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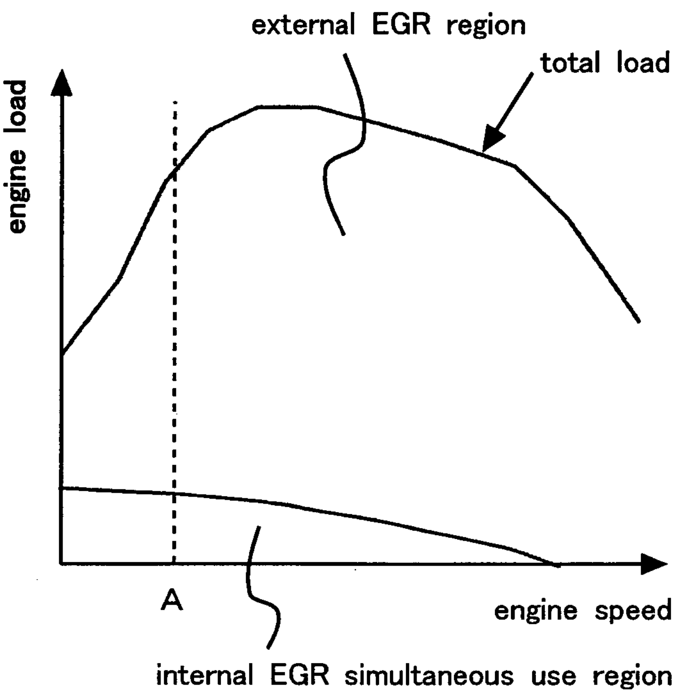
(54) Title: EXHAUST GAS RECIRCULATION SYSTEM OF INTERNAL COMBUSTION ENGINE



(57) Abstract: There is provided a technology that enables, in an exhaust gas recirculation system (30) of an internal combustion engine, to supply EGR gas in an improved manner. The system (30) is provided with a supercharger (15) having a turbine (56) provided in an exhaust passage (14) and a compressor (50) provided in an intake passage (13), an EGR passage (31) that connects the exhaust passage (4) at a point downstream of the turbine (56) and the intake passage (31) at a point upstream of the compressor (50), and internal EGR quantity changing means (60) for changing the quantity of internal EGR of the internal combustion engine. The ratio of the quantity of external EGR introduced into a cylinder (12) by supplying exhaust gas from said internal combustion engine through the EGR passage (31) and the quantity of internal EGR remaining in the interior of the cylinder (2) is changed according to the load on the internal combustion engine.

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DESCRIPTION

EXHAUST GAS RECIRCULATION SYSTEM OF INTERNAL COMBUSTION ENGINE

TECHNICAL FIELD

The present invention relates to an exhaust gas recirculation (EGR) system of an internal combustion engine.

BACKGROUND ART

A low pressure EGR passage that connects the exhaust passage downstream of the turbine of the turbocharger and the intake passage upstream of the compressor enables to supply low-temperature, low-pressure EGR gas (which will be referred to as low pressure EGR hereinafter). A high pressure EGR passage that connects the exhaust passage upstream of the turbine of the turbocharger and the intake passage downstream of the compressor enables to supply high-temperature, high-pressure EGR gas (which will be referred to as high pressure EGR hereinafter).

However, in the case of the low pressure EGR, the temperature of the EGR gas decreases as the exhaust gas passes through the turbine and an intercooler. For this reason, if the low pressure EGR is performed in a low load state, the temperature of the gas in the intake manifold decreases excessively, which leads to a decrease in the combustion temperature, which in turn can lead to an increase in the amount of hydrocarbon emissions.

In a known exhaust gas recirculation system of an internal combustion engine, the low pressure EGR is performed in the high load to middle load operation range, and the high pressure EGR is performed in the middle load to idling operation range, whereby premix compression ignition can be achieved in any operating state except for high load operations (see, for example, patent document 1: Japanese Patent Application Laid-Open No. 2002-21625, patent document 2: Japanese Patent Application Laid-Open No. 5-71428, patent document 3: Japanese Patent Application Laid-Open No. 2004-162552, patent document 4: Japanese Patent No. 3046707 and patent document 5: Japanese Patent Application Laid-Open No. 9-296740).

However, for example in the case of internal combustion engines that are designed to have low compression ratios with a view to decrease the amount of NOx emissions and to increase the power output, it is difficult to prevent a decrease in the combustion temperature even if the high pressure EGR is performed during low load operation, since the combustion temperature is low. In addition, since in the high pressure EGR, exhaust gas flows into the intake passage from a point on the exhaust passage upstream of the turbine, the energy supplied to the turbine is decreased. This can lead to a decrease in the supercharging pressure and a decrease in the intake air quantity.

In conventional internal EGR techniques, the nozzle of the variable geometry turbocharger is closed to an excessive extent. Then, the pressure of the exhaust gas in the upstream of the turbine increases. This causes an increase in the pumping loss and leads to a decrease in the fuel economy. In addition, since in the internal EGR, the temperature of recirculated exhaust gas is not reduced by an EGR cooler, the internal EGR can increase the temperature in the combustion chamber excessively. Consequently, there is a risk that the amount of NOx emissions may increase.

