the low pressure EGR gas is reduced.

[0038] Here, in this embodiment, a cyclone type collection device 11 is arranged in the low pressure EGR passage 31 at a location downstream of the low pressure EGR cooler 33. In the cyclone type collection device 11, when the low pressure EGR gas containing foreign matters flows into the cyclone type collection device 11, the low pressure EGR gas descends while rotating along a cylindrical wall of the cyclone type collection device 11 of which the size or diameter decreases toward its lower end, during which a centrifugal force acts on the foreign matters so that the foreign matters are caused to move in the direction of the wall thereby to be separated from the low pressure EGR gas. The low pressure EGR gas

with the foreign matters separated therefrom flows in the direction of a central portion of the cyclone type collection device 11, and flows out of a discharge opening formed in an upper portion of the cyclone type collection device 11. On the other hand, the foreign matters separated from the low pressure EGR gas continue to descend after the separation thereof from the low pressure EGR gas, so that they are collected to a foreign matter collection part in a lower portion of the cyclone type collection device 11.

[0039] In this embodiment, a flow rate regulating passage 12 is arranged which serves to connect between the foreign matter collection part in the lower portion of the cyclone type collection device 11 and the exhaust passage 4 downstream of its connection portion with the low pressure EGR passage 31. The flow rate regulating passage 12 serves to cause the low pressure EGR gas to flow out of the foreign matter collection part of the cyclone type collection device 11 into the exhaust passage 4 together with the foreign matters.

[0040] A flow rate regulating valve 13 is arranged in the flow rate regulating passage 12. The flow rate regulating valve 13 regulates the flow rate of the low pressure EGR gas flowing through the flow rate regulating passage 12. This flow rate regulating valve 13 is driven to open and close by an electric actuator.

[0041] In the internal combustion engine 1 constructed as stated above, there is arranged in combination therewith an ECU 14 which is an electronic control unit for controlling the internal combustion engine 1. The ECU 14 is a unit that controls the operating state of the internal combustion engine 1 in accordance with the operating conditions of the internal combustion engine 1 and/ or driver's requirements.

[0042] The air flow meter 7 and a crank position sensor 15 for detecting an engine rotational speed are connected to the ECU 14 through wiring, and the outputs of these various sensors are inputted to the ECU 14.

[0043] On the other hand, the respective actuators of the throttle valve 6, the exhaust throttle valve 10, the low pressure EGR valve 32, and the flow rate regulating valve 13 are connected to the ECU 14 through wiring, so that these pieces of equipment are controlled by the ECU 14.

[0044] In this embodiment, the flow rate of the low pressure EGR gas is controlled by using the low pressure EGR valve 32 in accordance with the operating state of the internal combustion engine 1. By this control, a so-called EGR operation is carried out in which the internal combustion engine 1 is operated in a state where the low pressure EGR gas is contained in the intake air sucked into the internal combustion engine 1, whereby the oxygen concentration of the intake air is reduced to lower the combustion temperature and the combustion speed, thus exhibiting the effect of reducing NOx generated during combustion.

[0045] Fig. 2 shows the flow rate of the low pressure EGR gas which is required in accordance with the operating state of the internal combustion engine 1. The axis of abscissa in Fig. 2 represents the engine load of the internal combustion engine 1, and the axis of ordinate represents the flow rate of the low pressure EGR gas. In two characteristic curves in Fig. 2, an upper characteristic curve is a characteristic curve in the case where the number of revolutions per unit time (hereinafter referred to as engine revolution number) of the internal combustion engine 1 is high, and a lower characteristic curve is a characteristic curve in the case where the number of revolutions per unit time of the internal combustion engine 1 is low. As shown in Fig. 2, the flow rate of the low pressure EGR gas required of the internal combustion engine 1 tends to increase in accordance with the increasing number of revolutions per unit time of the engine when the engine load as an operating state of the internal combustion engine 1 is in a light or middle load range. The flow rate of the low pressure EGR gas required in accordance with the operating state of the internal combustion engine 1 is supplied by the use of a map as shown in Fig. 2.

[0046] Incidentally, in this embodiment, the cyclone type collection device 11 is arranged in the low pressure EGR passage 31. The cyclone type collection device 11 arranged in the low pressure EGR passage 31 can also collect foreign matters of smaller particle sizes as the flow rate of the low pressure EGR gas increases and the flow speed of the low pressure EGR gas becomes faster. However, in cases where the flow rate of the low pressure EGR gas increases, a pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 becomes larger. As this pressure loss becomes larger, a desired amount of the low pressure EGR gas will no longer be supplied to the internal combustion engine 1, so the low pressure EGR gas will be short or insufficient. Thus, due to the factor of shortage of the low pressure EGR gas, the oxygen concentration of intake air will not lower, and hence the combustion temperature and the combustion speed will not be decreased, as a result of which NOx will be generated at the time of combustion, thereby inducing the deterioration of exhaust emissions.

[0047] In addition, if the exhaust throttle valve 10 is controlled to a closed side in order to supply the low pressure EGR gas which is in shortage, the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 will become still larger, and at the same time, the flow of the exhaust gas will also be delayed or stagnated and a pumping loss will be increased, thus inducing the reduction in the output of the internal combustion engine 1 and the deterioration of fuel consumption.

[0048] Accordingly, in this embodiment, the opening and closing control of the flow rate regulating valve 13 is carried out in accordance with the pressure loss occurring at the time when the low pressure EGR gas flowing through the low pressure EGR passage 31 passes through the cyclone type collection device 11.

[0049] Here, the pressure loss at the time of the low

pressure EGR gas passing through the cyclone type collection device 11 has a correlation to the flow rate of the low pressure EGR gas which flows into the cyclone type collection device 11, and hence, the larger the flow rate of the low pressure EGR gas, the larger the pressure loss also becomes. For this reason, as the practical control of the flow rate regulating valve 13, the flow rate of the low pressure EGR gas whose correlation to the pressure loss has been beforehand obtained is calculated, and the opening and closing control of the flow rate regulating valve 13 is carried out in accordance with the flow rate of the low pressure EGR gas thus calculated.

[0050] Specifically, the flow rate regulating valve 13 is closed in cases where the flow rate of the low pressure EGR gas flowing through the low pressure EGR passage 31 is less than a first predetermined flow rate used as a threshold which gives priority to reducing the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 rather than collecting foreign matters by the cyclone type collection device 11.

[0051] On the other hand, the flow rate regulating valve 13 is opened in cases where the flow rate of the low pressure EGR gas becomes equal to or more than the first predetermined flow rate. In addition, the opening degree of the flow rate regulating valve 13 at the time of being opened is defined in a range in which the cyclone type collection device 11 is able to collect foreign matters of particle sizes equal to or larger than a particle size which affects the intake system of the internal combustion engine 1.

[0052] Here, note that the first predetermined flow rate is a flow rate of the low pressure EGR gas that is used as a threshold which gives priority to reducing the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 rather than collecting foreign matters by the cyclone type collection device 11, when the flow rate of the low pressure EGR gas is equal to or larger than the threshold.

[0053] According to this embodiment, in cases where the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 becomes larger, that is, in cases where the flow rate of the low pressure EGR gas flowing into the cyclone type collection device 11 increases, the flow rate regulating valve 13 is opened. With this, in cases where the flow rate of the low pressure EGR gas increases, the low pressure EGR gas is caused to pass from the cyclone type collection device 11 to the flow rate regulating passage 12, so that the low pressure EGR gas stagnating in the cyclone type collection device 11 can be decreased. Thus, the pressure loss generated at the time of the low pressure EGR gas passing through the cyclone type collection device 11 becomes smaller.

[0054] Fig. 3 is a view showing the relation between the flow rate of the low pressure EGR gas flowing into the cyclone type collection device 11 and the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11. In Fig. 3, a first characteristic curve represents the relation between the flow rate of the low pressure EGR gas in the case where the flow rate regulating valve 13 is in a closed state and the pressure loss, and a second characteristic curve represents the relation between the flow rate of the low pressure EGR gas at the time when the flow rate regulating valve 13 is opened and the pressure loss. As shown in Fig. 3, by opening the flow rate regulating valve 13, the pressure loss shifts from a location A of the first characteristic curve to a location B of the second characteristic curve, so that the pressure loss with respect to the flow rate of the low pressure EGR gas becomes small.

[0055] Because the pressure loss is reduced in this manner, a desired amount of low pressure EGR gas can be supplied to the internal combustion engine 1, and the low pressure EGR gas supplied to the internal combustion engine 1 does not become short. Accordingly, a sufficient amount of low pressure EGR gas is supplied so that the oxygen concentration of intake air is decreased to lower the combustion temperature and the combustion speed, as a result of which NOx generated at the time of combustion can be decreased, thus making it possible to suppress the deterioration of exhaust emissions.

[0056] In addition, it becomes unnecessary to control the exhaust throttle valve 10 to a closed side in order to supply the low pressure EGR gas to supplement the shortage thereof, and hence the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 does not become still larger, and the flow of the exhaust gas does not stagnate, whereby the pumping loss does not increase, thereby making it possible to suppress the reduction in the output of the internal combustion engine 1 and the deterioration of fuel consumption.

[0057] Here, if the low pressure EGR gas is caused to flow from the cyclone type collection device 11 to the flow rate regulating passage 12, the flow speed of the low pressure EGR gas passing through the cyclone type collection device 11 becomes slow, so the cyclone type collection device 11 will be unable to collect foreign matters of small particle sizes, and the collection efficiency of the foreign matters of small particle sizes will be decreased. However, in this embodiment, the degree of opening of the flow rate regulating valve 13 is controlled to an open side only within a range in which the cyclone type collection device 11 becomes possible to collect foreign matters of particle sizes equal to or more than a particle size which affects the intake system of the internal combustion engine 1. Thus, foreign matters of particle sizes equal to or larger than the particle size which affects the intake system of the internal combustion engine 1 can be collected by the cyclone type collection device 11.

