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(54) **ENGINE SYSTEM**

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(Continued)

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(Continued)

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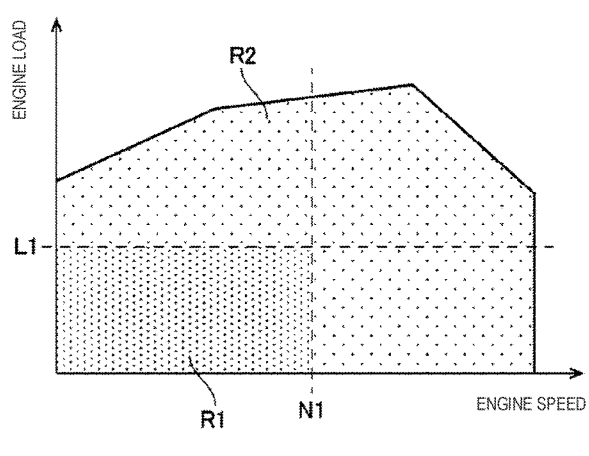
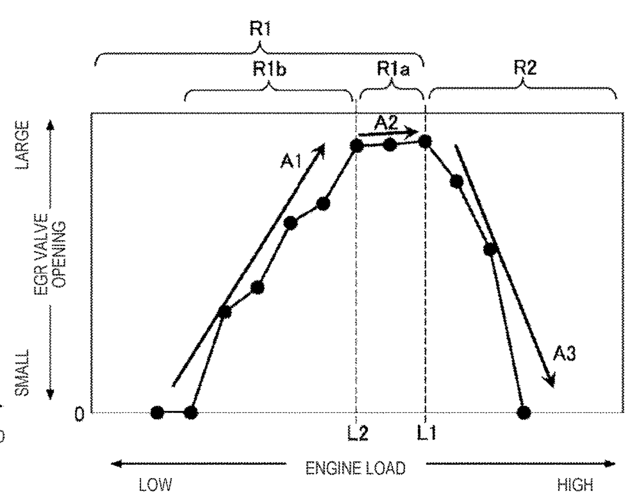
(57) **ABSTRACT**

An engine system is provided, which includes an engine, a swirl control valve, an EGR passage, an EGR gas adjusting mechanism, and a controller. The engine includes a cylinder, a piston, and a fuel injection valve. The swirl control valve is provided inside an intake passage and generates a swirl flow inside the cylinder when it closes. When an engine load is at or below a given threshold, the controller controls the swirl control valve to close. While the engine load is the threshold or below, the controller controls the EGR gas adjusting mechanism such that, at a fixed engine speed, an increase rate of an EGR gas amount with respect to an increase in the engine load is lower in a first load range than in a second load range, the first load range being on a higher load side of the second load range and including the threshold.

19 Claims, 5 Drawing Sheets





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F02D 41/30 (2006.01)
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(52) **U.S. Cl.**
CPC . *F02D 2200/101* (2013.01); *F02M 2026/003* (2016.02); *F02M 2026/009* (2016.02)

(58) **Field of Classification Search**
CPC F02D 41/3052; F02D 2041/0015; F02M 2026/003; F02M 2026/009
USPC 123/295, 308, 430, 432, 568.21
See application file for complete search history.