DISCLOSURE OF THE INVENTION

The present invention has been made in view of the above described problems and has as an object to provide a technique that enables, in an exhaust gas recirculation system of an internal combustion engine, to supply EGR gas in an improved manner.

To achieve the above object, the exhaust gas recirculation system of an internal combustion engine according to the present invention has the following features. The exhaust gas recirculation system of an internal combustion engine according to the present invention comprises:

a supercharger having a turbine provided in an exhaust passage and a compressor provided in an intake passage;

an EGR passage that connects an exhaust passage at a point downstream of said turbine and an intake passage at a point upstream of said compressor; and

internal EGR quantity changing means for changing the internal EGR quantity of the internal combustion engine,

wherein the ratio of the quantity of external EGR introduced into a cylinder by supplying exhaust gas from said internal combustion engine through said EGR passage and the quantity of internal EGR remaining in the interior of the cylinder is changed according to a load on the internal combustion engine.

The external EGR is performed by introducing burned gas discharged to the exhaust passage from the internal combustion engine into the interior of the cylinder through the EGR passage and the intake passage. The EGR passage is connecting the exhaust passage at a point downstream of the turbine and a portion of the intake passage in which intake air that has not been compressed by the compressor yet flows. Therefore, the pressure in the EGR passage can be made lower on the intake passage side than on the exhaust passage side even when the supercharging pressure is high. Accordingly, recirculation of the EGR gas is enabled even when the supercharging pressure is high.

On the other hand, the internal EGR is achieved by burned gas remaining in the cylinder without use of the EGR passage. For example, the internal EGR is performed by drawing the burned gas blown back into the intake passage into the interior of the cylinder again, by drawing burned gas discharge to the exhaust passage back into the interior of the cylinder or by decreasing the quantity of the burned gas discharged from the interior of the cylinder to increase the quantity of the residual burned gas remaining in the interior of the cylinder. The internal EGR can be performed by changing opening/closing characteristics of the exhaust valve by means of a variable valve actuation mechanism. The variable valve actuation mechanism is adapted to adjust the opening timing, closing timing, lift amount and operation angle of the exhaust valve thereby controlling the quantity of fresh air drawn into a cylinder of the internal combustion engine, the EGR quantity, the quantity of the residual gas in the cylinder (or the internal EGR quantity) and the pumping loss etc. to change the operating state of the internal combustion engine. For example, when the time to close the exhaust valve is arranged to be earlier than the exhaust top dead center, the quantity of burned gas blown back into the intake passage increases, and such burned gas is drawn into the cylinder during the intake stroke. Accordingly, the quantity of the residual burned gas remaining in the cylinder increases. On the other hand, when the time to close the exhaust valve is arranged to be later than the exhaust top dead center, the burned gas that has been once discharged into the exhaust passage flows back into the cylinder during the intake stroke. Accordingly, the quantity of the residual burned gas remaining in the cylinder increases. In this way, the internal EGR quantity can be increased.

Since the temperature of the internal EGR gas is higher than the temperature of the external EGR gas, the temperature inside the cylinder can be raised by increasing the proportion of the internal EGR gas in the interior of the cylinder. However, the higher the load on the internal combustion engine, the more the temperature inside the cylinder is increased by the internal EGR. Consequently, there is a risk that the combustion temperature may rise excessively and the amount of NOx emissions may increase. On the other hand, since the temperature of the external EGR gas is lower than the temperature of the internal EGR gas, the temperature inside the cylinder can be decreased by increasing the proportion of the external EGR gas in the interior of the cylinder. Therefore, at times of low load operations in which the combustion temperature is low, the proportion of the internal EGR may be made higher and the proportion of the external EGR may be made lower so that the combustion temperature can be prevented from becoming excessively low. By this feature, the amount of hydrocarbon emissions can be reduced. On the other hand, at times of high load operations in which the combustion temperature is high, the proportion of the internal EGR may be made lower and the proportion of the external EGR may be made higher so that the combustion temperature can be prevented from becoming excessively high. By this feature, NOx emissions can be reduced. Furthermore, performing the internal EGR can suppress a decrease in the quantity of the exhaust gas that passes through the turbine, and accordingly a decrease in the engine power output can be prevented.

According to the present invention, the temperature inside the cylinder may be controlled by, when the temperature inside the cylinder is to be increased, making the proportion of said internal EGR higher than that before increasing the temperature inside the cylinder and by, when the temperature inside the cylinder is to be decreased, making the proportion of said external EGR higher than that before decreasing the temperature inside the cylinder.

Since the gas of the external EGR and the gas of the internal EGR have different temperatures, the temperature of the overall EGR gas can be controlled by changing the ratio of the quantity of the external EGR gas and the quantity of the internal EGR gas in the interior of the cylinder. This enables to control the temperature inside the cylinder to a desired temperature. For example, when it is desired to decrease the temperature inside the cylinder, the proportion of the external EGR gas that has the lower temperature is increased. On the other hand, when it is desired to increase the temperature inside the cylinder, the proportion of the internal EGR gas that has the higher temperature is increased.

According to the present invention, the proportion of the external EGR may be made higher at times of high load operations of the internal combustion engine than at times of low load operations.