[0058] Fig. 4 is a view showing the relation between the particle sizes of foreign matters and foreign matter collection efficiencies in the cyclone type collection device 11. A in Fig. 4 denotes a foreign matter collection efficiency at a location A of a first characteristic curve in

the case where the flow rate regulating valve 13 used in Fig. 3 is in a closed state, and B denotes a foreign matter collection efficiency at a location B of a second characteristic curve at the time when the flow rate regulating valve 13 used in Fig. 3 is opened. Also, C denotes a foreign matter collection efficiency at a location C on the first characteristic curve when the flow rate of the low pressure EGR gas is small in the case where the flow rate regulating valve 13 in Fig. 3 is closed. In addition, a diagonally shaded area denotes a range (NG region) in which the particle sizes of foreign matters is equal to or more than the particle size which affects the intake system of the internal combustion engine 1. As shown in Fig. 4, by opening the flow rate regulating valve 13, a shift is made from the foreign matter collection efficiency of A to the foreign matter collection efficiency of B, whereby the foreign matter collection efficiency for collecting foreign matters of small particle sizes is lowered, but foreign matters of particle sizes equal to or larger than the particle size which affects the intake system of the internal combustion engine 1 in the NG region are able to be collected.

[0059] Accordingly, in the case of this embodiment, influences such as the damage of the compressor 5a due to the inclusion of those foreign matters which reach the compressor 5a while being not able to be caught or collected by the cyclone type collection device 11 will not be exerted to the intake system of the internal combustion engine.

[0060] Next, reference will be made to a control routine for the flow rate of the low pressure EGR gas according to this embodiment. Fig. 5 is a flow chart showing the control routine for the flow rate of the low pressure EGR gas according to this embodiment. This routine is carried out in a repeated manner at each predetermined time interval. Here, note that the ECU 14 performing this routine corresponds to a first control means of the present invention.

[0061] In step S101, the ECU 14 reads the outputs of the various kinds of sensors, and detects the operating state of the internal combustion engine 1.

[0062] In step S102, the ECU 14 determines, from the operating state of the internal combustion engine 1 detected in step S101, whether it is necessary to introduce a low pressure EGR gas to the internal combustion engine 1.

[0063] In cases such as where it is necessary to reduce the amount of NOx generated at the time of combustion by decreasing the oxygen concentration of intake air thereby to lower the combustion temperature and the combustion speed, it is determined that it is necessary to introduce a low pressure EGR gas to the internal combustion engine 1.

[0064] In step S102, when an affirmation determination is made that a low pressure EGR gas need be introduced to the internal combustion engine 1, the control routine shifts to step S103. On the other hand, when a negative determination is made in step S102 that a low pressure EGR gas need not be introduced to the internal combustion engine 1, the control routine shifts to step S106.

[0065] In step S103, the ECU 14 calculates the flow rate of the low pressure EGR gas to be introduced from the operating state of the internal combustion engine 1 detected in step S101.

[0066] The flow rate of the low pressure EGR gas can be calculated by obtaining a map as shown in Fig. 2 beforehand, and by taking the engine load and the engine revolution number of the internal combustion engine 1 into this map.

[0067] In step S104, the ECU 14 calculates the degree of opening of the flow rate regulating valve 13 from the flow rate of the low pressure EGR gas calculated in step S103.

[0068] In cases where the flow rate of the low pressure EGR gas calculated in step S103 is less than the first predetermined flow rate, priority is given to collecting foreign matters by means of the cyclone type collection device 11, so the degree of opening of the flow rate regulating valve 13 is zero (in a valve closed state). In cases where the calculated flow rate of the low pressure EGR gas is equal to or more than the first predetermined flow rate, the flow rate of the low pressure EGR gas thus calculated is taken into the map obtained beforehand as shown in Fig. 3 or Fig. 4, and the degree of opening of the flow rate regulating valve 13 is calculated within a range in which the cyclone type collection device 11 is able to collect foreign matters of particle sizes equal to or larger than the particle size which affects the intake system of the internal combustion engine 1. This degree of opening is a value larger than zero. Here, note that the larger the flow rate of the low pressure EGR gas, the larger the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 becomes. From this, the larger the flow rate of the low pressure EGR gas, the greater the degree of opening of the flow rate regulating valve 13 should be so as to make the pressure loss smaller.

[0069] In step S105, the ECU 14 controls the degree of opening of the flow rate regulating valve 13 to the value calculated in step S104.

[0070] On the other hand, in step S106, the ECU 14 closes the flow rate regulating valve 13, thereby placing it into a fully closed state.

[0071] In step S107, in cases where the low pressure EGR gas is introduced to the internal combustion engine 1, the ECU 14 executes an EGR operation by actually introducing the low pressure EGR gas at the low pressure EGR gas flow rate as calculated in step S103. In addition, at this time, a high pressure EGR gas or an internal EGR gas may be introduced. On the other hand, in cases where the low pressure EGR gas is not introduced to the internal combustion engine 1, the EGR operation is carried out while introducing only the high pressure EGR gas or the internal EGR gas. After the processing of this step, this routine is once ended.

[0072] By performing the above control routine, it is

possible to reduce the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11.

<Second Embodiment>

[0073] Next, a second embodiment of the present invention will be described. Here, a construction different from that of the above-mentioned embodiment will be described, and an explanation of the same construction will be omitted.

[0074] Fig. 6 is a view showing the schematic construction of an internal combustion engine and its intake and exhaust systems to which an exhaust gas recirculation apparatus of an internal combustion engine according to this second embodiment of the present invention is applied.

[0075] In this embodiment, a cyclone type collection device 11 is arranged immediately downstream of an exhaust gas purification device 9 while being integrally formed with the exhaust gas purification device 9. In this embodiment, too, a flow rate regulating passage 12 is arranged which serves to connect between a foreign matter collection part in a lower portion of the cyclone type collection device 11 and an exhaust passage 4 downstream of its connection portion with a low pressure EGR passage 31. A flow rate regulating valve 13 is arranged in the flow rate regulating passage 12.

[0076] The low pressure EGR passage 31 serves to connect between a portion of the exhaust passage 4 at a downstream side of the cyclone type collection device 11 and at an upstream side of its connection portion with the flow rate regulating passage 12 and a portion of an intake passage 3 at an upstream side of a compressor 5a and at a downstream side of a throttle valve 6.

[0077] A three-way valve 16 is arranged at a connection part at which the low pressure EGR passage 31, the upstream portion of the exhaust passage 4, and the downstream portion of the exhaust passage 4 are connected with one another. This three-way valve 16 is operated by an electric actuator. The actuator for the three-way valve 16 is connected to an ECU 14 through wiring, so that the three-way valve 16 is controlled by the ECU 14.

[0078] Fig. 7 is a view showing the three-way valve 16 according to this embodiment. The three-way valve 16 shown in Fig. 7 can be changed among three states, i.e., a state (low pressure EGR gas off-state) in which the upstream portion of the exhaust passage 4 at the upstream side of the three-way valve 16 and the downstream portion of the exhaust passage 4 at the downstream side of the three-way valve 16 are connected with each other while cutting off or blocking the low pressure EGR passage 31, shown in Fig. 7(a), a state (low pressure EGR gas on-state) in which the upstream portion of the exhaust passage 4, the downstream portion of the exhaust passage 4 and the low pressure EGR passage 31 are connected with one another, as shown in Fig. 7 (b), and a state (all passages off-state) in which all the passages are cut off or blocked from one another, as shown in Fig. 7(c).

[0079] In the low pressure EGR gas on-state shown in Fig. 7(a) or in the low pressure EGR gas off-state shown in Fig. 7(b), by regulating the passage sectional area of a boundary portion with the upstream portion of the exhaust passage 4 or the downstream portion of the exhaust passage 4, the three-way valve 16 can adjust the amount of exhaust gas flowing into the downstream portion of the exhaust passage 4, and can play the role of an exhaust throttle valve. In the low pressure EGR gas on-state shown in Fig. 7(b), by regulating the passage sectional area of a boundary portion with the low pressure EGR passage 31, the three-way valve 16 can adjust the amount of low pressure EGR gas flowing through the low pressure EGR passage 31, and can play the role of a low pressure EGR valve. In the state of cutting off or blocking all the passages shown in Fig. 7(c), the whole exhaust gas can be caused to flow through the flow rate regulating passage 12, whereby foreign matters deposited on the foreign matter collection part in the lower portion of the cyclone type collection device 11 can be discharged to the exhaust passage 4.

[0080] Incidentally, in this embodiment, the cyclone type collection device 11 is arranged in the exhaust passage 4. The cyclone type collection device 11 arranged in the exhaust passage 4 can also collect foreign matters of smaller particle sizes as the flow rate of the exhaust gas increases and the flow speed of the exhaust gas becomes faster. However, in cases where the exhaust gas flow rate increases, a pressure loss at the time of the exhaust gas passing through the cyclone type collection device 11 becomes larger. As this pressure loss increases, a pumping loss will be increased, thus inducing the reduction in the output of the internal combustion engine 1 and the deterioration of fuel consumption.

[0081] Accordingly, in this embodiment, the opening and closing control of the flow rate regulating valve 13 is carried out in accordance with the pressure loss occurring at the time when the exhaust gas flowing through the exhaust passage 4 passes through the cyclone type collection device 11.

[0082] Here, the pressure loss at the time of the exhaust gas passing through the cyclone type collection device 11 has a correlation to the flow rate of the exhaust gas which flows into the cyclone type collection device 11, and hence, the larger the flow rate of the exhaust gas, the larger the pressure loss also becomes. For this reason, as the practical control of the flow rate regulating valve 13, the flow rate of the exhaust gas whose correlation to the pressure loss has been beforehand obtained is calculated, and the opening and closing control of the flow rate regulating valve 13 is carried out in accordance with the flow rate of the exhaust gas thus calculated.

[0083] Specifically, the flow rate regulating valve 13 is closed in cases where the flow rate of the exhaust gas flowing through the exhaust passage 4 is less than a

second predetermined flow rate used as a threshold which gives priority to reducing the pressure loss at the time of the exhaust gas passing through the cyclone type collection device 11 rather than collecting foreign matters by the cyclone type collection device 11.