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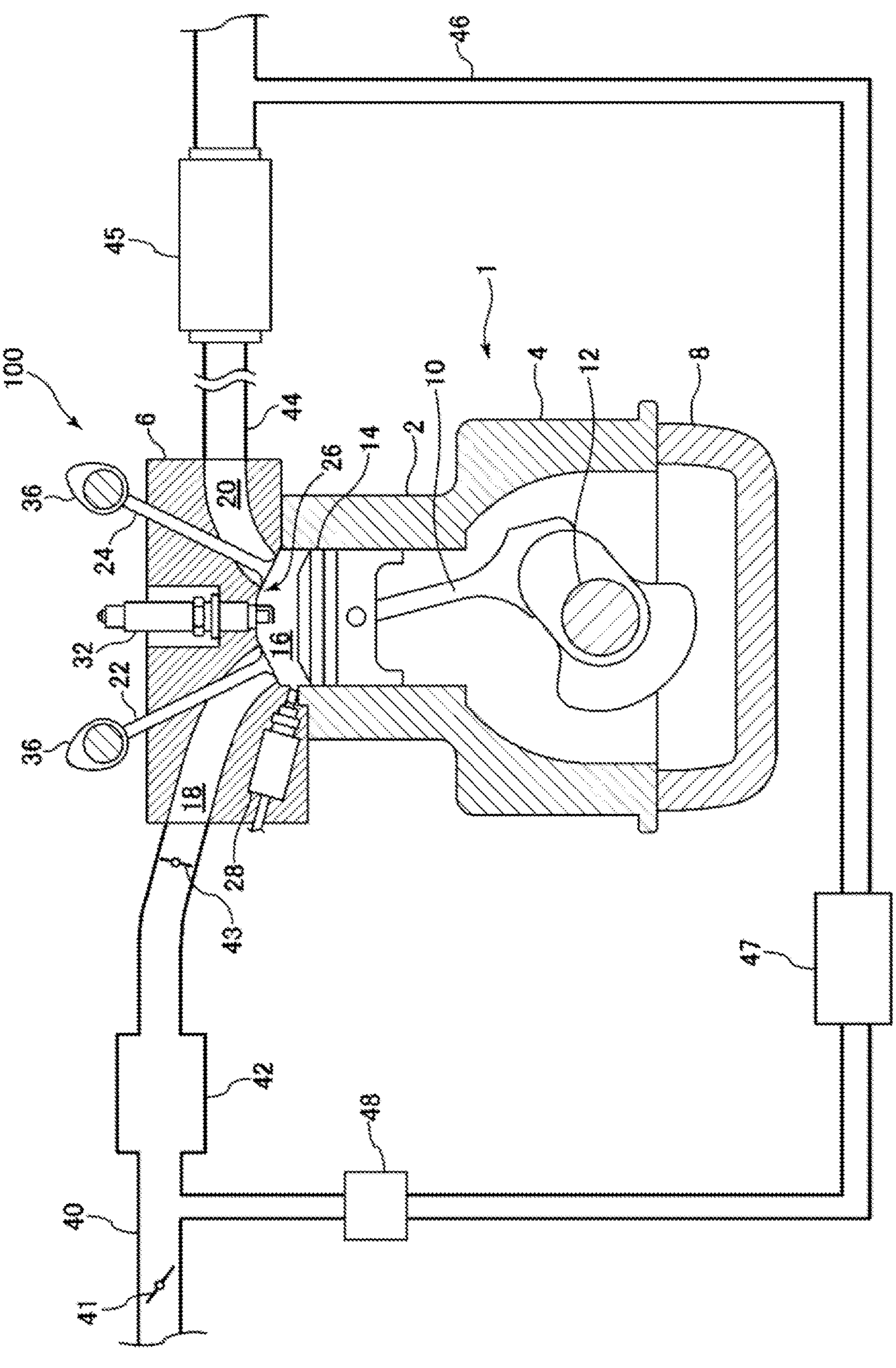
100
6
36
24
32
22
36
18
20
26
14
2
10
1
4
12
8
16
28
43
44
45
46
47
48
42
40
41