At times of high load operations, the temperature inside the cylinder will become higher. In such cases, the temperature of the overall EGR gas can be reduced by making the proportion of the external EGR higher. Thus, generation of NOx involved by excessive rise in the combustion temperature can be prevented. In connection with this, the proportion of the external EGR may be changed in such a way that the higher the load is, the higher the proportion of the external EGR is in a predetermined load range.

According to the present invention, the proportion of the external EGR may be decreased to be zero at times of low load operations of the internal combustion engine.

The combustion temperature sometimes decreases excessively at times of low load operations. Therefore, there is little need to decrease the combustion temperature by increasing the proportion of the external EGR. In addition, by decreasing the proportion of the external EGR to zero at times of low load operations, the temperature of the overall EGR gas can be made higher, whereby the amount of hydrocarbon emissions can be further reduced. In view of the above, the external EGR may be disabled when the combustion temperature is lower than a predetermined temperature. Here, "low loads" refer to idling or low loads near idling. Low loads may include such loads at which there is a risk that hydrocarbon emissions can be produced if the external EGR is performed, or at which there is a risk that the amount of hydrocarbon emissions can exceed an allowable value.

According to the present invention, the aforementioned supercharger may be a variable geometry turbocharger. When the proportion of the external EGR is to be made higher, the nozzle of the variable geometry turbocharger may be opened to a larger degree than when the proportion of the external EGR is not to be made higher.

Even in cases where the quantity of the exhaust gas is small such as at times when the internal combustion engine is in low load operating states, the rotation speed and torque of the exhaust gas turbine can be increased by turning the nozzle of the variable geometry turbocharger in the closing direction to increase the velocity of flow of the exhaust gas. However, turning the nozzle in the closing direction causes an increase in the back pressure. This leads to an increase in the proportion of the internal EGR gas and a decrease in the proportion of the external EGR gas. In addition, the increase in the back pressure leads to an increase in the pumping loss.

The proportion of the internal EGR gas can be increased also by changing the timing of opening and closing the exhaust valve by, for example, using a variable valve actuation mechanism. In the case that the proportion of the internal EGR gas is increased by means of the variable valve actuation mechanism, the back pressure can be made lower than, and accordingly the pumping loss can be made lower than in the case that the nozzle is turned in the closing direction. In addition, since the nozzle may be opened to a larger degree in accordance with the increase in the proportion of the internal EGR gas, the pumping loss can be further reduced.

As described above, in the exhaust gas recirculation system of an internal combustion engine according to the present invention, supply of the EGR gas can be controlled more appropriately by changing the ratio of the internal EGR quantity and the external EGR quantity according to the load on the internal combustion engine. With this feature, the amount of NOx emissions and hydrocarbon emissions can be decreased. Furthermore, the engine power output can be enhanced by increasing the supercharging pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates the general structure of an internal combustion engine to which an exhaust gas recirculation system of an internal combustion engine according to an embodiment is applied and its air-intake and exhaust systems and supercharger.

Figs. 2(A) and 2(B) are cross sectional views showing the structure of a variable geometry turbocharger. Fig. 2(A) shows the state in which nozzle vanes are open, while Fig. 2(B) shows the state in which nozzle vanes are closed.

Fig. 3 is a graph showing the distribution of EGR types in relation to the engine speed and the engine load.

Fig. 4 is a graph showing the distribution of EGR types in relation to the engine load at a specific engine speed indicated by A in Fig. 3.

THE BEST MODE FOR CARRYING OUT THE INVENTION

In the following, specific embodiments of the exhaust gas recirculation system of an internal combustion engine according to the present invention will be described with reference to the accompanying drawings.

(First Embodiment)

Fig. 1 schematically illustrates the general structure of an internal combustion engine to which the exhaust gas recirculation system for an internal combustion engine according to the present invention is applied and its air-intake and exhaust systems and supercharger. The internal combustion engine 1 illustrated in Fig. 1 is a water-cooled, four-cycle diesel engine having four cylinders 2. The internal combustion engine 1 has a low compression ratio in the range of, for example, 14 to 15.8.

To the internal combustion engine 1 are connected an intake pipe 3 and an exhaust pipe 4. The intake pipe 3 is provided, at some midpoint, with a compressor housing 5a of a turbocharger 5 that operates using as the drive source the energy of the exhaust gas. At a position upstream of the compressor housing 5a, the intake pipe 3 is provided with an intake throttle 6 for regulating the flow rate of the intake air flowing in the intake pipe 3. The intake throttle 6 is opened and closed by an electric actuator. At a position upstream of the intake throttle 6, the intake pipe 3 is provided with an air flow meter 7 that outputs a signal indicative of the flow rate of the intake air flowing in the intake pipe 3. The intake air quantity of the internal combustion engine 1 is measured by the air flow meter 7.

On the other hand, the exhaust pipe 4 is provided, at some midpoint, with a turbine housing 5b of the aforementioned turbocharger 5. At a position downstream of the turbine housing 5b, the exhaust pipe 4 is also provided with an exhaust gas purification catalyst 8.