[0084] On the other hand, the flow rate regulating valve 13 is opened in cases where the flow rate of the exhaust gas becomes equal to or more than the second predetermined flow rate. In addition, the opening degree of the flow rate regulating valve 13 at the time of being opened is defined in a range in which the cyclone type collection device 11 is able to collect foreign matters of particle sizes equal to or larger than a particle size which affects the intake system of the internal combustion engine 1.

[0085] Here, the second predetermined flow rate is a flow rate of the exhaust gas that is used as a threshold which gives priority to reducing the pressure loss at the time of the exhaust gas passing through the cyclone type collection device 11 rather than collecting foreign matters by the cyclone type collection device 11, when the flow rate of the exhaust gas is equal to or larger than the threshold.

[0086] According to this embodiment, in cases where the pressure loss at the time of the exhaust gas passing through the cyclone type collection device 11 becomes larger, that is, in cases where the flow rate of the exhaust gas flowing into the cyclone type collection device 11 increases, the flow rate regulating valve 13 is opened. By this, in cases where the flow rate of the exhaust gas increases, the exhaust gas is caused to pass from the cyclone type collection device 11 to the flow rate regulating passage 12, so that the exhaust gas stagnating in the cyclone type collection device 11 can be decreased. Thus, the pressure loss generated at the time of the exhaust gas passing through the cyclone type collection device 11 becomes smaller.

[0087] The relation between the flow rate of the exhaust gas flowing into the cyclone type collection device 11 and the pressure loss at the time of the exhaust gas passing through the cyclone type collection device 11 is similar to the relation between the flow rate of the low pressure EGR gas flowing into the cyclone type collection device 11 and the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 as shown in Fig. 3. Accordingly, as shown in Fig. 3, by opening the flow rate regulating valve 13, the pressure loss shifts from a location A of a first characteristic curve to a location B of a second characteristic curve, so that the pressure loss with respect to the flow rate of the exhaust gas becomes small.

[0088] Because the pressure loss is reduced in this manner, the pumping loss can be reduced, thus making it possible to suppress the reduction in the output of the internal combustion engine 1 and the deterioration of fuel consumption.

[0089] Here, if the exhaust gas is caused to flow from the cyclone type collection device 11 to the flow rate regulating passage 12, the flow speed of the exhaust gas passing through the cyclone type collection device 11 becomes slow, so the cyclone type collection device 11 will be unable to collect foreign matters of small particle sizes, and the collection efficiency of the foreign matters of small particle sizes will be decreased. However, in this embodiment, the degree of opening of the flow rate regulating valve 13 is controlled to an open side only within a range in which the cyclone type collection device 11 becomes possible to collect foreign matters of particle sizes equal to or more than the particle size which affects the intake system of the internal combustion engine 1. Thus, foreign matters of particle sizes equal to or larger than the particle size which affects the intake system of the internal combustion engine 1 can be collected by the cyclone type collection device 11.

[0090] In this embodiment, too, the relation between the particle sizes of foreign matters and the foreign matter collection efficiency in the cyclone type collection device 11 becomes as shown in Fig. 4. Therefore, as shown in Fig. 4, by opening the flow rate regulating valve 13, a shift is made from the foreign matter collection efficiency of A to the foreign matter collection efficiency of B, whereby the foreign matter collection efficiency for collecting foreign matters of small particle sizes is lowered, but foreign matters of particle sizes equal to or larger than the particle size which affects the intake system of the internal combustion engine 1 are able to be collected.

[0091] Accordingly, in the case of this embodiment, influences such as the damage of the compressor 5a due to the inclusion of those foreign matters which reach the compressor 5a by way of the low pressure EGR passage 31 while being not able to be caught or collected by the cyclone type collection device 11 will not be exerted to the intake system of the internal combustion engine.

[0092] Here, in this embodiment, the cyclone type collection device 11 is arranged immediately downstream of the exhaust gas purification device 9 while being integrally formed with the exhaust gas purification device 9. For this reason, the exhaust gas carries away an amount of heat from the exhaust gas purification device 9 having an oxidation catalyst which has become high temperature at the time of activation thereof or a NOx catalyst, so that the exhaust gas in a warmed state flows into the cyclone type collection device 11.

[0093] Fig. 8 is a view showing the characteristics of the temperature of the exhaust gas and the amount of water vapor. The axis of abscissa in Fig. 8 represents the temperature of the exhaust gas, and the axis of ordinate represents the amount of water vapor. As shown in Fig. 8, if the exhaust gas in the cyclone type collection device 11 is high in temperature as in this embodiment, the entire amount of water vapor will exist in a vapor side with respect to a boundary line between water and vapor, and no condensate is generated. On the other hand, if the exhaust gas is low in temperature as shown in a broken line, the amount of water vapor will protrude into a water side with respect to the boundary line of water and vapor, and this amount of protrusion will be condensate.

Thus, in this embodiment, the exhaust gas is at high temperature in the cyclone type collection device 11, so the amount of saturated vapor or steam of the exhaust gas does not decrease, thereby making it possible to suppress the generation of condensate from the exhaust gas in the cyclone type collection device 11.

[0094] Accordingly, it is possible to suppress the corrosion reliability of intake and exhaust piping from being affected resulting from the generation of condensate.

[0095] Next, reference will be made to a control routine for the flow rate of the exhaust gas according to this embodiment. Fig. 9 is a flow chart showing the control routine for the flow rate of the exhaust gas according to this embodiment. This routine is carried out in a repeated manner at each predetermined time interval. Here, note that the ECU 14 performing this routine corresponds to a second control means of the present invention.

[0096] In step S201, the ECU 14 reads the outputs of various kinds of sensors, and detects the operating state of the internal combustion engine 1.

[0097] In step S202, the ECU 14 calculates the flow rate of the exhaust gas from the operating state of the internal combustion engine 1 detected in step S201.

[0098] In step S203, the ECU 14 calculates the degree of opening of the flow rate regulating valve 13 from the flow rate of the exhaust gas calculated in step S202.

[0099] In cases where the flow rate of the exhaust gas calculated in step S202 is less than the second predetermined flow rate, priority is given to collecting foreign matters by means of the cyclone type collection device 11, so the degree of opening of the flow rate regulating valve 13 is zero (in a valve closed state). In cases where the calculated flow rate of the exhaust gas is equal to or more than the second predetermined flow rate, the flow rate of the exhaust gas thus calculated is taken into a map which corresponds to the flow rate of exhaust gas, has been obtained beforehand, and is similar to the one as shown in Fig. 3 or Fig. 4, and the degree of opening of the flow rate regulating valve 13 is calculated within a range in which the cyclone type collection device 11 is able to collect foreign matters of particle sizes equal to or larger than the particle size which affects the intake system of the internal combustion engine 1. This degree of opening is a value larger than zero. Here, note that the larger the flow rate of the exhaust gas, the larger the pressure loss at the time of the exhaust gas passing through the cyclone type collection device 11 becomes. From this, the larger the flow rate of the exhaust gas, the greater the degree of opening of the flow rate regulating valve 13 should be so as to make the pressure loss smaller.

[0100] In step S204, the ECU 14 controls the degree of opening of the flow rate regulating valve 13 to the value calculated in step S203. After the processing of this step, this routine is once ended.

[0101] By performing the above control routine, it is possible to reduce the pressure loss at the time of the exhaust gas passing through the cyclone type collection device 11.

[0102] Here, note that in this embodiment, the cyclone type collection device 11 is arranged integrally with and immediately downstream of the exhaust gas purification device 9, but it is not limited to this, and if the exhaust gas flowing into the cyclone type collection device 11, which has been heated to high temperatures by carrying away an amount of heat from the exhaust gas purification device 9, does not generate condensate in the cyclone type collection device 11, the cyclone type collection device 11 may be formed separately from and arranged away from the exhaust gas purification device 9.

<Third Embodiment>

[0103] Next, a third embodiment of the present invention will be described. Here, a construction different from that of the above-mentioned embodiment will be described, and an explanation of the same construction will be omitted.

[0104] Fig. 10 is a view showing the schematic construction of an internal combustion engine and its intake and exhaust systems to which an exhaust gas recirculation apparatus of an internal combustion engine according to this third embodiment of the present invention is applied.

[0105] In this embodiment, a bypass passage 17 for causing a low pressure EGR gas to bypass a cyclone type collection device 11 is arranged in a low pressure EGR passage 31.

[0106] In the bypass passage 17, there is arranged a bypass valve 18 that is opened so as to circulate the low pressure EGR gas through the bypass passage 17, and is closed so as to block the circulation of the low pressure EGR gas in the bypass passage 17. This bypass valve 18 is driven to open and close by an electric actuator. The actuator for the bypass valve 18 is connected to an ECU 14 through wiring, so that the bypass valve 18 is controlled by the ECU 14.

[0107] Incidentally, in this embodiment, the cyclone type collection device 11 is arranged in the low pressure EGR passage 31. When the low pressure EGR gas passes through the cyclone type collection device 11, not a little pressure loss will be caused. As this pressure loss becomes larger, a desired amount of the low pressure EGR gas will no longer be supplied to the internal combustion engine, so the low pressure EGR gas will be short or insufficient. Thus, due to the factor of shortage of the low pressure EGR gas, the oxygen concentration of intake air will not lower, and hence the combustion temperature and the combustion speed will not be decreased, as a result of which NOx will be generated at the time of combustion, thereby inducing the deterioration of exhaust emissions.

[0108] In addition, if the exhaust throttle valve 10 is controlled to a closed side in order to supply the low pressure EGR gas which is in shortage, the pressure loss at the time of the low pressure EGR gas passing through

the cyclone type collection device 11 will become still larger, and at the same time, the flow of the exhaust gas will also be delayed or stagnated and a pumping loss will be increased, thus inducing the reduction in the output of the internal combustion engine 1 and the deterioration of fuel consumption.

[0109] Accordingly, in this embodiment, the bypass valve 18 is opened in cases where the flow rate of the low pressure EGR gas flowing through the low pressure EGR passage 31 is less than a third predetermined flow rate that is a threshold which does not allow foreign matters entrained in the low pressure EGR gas to reach a compressor 5a, and in cases where the number of revolutions per unit time of a turbocharger 5 is lower than a predetermined number of revolutions per unit time that is a threshold with which the compressor 5a will not be damaged even if foreign matters of small particle sizes unable to be collected by the cyclone type collection device 11 reach the compressor 5a.