FIG. 1

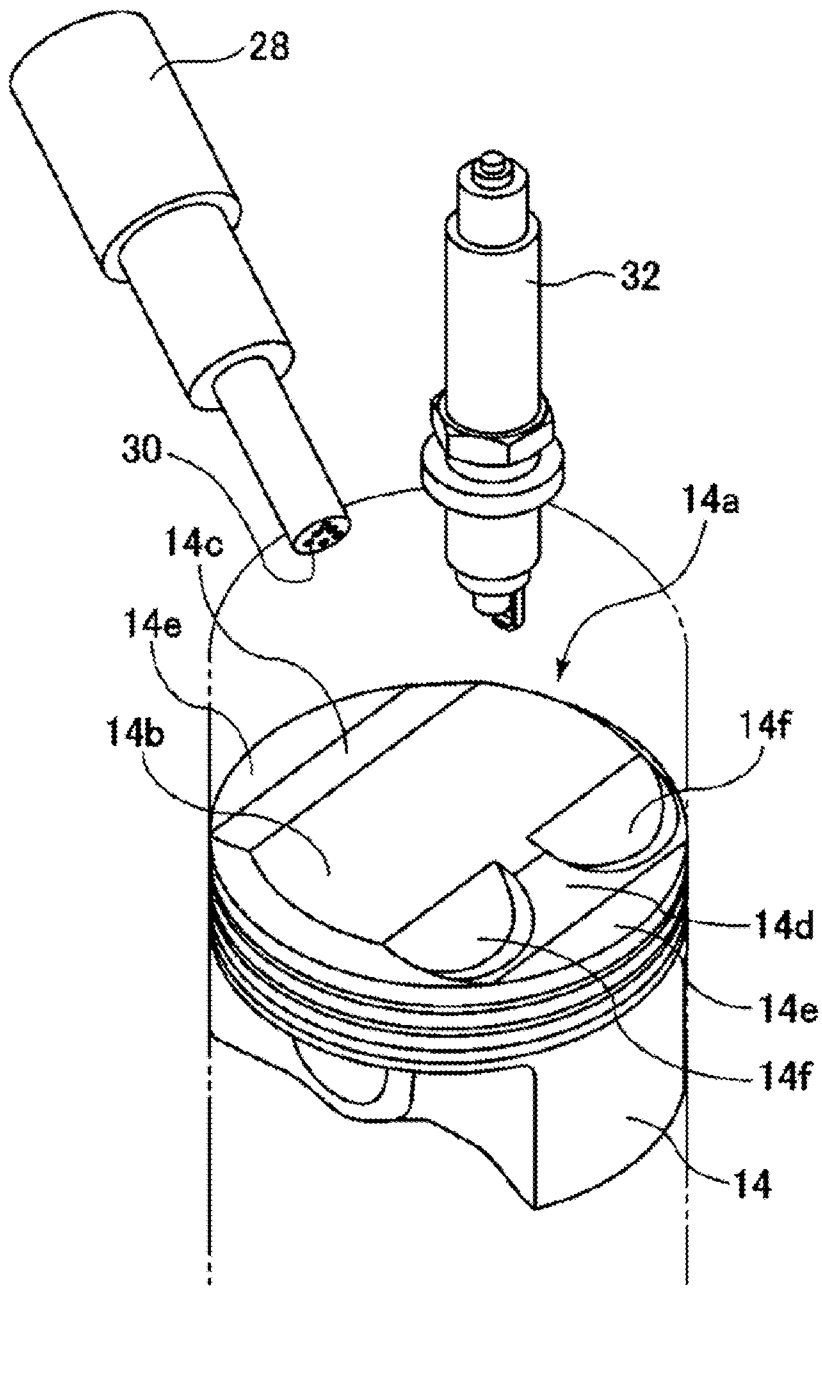

FIG. 2

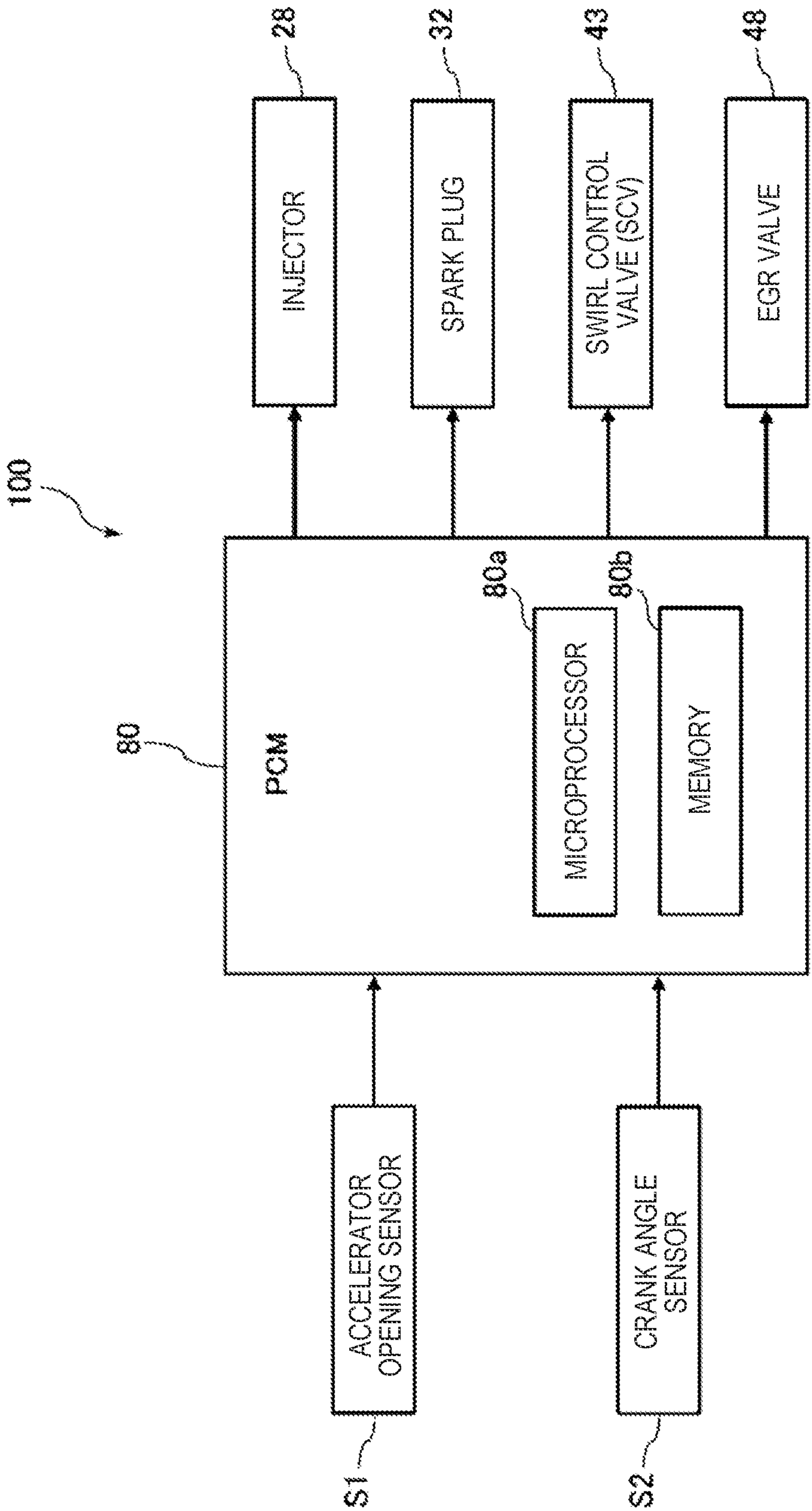
100
80
PCM
80a
MICROPROCESSOR
80b
MEMORY
28
INJECTOR
32
SPARK PLUG
43
SWIRL CONTROL VALVE (SCV)
48
EGR VALVE
ACCELERATOR OPENING SENSOR
S1
CRANK ANGLE SENSOR
S2