The internal combustion engine 1 is equipped with an EGR system 30 that recirculates a part of the exhaust gas flowing in the exhaust pipe 4 to the intake pipe 3. The EGR system 30 has an EGR passage 31, an EGR valve 32 and an EGR cooler 33. The EGR passage 31 connects the exhaust pipe 4 at a point downstream of the turbine housing 5b and the intake pipe 3 at a point upstream of the compressor housing 5a. A part of the exhaust gas is recirculated through the EGR passage 31. In this embodiment, the exhaust gas recirculated through the EGR passage 31 will be referred to as the external EGR gas. The EGR valve 32 is adapted to control the cross section of the EGR passage 31 to thereby regulate the quantity of the external EGR gas flowing in the EGR passage 31. The EGR cooler 33 is provided to reduce the temperature of the external EGR gas passing through it.

The turbocharger 5 used in this embodiment is a variable geometry turbocharger. Figs. 2(A) and 2(B) are cross sectional views showing the structure of the variable geometry turbocharger. Fig. 2(A) illustrates a state in which nozzle vanes 51 are open, while Fig 2(B) illustrates a state in which the nozzle vanes 51 are closed.

As shown in these drawings, the variable geometry turbocharger has an exhaust gas turbine 5c provided in the turbine housing 5b and a plurality of nozzle vanes 51 provided on the circumference of the exhaust gas turbine 5c. The nozzle vanes 51 are opened and closed by an actuator 52. When the nozzle vanes 51 are turned in the closing direction, the openings between adjacent nozzles are narrowed down, and the flow paths between the nozzle vanes 51 are made smaller. On the other hand, when the nozzle vanes 51 are turned in the opening direction, the openings between adjacent nozzles are widened, so that the flow paths between the nozzle vanes 51 are made larger.

In the variable geometry turbocharger having the above described structure, the direction of the flow paths between the nozzle vanes 51 and the openings between the nozzle vanes 51 can be changed by controlling the rotation direction and rotation amount of the nozzle vanes 51 by means of the actuator 52. In other words, by controlling the rotation direction and rotation amount of the nozzle vanes 51, the direction, flow rate and quantity of the exhaust gas blowing on the exhaust turbine 5c are adjusted.

The internal combustion engine 1 according to this embodiment is equipped with a variable valve actuation mechanism 60. Each cylinder 2 is equipped with two exhaust valves 61, and each exhaust valve 61 is opened and closed by an exhaust cam 62. The exhaust cam 62 is attached on an exhaust cam shaft 63. On one end of the exhaust camshaft 63 is provided an exhaust pulley 64. There is also provided a variable rotational phase mechanism (which will be referred to as the VVT hereinafter) 65 that can change the relative rotational phase between the exhaust camshaft 63 and the exhaust pulley 64. The VVT 65 is adapted to control the relative rotational phase between the exhaust camshaft 63 and the exhaust pulley 64 according to a command from the ECU 10.

The exhaust camshaft 63 is rotated by the driving force of the crankshaft. The exhaust camshaft 63 is rotated by the driving force of the crankshaft, whereby the exhaust cam 62 is rotated, so that the exhaust valve 61 is opened or closed. In this embodiment, the timing of opening and closing the exhaust valve 61 is advanced or retarded relative the exhaust top dead center by means of the variable valve actuation mechanism 60 so that the quantity of burned gas in the interior of the cylinder 2 is varied. In this embodiment, the burned gas remaining in the interior of the cylinder 2 will be referred to as the internal EGR gas.

To the internal combustion engine 1 having the above described structure is annexed an electronic control unit referred to as the ECU 10 for controlling the internal combustion engine 1. The ECU 10 is a unit that controls the operation state of the internal combustion engine 1 according to operation conditions of the internal combustion engine 1 and driver's demands. The ECU 10 is connected, through electric wiring, with various sensors such as an accelerator position sensor 12 that outputs an electric signal indicative of the position of the accelerator pedal 11 depressed by the driver to enable to detect the engine load and a crank position sensor 13 that detects the engine speed. Output signals of the various sensors are input to the ECU 10. The ECU 10 is also connected, through electric wiring, with the intake throttle 6, the EGR valve 32, the actuator 52 and the VVT 65. These devices are controlled by the ECU 10.

In this embodiment, the internal EGR quantity and the external EGR quantity are controlled by the ECU 10. The internal EGR quantity can be regulated by controlling the VVT 65. The earlier the timing of closing the exhaust valve 61 is made relative to the exhaust top dead center, the larger the quantity of the burned gas remaining in the interior of the cylinder 2 without being discharged to the exhaust pipe 4 becomes. When the intake valve is opened thereafter, the burned gas flows back into the intake pipe 3. However, the burned gas having thus flowed back into the intake pipe 3 flows into the cylinder 2 again during the intake stroke performed immediately. Accordingly, the earlier the timing of closing the exhaust valve 61 is made relative to the exhaust top dead center, the larger the internal EGR quantity can be made. On the other hand, the later the timing of closing the exhaust valve 61 is made relative to the exhaust top dead center, the larger the burned gas flowing back into the cylinder 2 from the exhaust pipe 4 during the intake stroke becomes. Accordingly, the later the timing of closing the exhaust valve 61 is made relative to the exhaust top dead center, the larger the internal EGR quantity can be made. In this embodiment, the variable valve actuation mechanism 60 constitutes the internal EGR quantity changing means according to the present invention.