[0110] Here, note that the third predetermined flow rate means a flow rate of the low pressure EGR gas that is a threshold below which foreign matters entrained in the low pressure EGR gas are unable to reach the compressor 5a. In addition, the predetermined number of revolutions per unit time means a number of revolutions of the turbocharger 5 that is a threshold below which foreign matters of small particle sizes unable to be collected by the cyclone type collection device 11, even if reach the compressor 5a, will not damage the compressor 5a.

[0111] Fig. 11 is a view showing a region in which the bypass valve 18 is opened in accordance with the operating state of the internal combustion engine 1. The axis of abscissa in Fig. 11 represents the engine revolution number of the internal combustion engine 1, and the axis of ordinate represents the engine load of the internal combustion engine 1. In Fig. 11, a plurality of solid line characteristic curves denote the flow rates of the low pressure EGR gas which are required in accordance with the operating state of the internal combustion engine 1, wherein the flow rate of the low pressure EGR gas required of the internal combustion engine tends to increase in accordance with the increasing number of revolutions per unit time of the engine when the engine load is in a light or middle load range. A plurality of broken line characteristic curves denote the numbers of revolutions per unit time of the turbocharger 5 which are required in accordance with the operating state of the internal combustion engine, wherein the number of revolutions per unit time of the turbocharger 5 required of the internal combustion engine 1 tends to increase in accordance with the increasing number of revolutions per unit time of the engine when the engine load is in a high load range. In addition, a diagonally shaded area denotes a region (bypass valve opening region) in which a condition for opening the bypass valve 18 is fulfilled. The diagonally shaded area which is a bypass valve opening region is a region in which the flow rate of the low pressure EGR gas is less than the third predetermined flow rate and the number of revolutions per unit time of the turbocharger is lower than the predetermined number of revolutions per unit time.

[0112] According to this embodiment, in cases where the operating state of the internal combustion engine 1 is in the bypass valve opening region of the diagonally shaded area in Fig. 11, the bypass valve 18 is opened. With this, the low pressure EGR gas flowing through the low pressure EGR passage 31 is caused to bypass the cyclone type collection device 11, so that the low pressure EGR gas flows through the bypass passage 17. For this reason, there will be no pressure loss generated at the time of the low pressure EGR gas passing through the cyclone type collection device 11. Therefore, the pressure loss on the route of the low pressure EGR passage 31 becomes small.

[0113] Fig. 12 is a view showing the relation between the flow rate of the low pressure EGR gas and the pressure loss on the route of the low pressure EGR passage 31. In Fig. 12, a broken line characteristic curve denotes the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 with respect to the flow rate of the low pressure EGR gas, and a solid line characteristic curve denotes the pressure loss at the time of the low pressure EGR gas passing through the bypass passage 17 with respect to the flow rate of the low pressure EGR gas. As shown in Fig. 12, the pressure loss becomes small in cases where the bypass valve 18 is opened so that the low pressure EGR gas passes through the bypass passage 17.

[0114] Because the pressure loss on the route of the low pressure EGR passage 31 is reduced in this manner, a desired amount of low pressure EGR gas can be supplied to the internal combustion engine 1, and the low pressure EGR gas supplied to the internal combustion engine 1 does not become short. Accordingly, a sufficient amount of low pressure EGR gas is supplied so that the oxygen concentration of intake air is decreased to lower the combustion temperature and the combustion speed, as a result of which NOx generated at the time of combustion can be decreased, thus making it possible to suppress the deterioration of exhaust emissions.

[0115] In addition, it becomes unnecessary to control the exhaust throttle valve 10 to a closed side in order to supply the low pressure EGR gas to supplement the shortage thereof, and hence the pressure loss at the time of the low pressure EGR gas passing through the cyclone type collection device 11 does not become still larger, and the flow of the exhaust gas does not stagnate, whereby the pumping loss does not increase, thereby making it possible to suppress the reduction in the output of the internal combustion engine 1 and the deterioration of fuel consumption.

[0116] Here, when the low pressure EGR gas is caused to flow into the bypass passage 17, the low pressure EGR gas does not pass through the cyclone type collection device 11, and the cyclone type collection device 11 can not collect foreign matters. However, in this

embodiment, the bypass valve 18 is opened in cases where the flow rate of the low pressure EGR gas flowing through the low pressure EGR passage 31 is less than a third predetermined flow rate that is a threshold which does not allow foreign matters entrained in the low pressure EGR gas to reach a compressor 5a, and in cases where the number of revolutions per unit time of a turbocharger 5 is lower than a predetermined number of revolutions per unit time that is a threshold with which the compressor 5a will not be damaged even if foreign matters of small particle sizes unable to be collected by the cyclone type collection device 11 reach the compressor 5a. For this reason, even if foreign matters are unable to be collected by the cyclone type collection device 11, the foreign matters entrained on the low pressure EGR gas will not reach the compressor 5a, or even if foreign matters of small particle sizes, which can not be fully collected by the cyclone type collection device 11, reaches the compressor 5a, the compressor 5a will not be damaged. Accordingly, it is possible to suppress adverse effects due to the inclusion of foreign matters on the intake system of the internal combustion engine 1.

[0117] Next, reference will be made to a control routine for the bypass valve 18 according to this embodiment. Fig. 13 is a flow chart showing the control routine for the bypass valve 18 according to this embodiment. This routine is carried out in a repeated manner at each predetermined time interval. Here, note that the ECU 14 performing this routine corresponds to a third control means of the present invention.

[0118] In step S301, the ECU 14 reads the outputs of various kinds of sensors, and detects the operating state of the internal combustion engine 1. Here, the number of revolutions per unit time of the turbocharger 5 is also detected by a compressor revolution number sensor, etc., which is arranged adjacent to the compressor 5a.

[0119] In step S302, the ECU 14 determines, from the operating state of the internal combustion engine 1 detected in step S301, whether it is necessary to introduce a low pressure EGR gas to the internal combustion engine 1.

[0120] In step S302, when an affirmation determination is made that a low pressure EGR gas need be introduced to the internal combustion engine 1, the control routine shifts to step S303. On the other hand, when a negative determination is made in step S302 that a low pressure EGR gas need not be introduced to the internal combustion engine 1, the control routine shifts to step S307.

[0121] In step S303, the ECU 14 calculates the flow rate of the low pressure EGR gas to be introduced from the operating state of the internal combustion engine 1 detected in step S301.

[0122] In step S304, the ECU 14 determines whether the flow rate of the low pressure EGR gas calculated in step S303 is less than the third predetermined flow rate.

[0123] In step S304, when an affirmation determination is made that the flow rate of the low pressure EGR gas is less than the third predetermined flow rate, the control routine shifts to step S305. On the other hand, when a negative determination is made in step S304 that the flow rate of the low pressure EGR gas is equal to or more than the third predetermined flow rate, the control routine shifts to step S307.

[0124] In step S305, the ECU 14 determines whether the number of revolutions per unit time of the turbocharger 5 detected in step S301 is lower than the predetermined number of revolutions per unit time (predetermined revolution number).

[0125] When an affirmative determination is made in step S305 that the number of revolutions per unit time of the turbocharger 5 is lower than the predetermined number of revolutions per unit time, the control routine shifts to step S306. On the other hand, when a negative determination is made in step S305 that the number of revolutions per unit time of the turbocharger 5 is equal to or more than the predetermined number of revolutions per unit time, the control routine shifts to step S307.

[0126] In step S306, the ECU 14 opens the bypass valve 18. After the processing of this step, this routine is once ended.

[0127] On the other hand, in step S307, the ECU 14 closes the bypass valve 18. After the processing of this step, this routine is once ended.

[0128] By performing the above control routine, the low pressure EGR gas is caused to bypass the cyclone type collection device 11, thereby making it possible to reduce the pressure loss on the route of the low pressure EGR passage 31.

[0129] An exhaust gas recirculation apparatus of an internal combustion engine according to the present invention is not limited to the above-mentioned embodiments, but can be subjected to various changes and modifications within the scope not departing from the gist of the present invention.

Claims

1. An exhaust gas recirculation apparatus of an internal combustion engine which is **characterized by** comprising:

   a turbocharger that has a turbine arranged in an exhaust passage of said internal combustion engine and a compressor arranged in an intake passage of said internal combustion engine;
   a low pressure EGR passage that takes in a part of an exhaust gas as a low pressure EGR gas from said exhaust passage downstream of said turbine, and recirculates the low pressure EGR gas to said intake passage upstream of said compressor;
   a cyclone type collection device that is arranged in said low pressure EGR passage and collects foreign matters in said low pressure EGR gas;

a flow rate regulating passage that causes said low pressure EGR gas to flow from a foreign matter collection part of said cyclone type collection device into said exhaust passage downstream of a connection part thereof with said low pressure EGR passage;
a flow rate regulating valve that is arranged in said flow rate regulating passage and regulates the flow rate of the low pressure EGR gas flowing through said flow rate regulating passage; and
a first control means that performs the opening and closing control of said flow rate regulating valve in accordance with a pressure loss occurring at the time when the low pressure EGR gas flowing through said low pressure EGR passage passes through said cyclone type collection device.

2. The exhaust gas recirculation apparatus of an internal combustion engine as set forth in claim 1, **characterized in that**
said first control means
closes said flow rate regulating valve, in cases where the flow rate of the low pressure EGR gas flowing through said low pressure EGR passage is less than a first predetermined flow rate used as a threshold which gives priority to reducing the pressure loss at the time of said low pressure EGR gas passing through said cyclone type collection device rather than collecting foreign matters by said cyclone type collection device, and
opens said flow rate regulating valve at a degree of opening in a range in which said cyclone type collection device is able to collect foreign matters of particle sizes equal to or larger than the particle size with which said cyclone type collection device affects an intake system of the internal combustion engine in cases where the flow rate of the low pressure EGR gas flowing through said low pressure EGR passage becomes equal to or more than said first predetermined flow rate.