FIG. 3

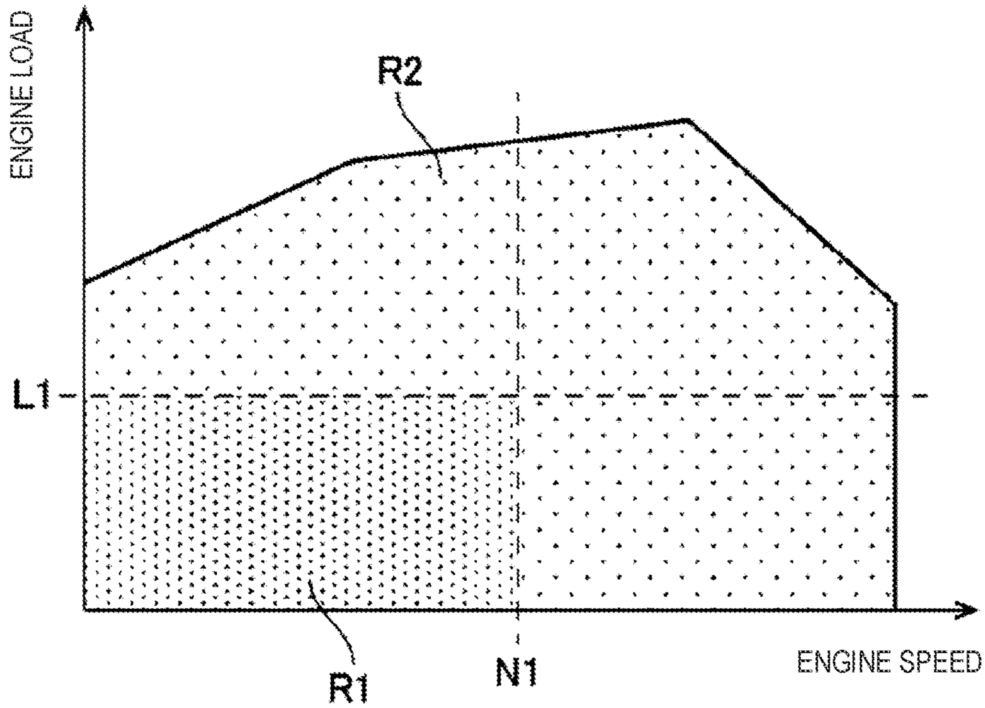
ENGINE LOAD
R2
L1
R1
N1
ENGINE SPEED

FIG. 4

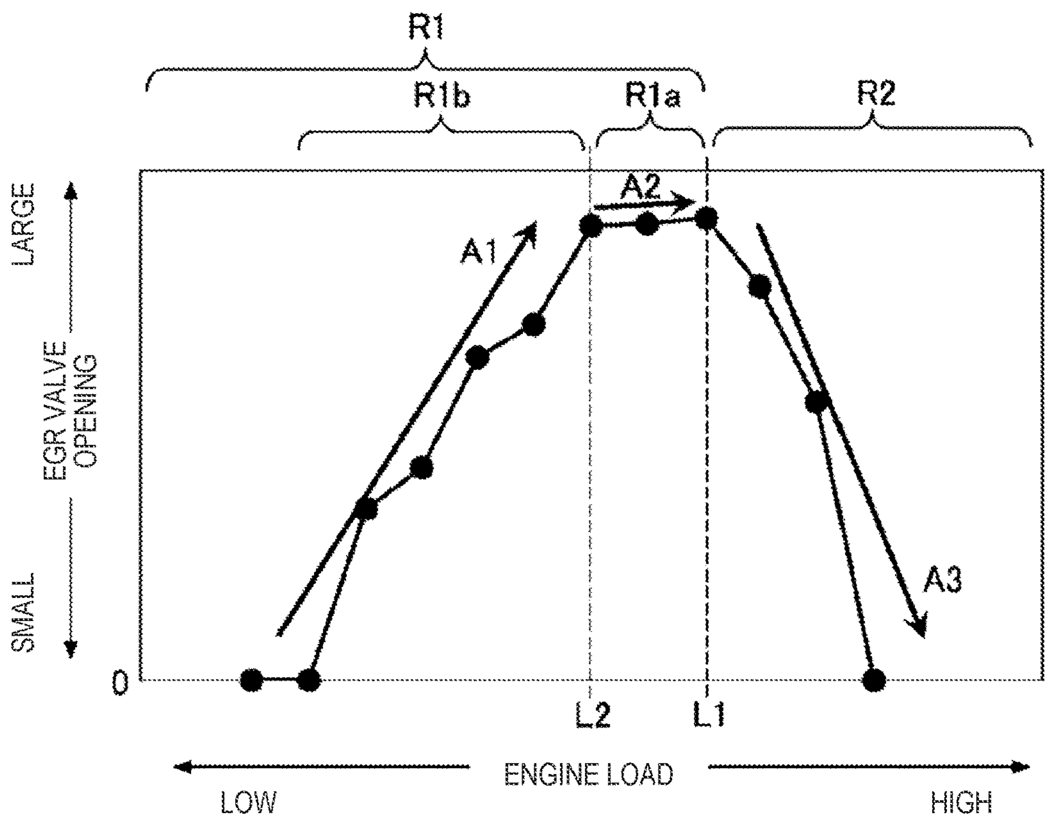
R1
R1b
R1a
R2
A2
A1
A3
LARGE
EGR VALVE OPENING
SMALL
0
L2
L1
ENGINE LOAD
LOW
HIGH