The external EGR quantity can be regulated by controlling the intake throttle 6. The pressure in the intake pipe 3 downstream of the intake throttle 6 can be decreased by making the opening of the intake throttle 6 smaller. When the pressure is decreased in this way, the difference in the pressure in the exhaust pipe 4 and the pressure in the intake pipe 3 increases. Consequently, a larger quantity of exhaust gas flows through the EGR passage 31, so that the external EGR quantity is increased. On such occasions, the EGR valve 32 is kept fully open. As per the above, the external EGR quantity can be regulated by controlling the degree of opening of the intake throttle 6. In connection with the above, instead of utilizing the intake throttle 6, an exhaust throttle may be provided in the exhaust pipe 4 at some point downstream of the point at which the EGR passage 31 is connected to the exhaust pipe 4, and the external EGR quantity may be regulated by controlling the degree of opening of the exhaust throttle. In this case, the smaller the opening of the exhaust throttle is made, the higher the pressure in the exhaust pipe 4 becomes, and the larger the external EGR quantity becomes. Furthermore, the external EGR quantity can also be regulated by controlling the degree of opening of the EGR valve 32. In this case, the larger the degree of opening of the EGR valve 32 is made, the larger the external EGR quantity becomes.

Since the internal EGR gas has a higher temperature than the external EGR gas, the temperature inside the cylinder 2 can be increase by making the internal EGR quantity larger. Since the temperature of the external EGR gas is lowered as it passes through the EGR passage 31 and the EGR cooler 33, the temperature inside the cylinder 2 can be decreased by making the external EGR gas quantity larger. By arranging the ratio of the internal EGR gas and the external EGR gas, the temperature inside the cylinder 2 can be adjusted to a desired temperature. This also enables to prevent excessive rise in the combustion temperature. Furthermore, by increasing or decreasing the external EGR quantity in accordance with an increase or decrease in the internal EGR quantity, the total quantity of the EGR gas can be kept unchanged. Since the proportion of the internal EGR gas can be increased using the variable valve actuation mechanism 60, there is no need to close the nozzle vanes 51 to an excessive degree, and the nozzle vanes 51 may be opened. Thus, the pumping loss can be reduced. Since in this embodiment, the EGR passage 31 is connected to the exhaust pipe 4 at a point downstream of the turbine housing 5b, the quantity of the exhaust gas passing through the turbine housing 5b can be made larger as compared in the case of EGR apparatuses in which the EGR passage is connected to the exhaust pipe at some point upstream of the turbine housing. Thus, the rotation rate of the exhaust turbine 5c can be made higher, and accordingly the supercharging pressure can be made higher. Therefore, the engine power output can be made higher.

As per the above, the temperature inside the cylinder 2 can be increased to thereby reduce the amount of hydrocarbon emissions even with an internal combustion engine having a low compression ratio in which the combustion temperature is relatively low. Furthermore, the temperature inside the cylinder 2 can be prevented from rising excessively. This enables to reduce the amount of NOx emissions. Still further, since the supercharging pressure can be made high even when the engine load is low, a sufficient quantity of oxygen can be supplied into the cylinder 2. This enables a further reduction in the amount of unburned hydrocarbon emissions.

(Second Embodiment)

In the second embodiment, the proportion of the internal EGR gas is made larger than the proportion of the external EGR gas when the engine load is low, while the proportion of the external EGR gas is made larger than the proportion of the internal EGR gas when the engine load is high. The construction of the system in this embodiment is the same as that in the first embodiment, and a description thereof will be omitted.

Fig. 3 is a graph showing a distribution of EGR types in relation to the engine speed and the engine load. Fig. 4 shows a distribution of EGR types in relation to the engine load at a specific engine speed indicated by A in Fig. 3. In

Fig. 3, the "external EGR region" refers to a region in which the ratio of the external EGR gas to the entire EGR gas in the cylinder 2 is made as high as possible. Although the proportion of the internal EGR gas does not become zero in a strict sense, since it is difficult to completely remove the burned gas remaining in the cylinder 2, the proportion of the internal EGR is shown as zero at some portions in Figs. 3 and 4 for the sake of simplicity. In the "internal EGR simultaneous use region", the proportion of the internal EGR is increased. In Fig. 4, the horizontal axis represents the engine load, and the vertical axis represents the proportion of the internal EGR and the proportion of the external EGR in the total EGR quantity.

As shown in Fig. 3, there is the "internal EGR simultaneous use region" in the low load region. At times of low loads, the temperature of the exhaust gas is low, and therefore the internal EGR is also used simultaneously. On the other hand, there is the "external EGR region" in the middle and high load region. At times of middle and high loads, the temperature of the exhaust gas is high, and therefore only the external EGR gas is supplied into the cylinder 2 to prevent excessive rise in the temperature inside the cylinder 2. As shown in Fig. 4, at times of very low loads, the proportion of the external EGR is decreased to zero. Thus, when the engine load is zero, only the internal EGR gas is supplied into the cylinder 2. When the engine load becomes somewhat large, the external EGR is also used simultaneously. As the engine load increases, the proportion of the external EGR gas is increased gradually. At times of middle and high loads, only the external EGR gas is supplied into the cylinder 2.