3. An exhaust gas recirculation apparatus of an internal combustion engine which is **characterized by** comprising:

a turbocharger that has a turbine arranged in an exhaust passage of said internal combustion engine and a compressor arranged in an intake passage of said internal combustion engine;
a catalyst that is arranged in said exhaust passage downstream of said turbine and becomes a high temperature when activated;
a cyclone type collection device that is arranged in said exhaust passage immediately downstream of said catalyst and collects foreign matters in an exhaust gas;
a low pressure EGR passage that takes in a part of an exhaust gas as a low pressure EGR gas from said exhaust passage downstream of said cyclone type collection device, and recirculates the low pressure EGR gas to said intake passage upstream of said compressor;
a flow rate regulating passage that causes the exhaust gas to flow from a foreign matter collection part of said cyclone type collection device into said exhaust passage downstream of a connection part thereof with said low pressure EGR passage;
a flow rate regulating valve that is arranged in said flow rate regulating passage and regulates the flow rate of the exhaust gas flowing through said flow rate regulating passage; and
a second control means that performs the opening and closing control of said flow rate regulating valve in accordance with a pressure loss occurring at the time when the exhaust gas flowing through said exhaust passage passes through said cyclone type collection device.

4. The exhaust gas recirculation apparatus of an internal combustion engine as set forth in claim 3, **characterized in that**
said second control means
closes said flow rate regulating valve in cases where the flow rate of the exhaust gas flowing through said exhaust passage is less than a second predetermined flow rate used as a threshold which gives priority to reducing the pressure loss at the time of the exhaust gas passing through said cyclone type collection device rather than collecting foreign matters by said cyclone type collection device, and
opens said flow rate regulating valve at a degree of opening in a range in which said cyclone type collection device is able to collect foreign matters of particle sizes equal to or larger than the particle size with which said cyclone type collection device affects an intake system of the internal combustion engine in cases where the flow rate of the exhaust gas flowing through said exhaust passage becomes equal to or more than said second predetermined flow rate.

5. An exhaust gas recirculation apparatus of an internal combustion engine which is **characterized by** comprising:

a turbocharger that has a turbine arranged in an exhaust passage of said internal combustion engine and a compressor arranged in an intake passage of said internal combustion engine;
a low pressure EGR passage that takes in a part of an exhaust gas as a low pressure EGR gas from said exhaust passage downstream of said turbine, and recirculates the low pressure EGR gas to said intake passage upstream of said compressor;

a cyclone type collection device that is arranged in said low pressure EGR passage and collects foreign matters in said low pressure EGR gas;
a bypass passage that serves to cause said low pressure EGR gas to bypass said cyclone type collection device in said low pressure EGR passage;
a bypass valve that opens and closes said bypass passage; and
a third control means that opens said bypass valve in cases where the flow rate of the low pressure EGR gas flowing through said low pressure EGR passage is less than a third predetermined flow rate that is a threshold which does not allow foreign matters to reach said compressor, and in cases where the number of revolutions per unit time of said turbocharger is lower than a predetermined number of revolutions per unit time that is a threshold with which said compressor will not be damaged even if foreign matters of small particle sizes unable to be collected by said cyclone type collection device reach said compressor.