In this embodiment, a target value of the internal EGR quantity is determined based on the operating state of the internal combustion engine 1, and the VVT 65 is controlled so that the actual internal EGR quantity becomes equal to the target value. Specifically, the relationship among the engine speed, the engine load and a control value of the VVT 65 is obtained in advance by, for example, experiments and prepared as a map. Thus, the control value of the VVT 65 is determined by substituting the values of the engine speed and the engine load into the map. In determining the control value of the of the VVT 65, the temperature of the cooling water of the internal combustion engine 1, the environmental temperature or the amount of hydrocarbon emissions may also be taken into consideration. The ECU 10 controls the VVT65 based on the control value of the VVT 65 thus determined, whereby the internal EGR quantity is regulated. On the other hand, a target value of the total EGR quantity in the interior of the cylinder is determined based on the operating state of the internal combustion engine 1, and the intake throttle 6 is controlled so that the target value of the total EGR quantity is achieved. In connection with this, a control value of the intake throttle 6 may be determined taking the temperature of the cooling water of the internal combustion engine 1, the environmental temperature or the amount of hydrocarbon emissions into consideration. For example, the degree of opening of the intake throttle 6 is controlled based on the intake air quantity detected by the air flow meter 7. The intake air quantity detected by the air flow meter 7 decreases in accordance with the total EGR quantity in the interior of the cylinder 2. Therefore, the total EGR quantity in the interior of the cylinder 2 can be determined indirectly based on the intake air quantity. Specifically, the relationship among the engine speed, the engine load, the intake air quantity and the degree of opening of the intake throttle 6 is obtained in advance by, for example, experiments and prepared as a map. Thus, the degree of opening of the intake throttle 6 can be determined by substituting the values of the engine speed, engine load and intake air quantity into the map. As per the above, in this embodiment, the internal EGR is controlled in an open-loop manner, and the external EGR is controlled in a feed-back manner based on the intake air quantity.

In the exhaust gas recirculation system of the internal combustion engine having the above described structure, when the internal combustion engine 1 is running with a low load, the temperature inside the cylinder 2 can be increase by making the proportion of the internal EGR gas higher. Thus, the combustion temperature is made higher, and emission of unburned hydrocarbon can be reduced. On the other hand, when the internal combustion engine 1 is running with a high load, the combustion temperature can be decreased by making the proportion of the external EGR gas higher or supplying only the external EGR gas. Thus, emission of NOx can be reduced. Since performing the internal EGR eliminates the need for performing conventional high pressure EGR, the nozzle vanes can be opened to a larger degree than in conventional systems. This enables to reduce the pumping loss, and therefore the fuel economy can be enhanced. By changing the ratio of the internal EGR gas and the external EGR gas gradually, the temperature of the EGR gas in the interior of the cylinder can be changed gradually. Therefore, abrupt changes in the temperature of the EGR gas in the cylinder 2 and the combustion temperature can be avoided. This makes it possible to control the temperature inside the cylinder 2 easily.

At times of idling or low load operating states near idling, a decrease in the EGR temperature in the interior of the cylinder 2 can be reduced by decreasing the proportion of the external EGR to zero. Therefore, a decrease in the combustion temperature inside the cylinder 2 can be prevented even in the case of an internal combustion engine with a low compression ratio. This makes it possible to reduce the amount of unburned hydrocarbon emissions.

CLAIMS

1. An exhaust gas recirculation system of an internal combustion engine, comprising:

a supercharger having a turbine provided in an exhaust passage and a compressor provided in an intake passage;

an EGR passage that connects the exhaust passage at a point downstream of said turbine and the intake passage at a point upstream of said compressor; and

internal EGR quantity changing means for changing the quantity of internal EGR of the internal combustion engine,

wherein the ratio of the quantity of external EGR introduced into a cylinder by supplying exhaust gas from said internal combustion engine through said EGR passage and the quantity of internal EGR remaining in the interior of the cylinder is changed according to a load on the internal combustion engine.

2. An exhaust gas recirculation system of an internal combustion engine according to claim 1, wherein the temperature inside the cylinder is controlled by, when the temperature inside the cylinder is to be increased, making the proportion of said internal EGR higher than that before increasing the temperature inside the cylinder and by, when the temperature inside the cylinder is to be decreased, making the proportion of said external EGR higher than that before decreasing the temperature inside the cylinder.

3. An exhaust gas recirculation system of an internal combustion engine according to claim 1 or 2, wherein at times

of high load operations of the internal combustion engine, the proportion of said external EGR is made higher than that at times of low load operations.

4. An exhaust gas recirculation system of an internal combustion engine according to claim 1 or 2, wherein the proportion of said external EGR is decreased to zero at times of low load operations of the internal combustion engine.

5. An exhaust gas recirculation system of an internal combustion engine according to any one of claims 1 to 4, wherein said supercharger is a variable geometry turbocharger, and when the proportion of said external EGR is to be made higher, a nozzle of the variable geometry turbocharger is opened to a larger degree than when the proportion of said external EGR is not to be made higher.

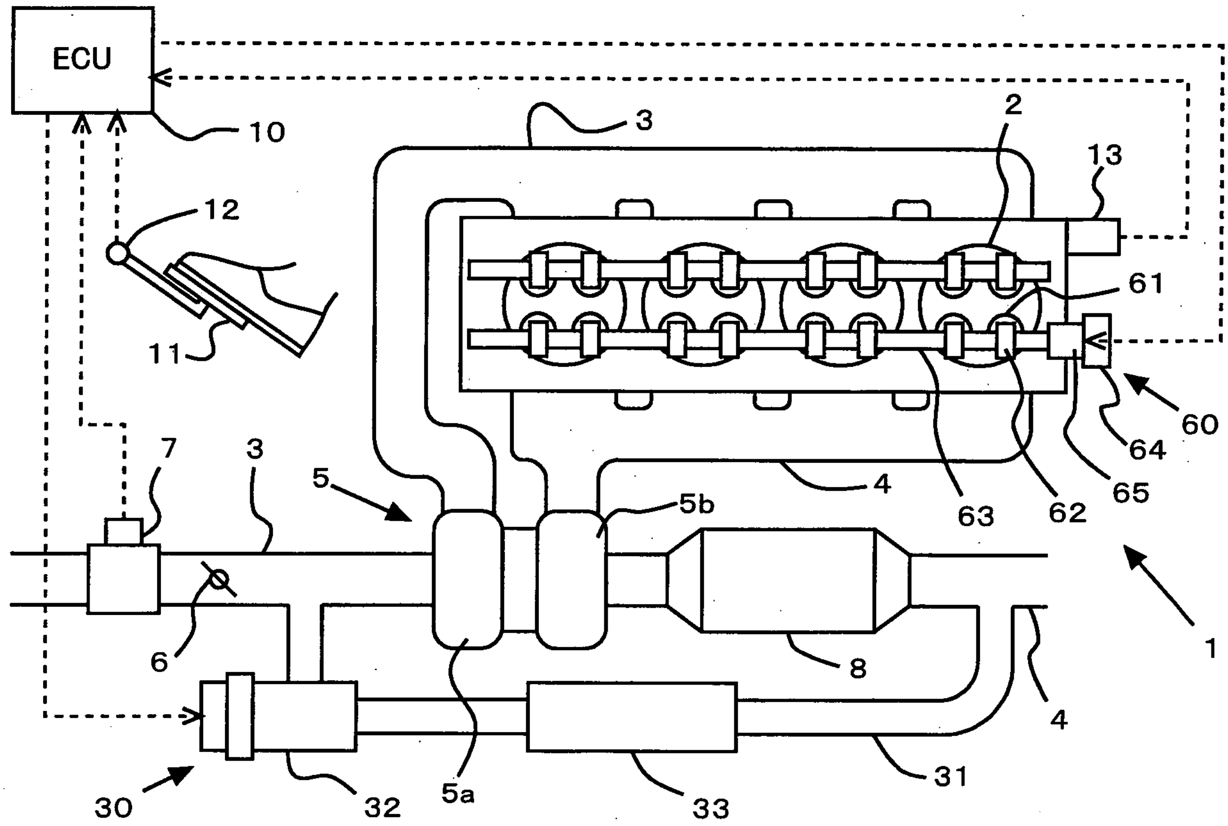

Fig. 1

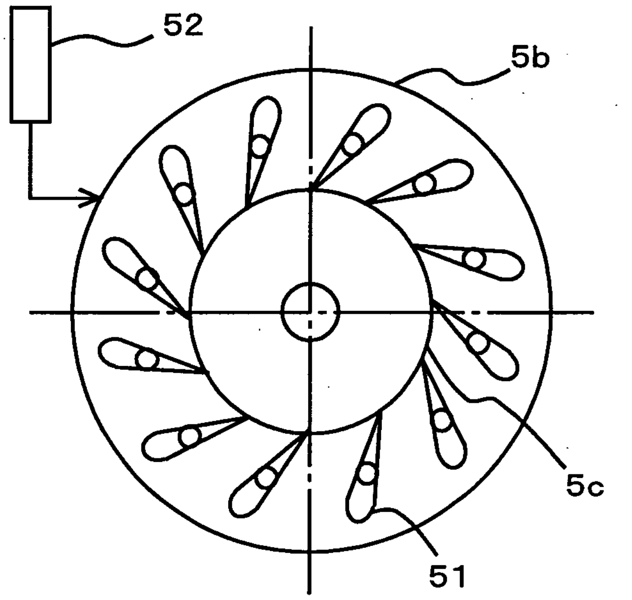

Fig. 2(A)