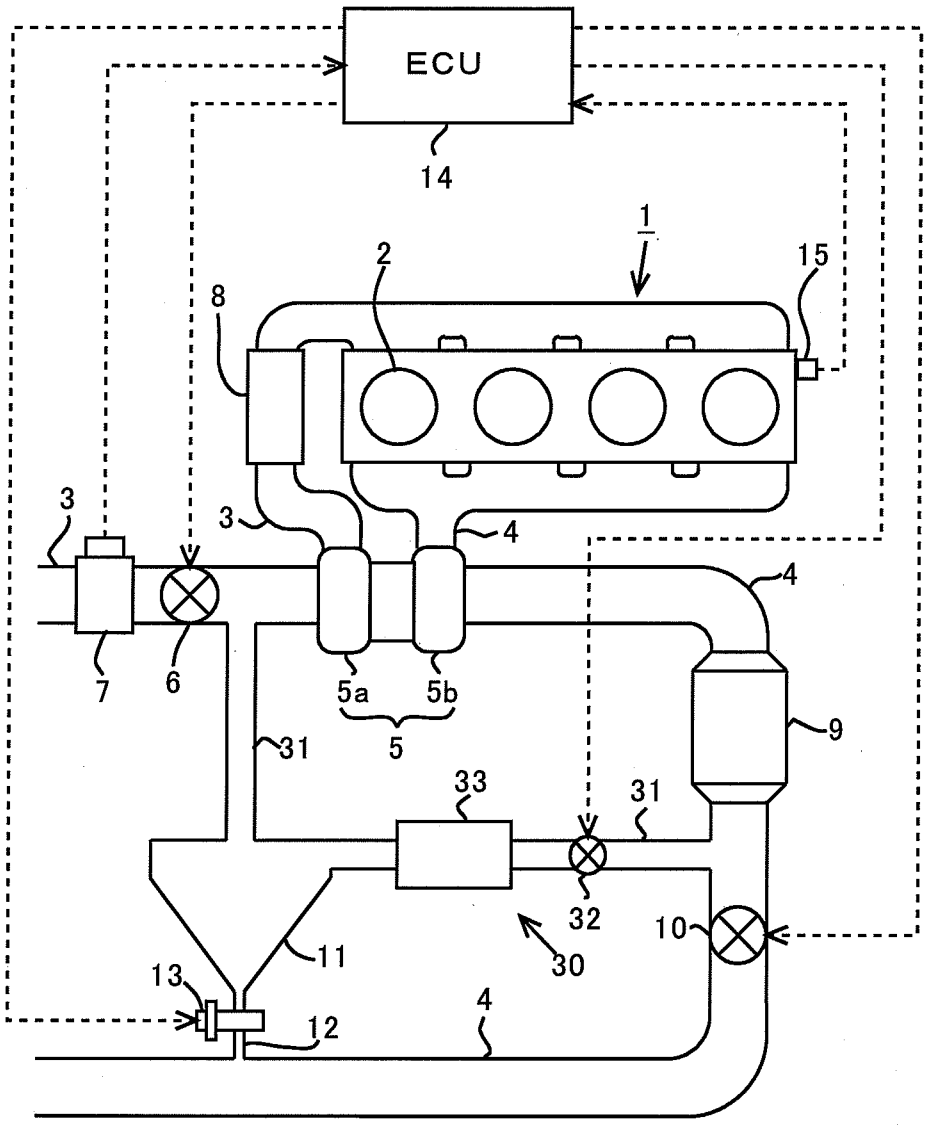


FIG.1

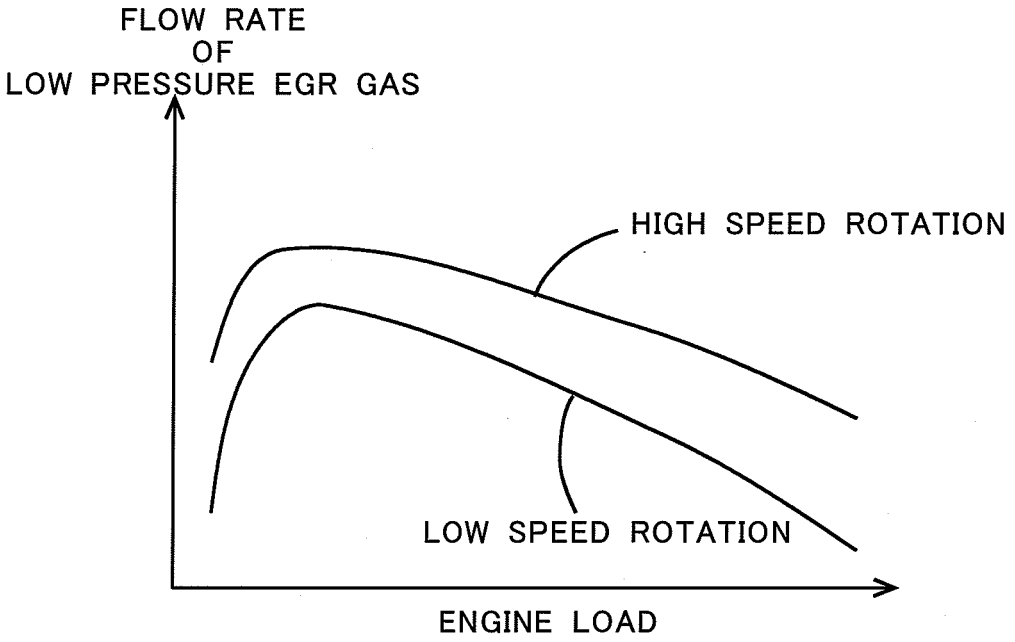

FLOW RATE
OF
LOW PRESSURE EGR GAS
HIGH SPEED ROTATION
LOW SPEED ROTATION
ENGINE LOAD

FIG.2

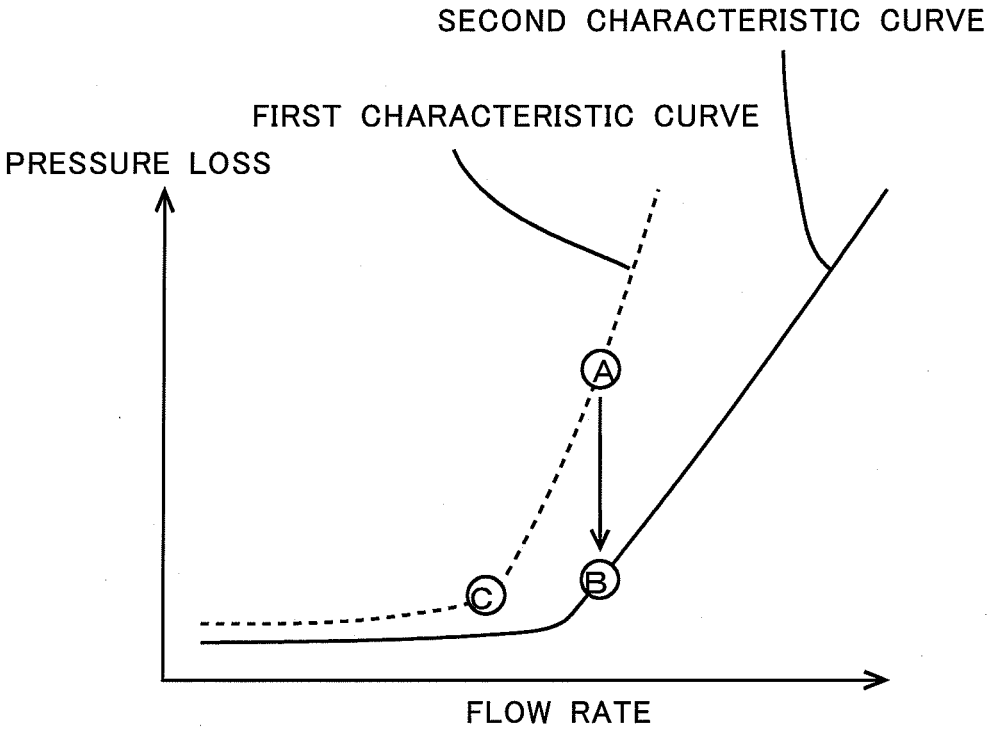

SECOND CHARACTERISTIC CURVE
FIRST CHARACTERISTIC CURVE
PRESSURE LOSS
A
B
C
FLOW RATE

FIG.3

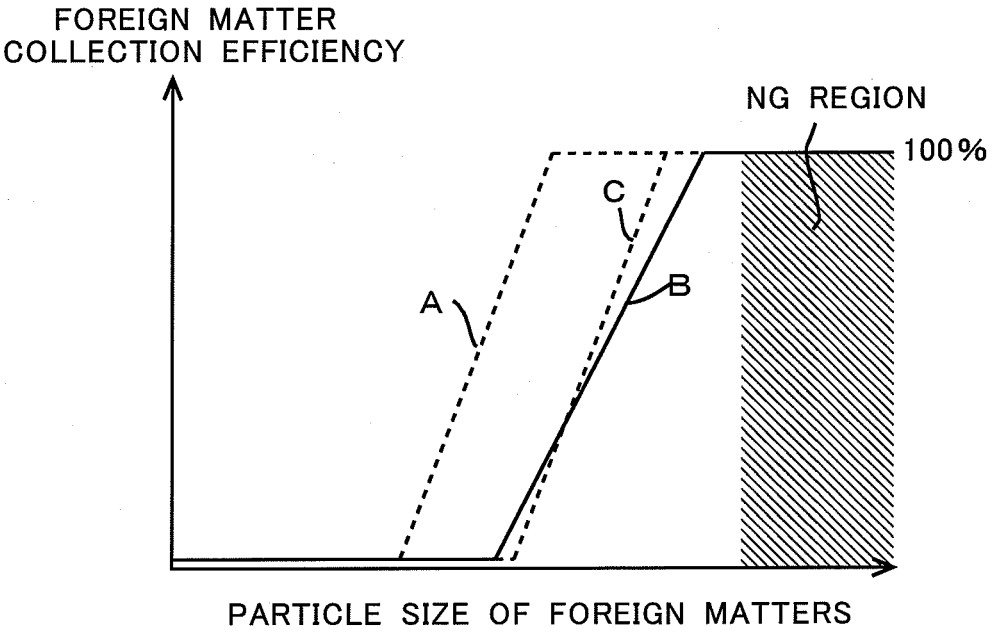

FOREIGN MATTER
COLLECTION EFFICIENCY
NG REGION
100%
C
B
A
PARTICLE SIZE OF FOREIGN MATTERS

FIG.4

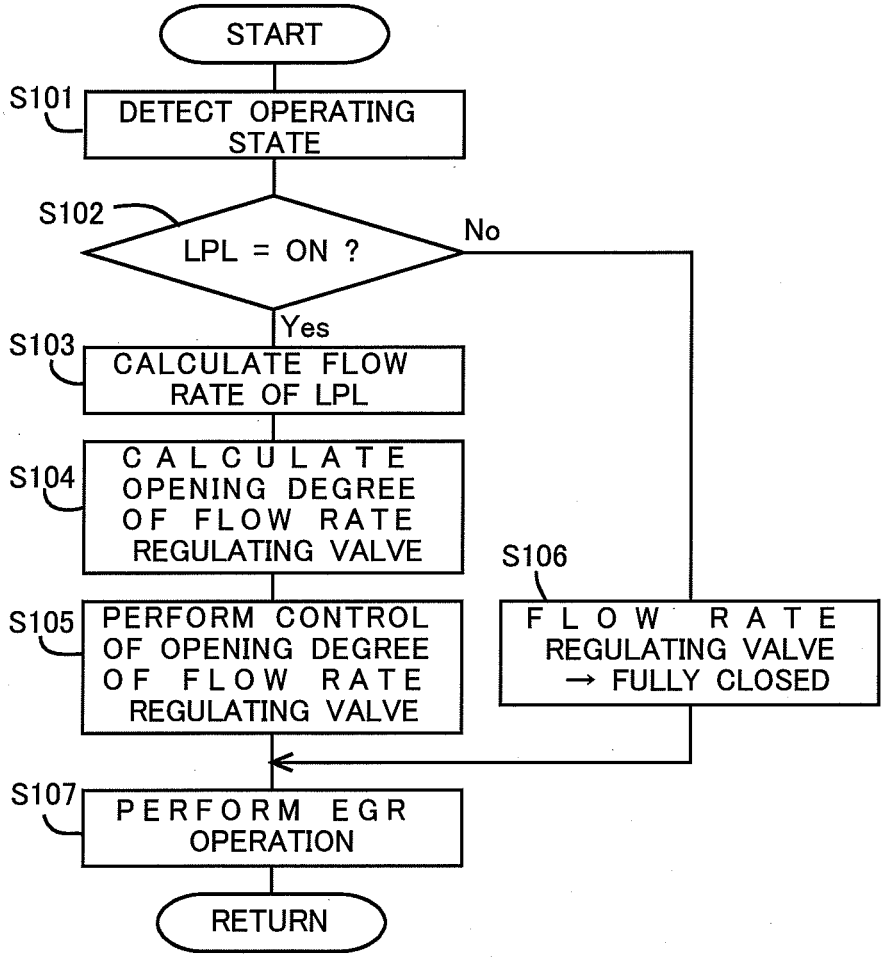

START
S101
DETECT OPERATING STATE
S102
LPL = ON ?
No
Yes
S103
CALCULATE FLOW RATE OF LPL
S104
CALCULATE OPENING DEGREE OF FLOW RATE REGULATING VALVE
S105
PERFORM CONTROL OF OPENING DEGREE OF FLOW RATE REGULATING VALVE
S106
FLOW RATE REGULATING VALVE → FULLY CLOSED
S107
PERFORM EGR OPERATION
RETURN

FIG.5

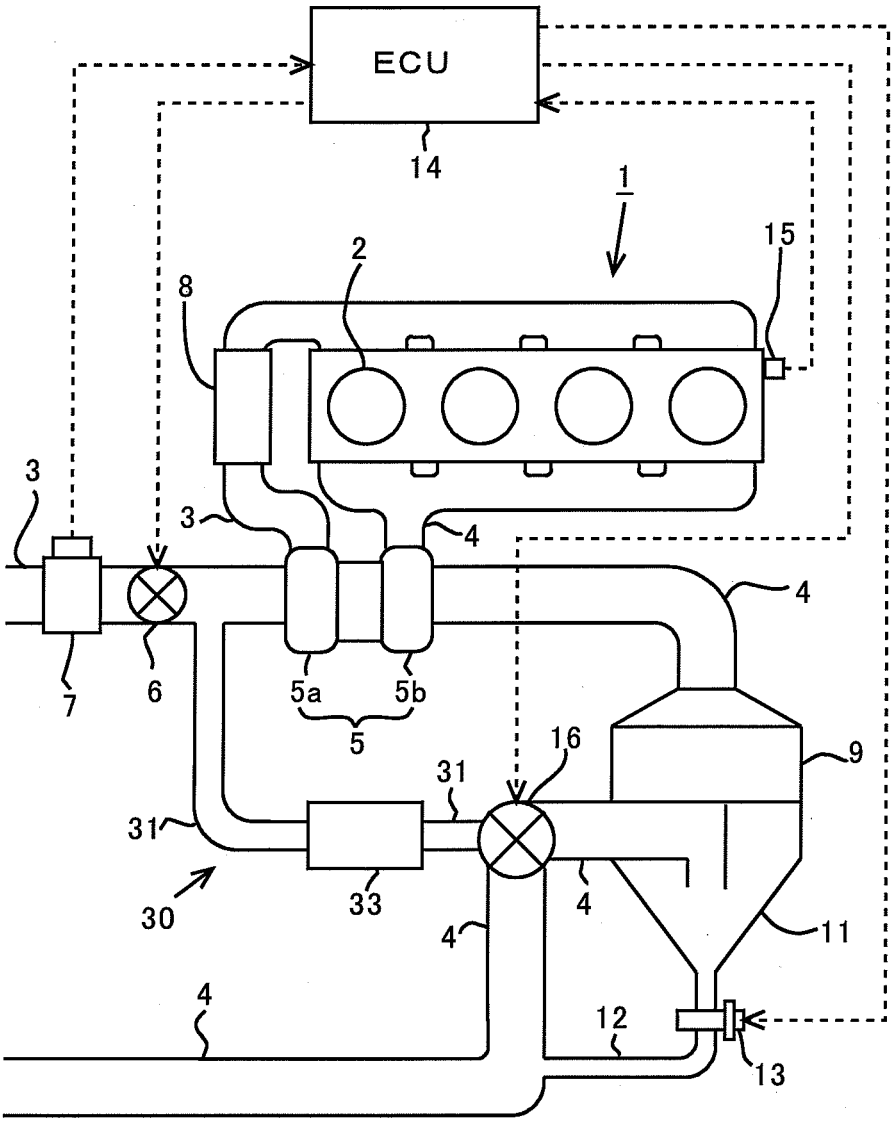


FIG.6

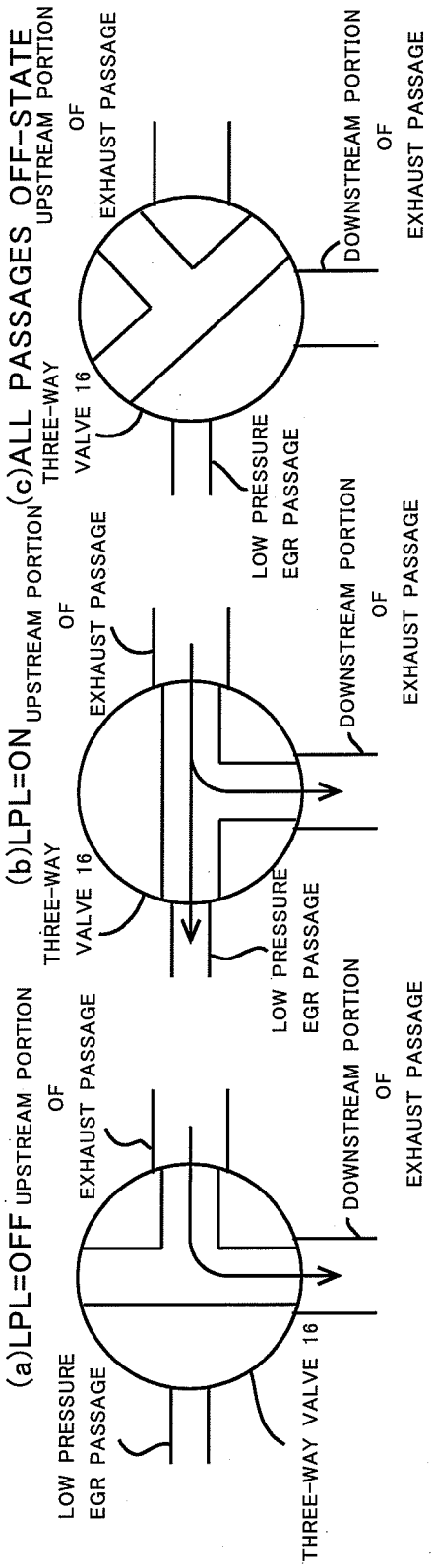


FIG.7A FIG.7B FIG.7C

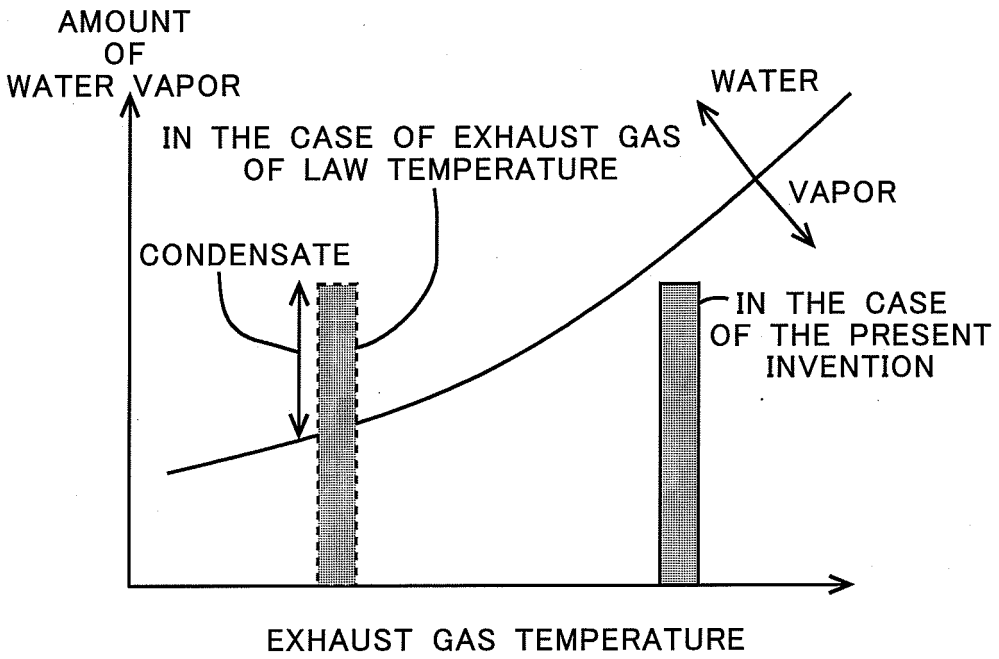

AMOUNT
OF
WATER VAPOR
WATER
IN THE CASE OF EXHAUST GAS
OF LAW TEMPERATURE
VAPOR
CONDENSATE
IN THE CASE
OF THE PRESENT
INVENTION
EXHAUST GAS TEMPERATURE

FIG.8

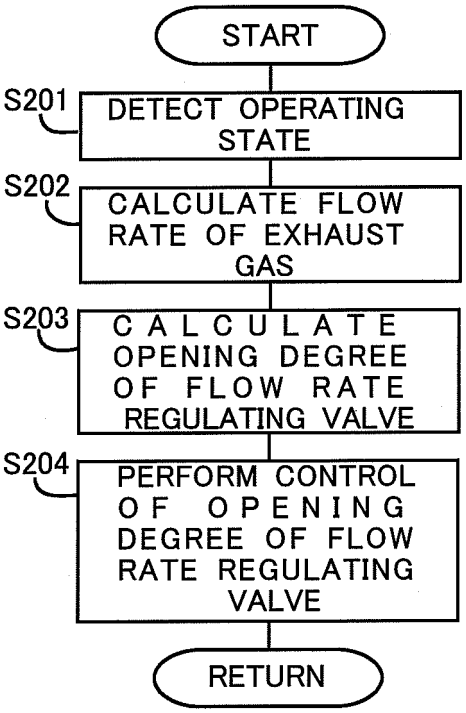

START
S201
DETECT OPERATING STATE
S202
CALCULATE FLOW RATE OF EXHAUST GAS
S203
CALCULATE OPENING DEGREE OF FLOW RATE REGULATING VALVE
S204
PERFORM CONTROL OF OPENING DEGREE OF FLOW RATE REGULATING VALVE
RETURN