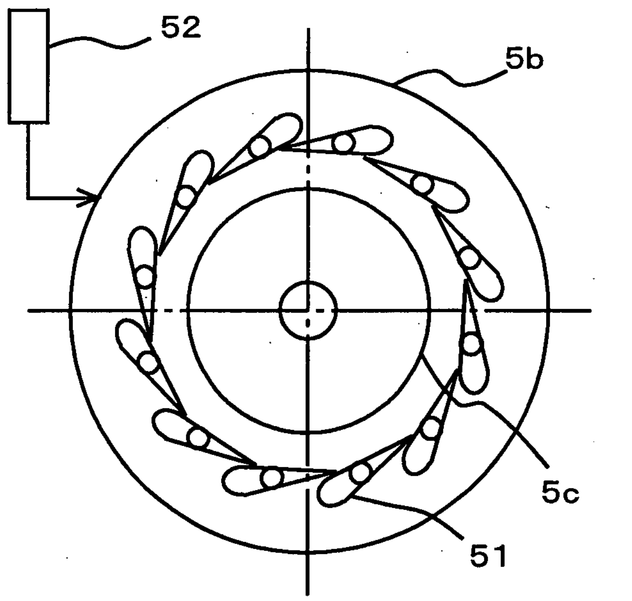

Fig. 2(B)

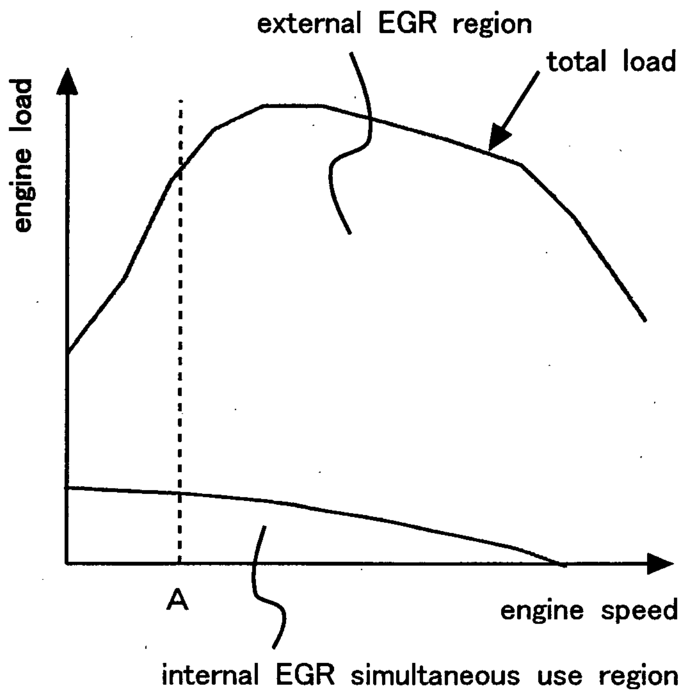
external EGR region
total load
engine load
A
engine speed
internal EGR simultaneous use region

Fig. 3

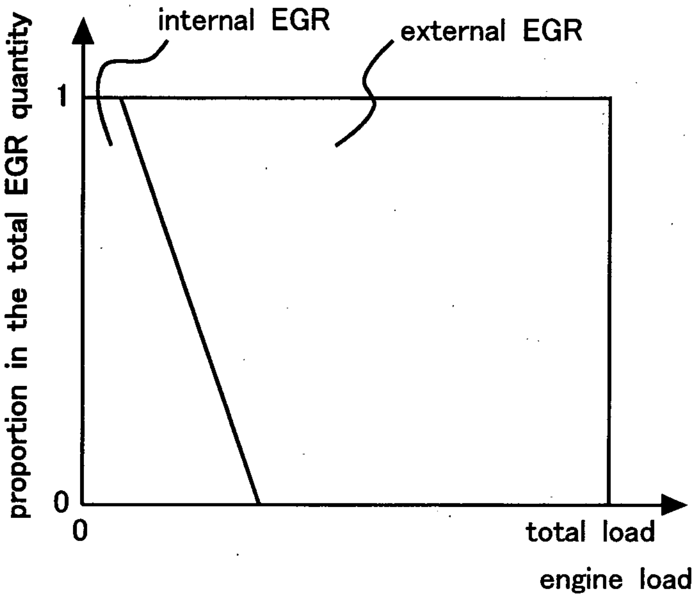
internal EGR
external EGR
proportion in the total EGR quantity
1
0
0
total load
engine load

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2007/061035

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02M25/07
ADD. F02D13/02

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)
F02M F02D F02B

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	page 5, paragraph 20 - page 7, paragraph 32	5
X	JP 2003 314318 A (NISSAN MOTOR CO LTD) 6 November 2003 (2003-11-06) abstract; figures	1-4
A	page 5, paragraph 26 - paragraph 28 page 5, paragraph 33 - page 6, paragraph 35	5
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[X] Further documents are listed in the continuation of Box C.

[X] 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 document 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
8 August 2007	27/08/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Döring, Marcus

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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P,X	FR 2 880 068 A (RENAULT SAS) 30 June 2006 (2006-06-30) abstract; figures page 2, line 20 - last line page 8, line 17 - page 17, last line	1-4
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X A	EP 1 455 078 A (FORD GLOBAL TECHNOLOGIES, INC.) 8 September 2004 (2004-09-08) abstract; figures column 6, paragraph 23 - column 8, paragraph 30 column 11, paragraph 41 - paragraph 42	1 2-5
A	JP 2002 021625 A (HINO MOTORS LTD) 23 January 2002 (2002-01-23) cited in the application abstract; figures page 3, paragraph 18 - page 4, paragraph 27	1-5

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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PCT/JP2007/061035

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