FIG.9

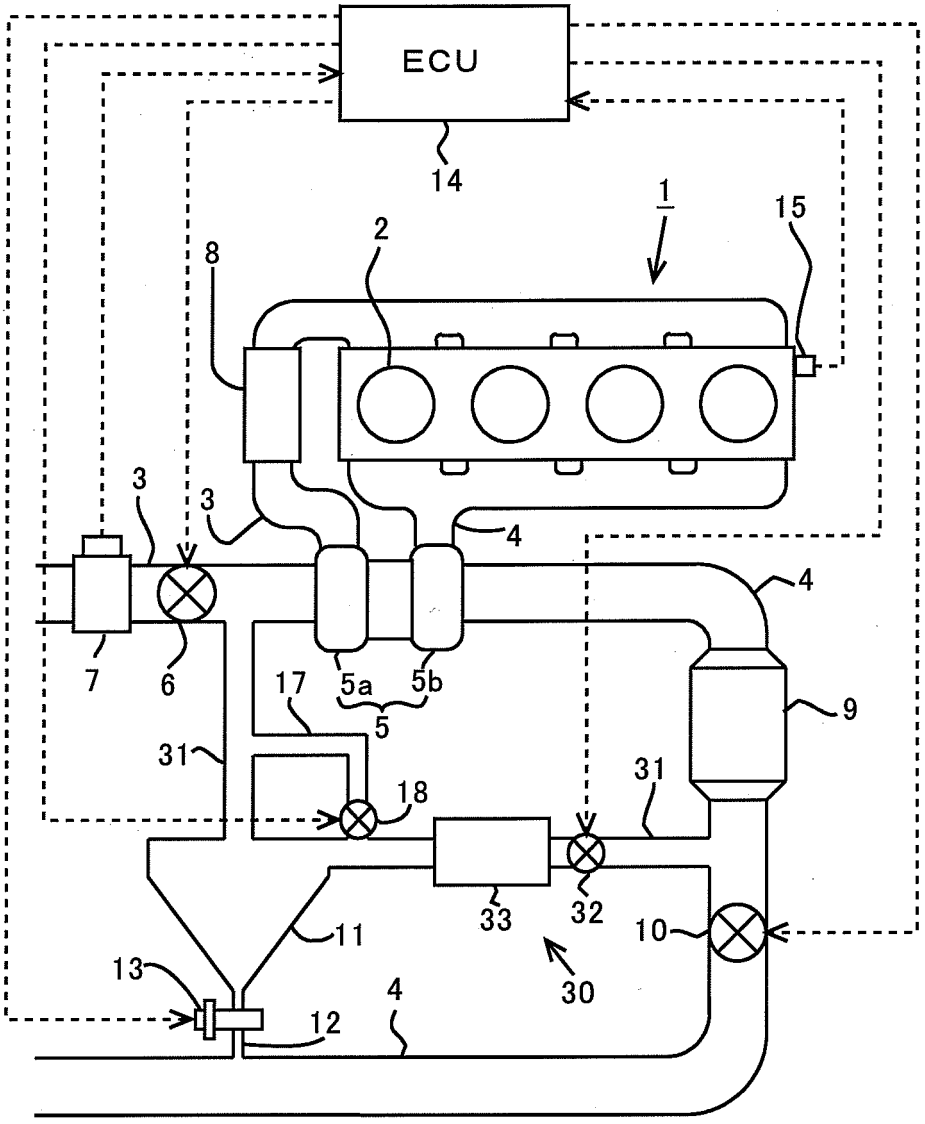


FIG.10

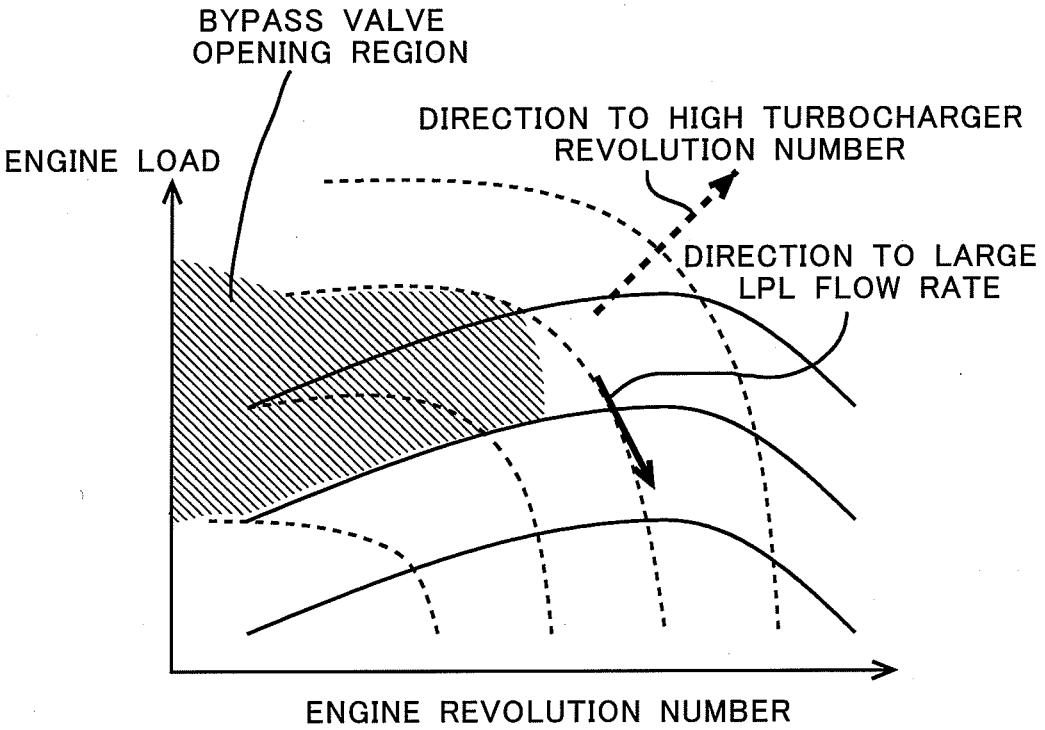

BYPASS VALVE
OPENING REGION
DIRECTION TO HIGH TURBOCHARGER
REVOLUTION NUMBER
ENGINE LOAD
DIRECTION TO LARGE
LPL FLOW RATE
ENGINE REVOLUTION NUMBER

FIG.11

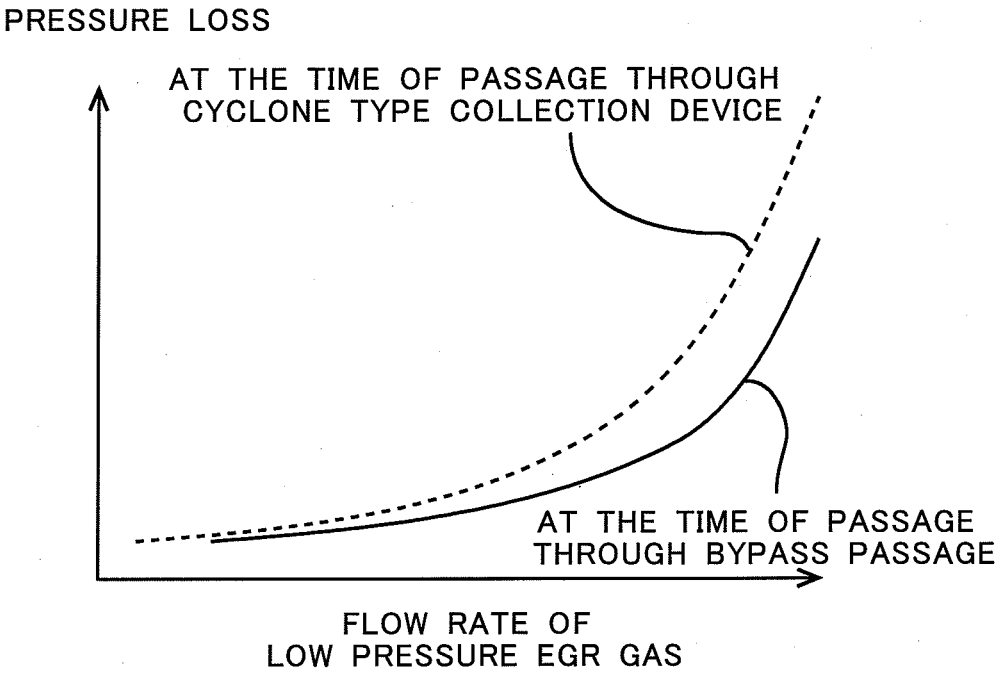

PRESSURE LOSS
AT THE TIME OF PASSAGE THROUGH CYCLONE TYPE COLLECTION DEVICE
AT THE TIME OF PASSAGE THROUGH BYPASS PASSAGE
FLOW RATE OF LOW PRESSURE EGR GAS

FIG.12

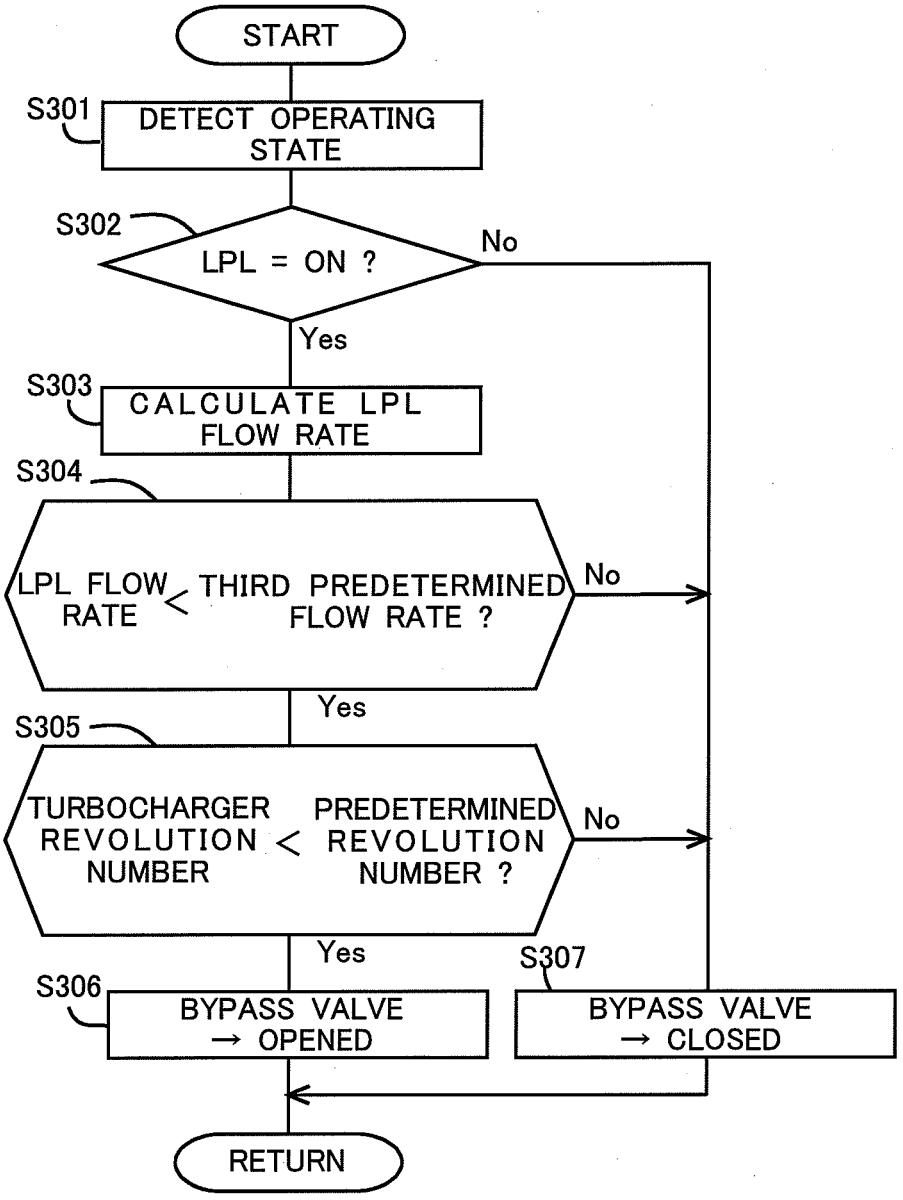

START
S301
DETECT OPERATING STATE
S302
LPL = ON ?
No
Yes
S303
CALCULATE LPL FLOW RATE
S304
LPL FLOW RATE < THIRD PREDETERMINED FLOW RATE ?
No
Yes
S305
TURBOCHARGER REVOLUTION NUMBER < PREDETERMINED REVOLUTION NUMBER ?
No
Yes
S306
BYPASS VALVE → OPENED
S307
BYPASS VALVE → CLOSED
RETURN

FIG.13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/068702

A. CLASSIFICATION OF SUBJECT MATTER
F02M25/07(2006.01)i

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)
F02M25/07

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2008
Kokai Jitsuyo Shinan Koho 1971-2008 Toroku Jitsuyo Shinan Koho 1994-2008

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 82083/1981(Laid-open No. 193954/1982) (Toyota Motor Co., Ltd.), 08 December, 1982 (08.12.82), Description, page 2, line 15 to page 5, line 17; Figs. 1, 2 (Family: none)	1-5
A	JP 2000-170608 A (Toyota Motor Corp.), 20 June, 2000 (20.06.00), Par. Nos. [0026], [0027]; Fig. 5 (Family: none)	1-5

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"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	Date of mailing of the international search report
26 December, 2008 (26.12.08)	13 January, 2009 (13.01.09)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/068702

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

The inventions of claims 1-4 relate to a flow rate regulation valve which is placed in a flow rate regulation path extending from a foreign matter collection section of a cyclone collector and whose opening and closing are controlled according to a pressure loss of gas passing through the cyclone collector.

The invention of claim 5 relates to a bypass valve which is placed in a bypass path bypassing a cyclone collector and whose opening and closing are controlled according to the flow rate of a low-pressure EGR gas and to the speed of a turbocharger.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

the

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (April 2007)

REFERENCES CITED IN THE DESCRIPTION

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

Patent documents cited in the description

- JP 2002130058 A **[0002]**
- JP 2000170608 A **[0002]**
- JP 2005155559 A **[0002]**
- JP H07158420 B **[0002]**