FIG. 5

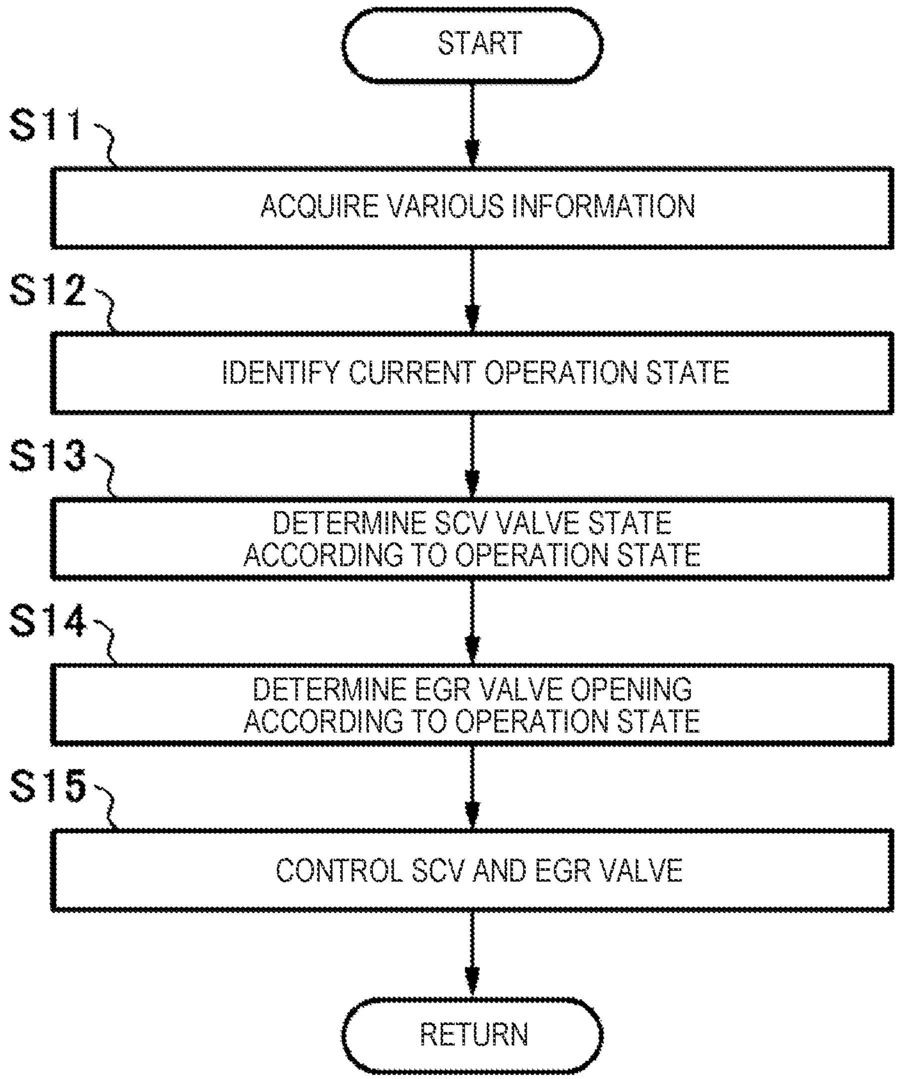
START
S11
ACQUIRE VARIOUS INFORMATION
S12
IDENTIFY CURRENT OPERATION STATE
S13
DETERMINE SCV VALVE STATE ACCORDING TO OPERATION STATE
S14
DETERMINE EGR VALVE OPENING ACCORDING TO OPERATION STATE
S15
CONTROL SCV AND EGR VALVE
RETURN

FIG. 6

ENGINE SYSTEM

TECHNICAL FIELD

The present disclosure relates to an engine system having a swirl control valve which generates a swirl flow inside a cylinder.

BACKGROUND OF THE DISCLOSURE

Conventionally, technologies are known, in which a swirl control valve (hereinafter, suitably be referred to as an "SCV") is provided to one of two intake ports which supply intake air to each cylinder, and opening of the SCV is set to a close side (typically, fully closed) to generate a swirl flow inside the cylinder. For example, JP2002-130025A discloses a technology to switch opening of such an SCV according to an operation state of an engine. In detail, the SCV is closed in a low load range of the engine, and is opened in a high load range. Particularly, in the low load range, fuel is injected during a compression stroke while a swirl flow is generated so as to achieve an operation with stratified-charge combustion, whereas in the high load range, fuel is injected during an intake stroke while a tumble flow is generated so as to achieve an operation with homogeneous combustion.

Moreover, for example, JP2018-193987A discloses a technology in which an engine is provided with, in addition to an SCV as described above, an EGR (exhaust gas recirculation) system which recirculates exhaust gas of the engine to an intake passage as EGR gas, and an EGR rate which is a rate of an amount of EGR gas contained in intake air (fresh air +EGR gas) supplied to the engine is reduced as an engine load increases.

As described in JP2002-130025A, in many cases, the engine system including the SCV controls the SCV to fully close in the low load range, and controls the SCV to fully open in the high load range. Moreover, from the viewpoint of reducing a pumping loss of the engine, in the low load range, it is desired to control the EGR system to increase the amount of EGR gas to be recirculated to the intake passage.

Here, when the SCV is switched from fully closed to fully opened corresponding to the shift of the operation state of the engine from the low load range to the high load range, a state where only one intake port communicates with each cylinder is shifted to a state where two intake ports communicate with the cylinder. Therefore, while the SCV is switched from fully closed to fully opened, a blown back amount (backflow amount) of exhaust gas from an exhaust passage to the intake passage during a valve overlap period where both of an intake valve and an exhaust valve open increases compared with before the switching, which is likely to increase an amount of exhaust gas (i.e., internal EGR gas) introduced into the cylinder. As a result, when a comparatively large amount of EGR gas (i.e., external EGR gas) is recirculated by the EGR system in the low load range as described above, the total amount of exhaust gas (i.e., the total amount of external EGR gas and internal EGR gas) introduced into the cylinder upon the switching of the SCV from fully closed to fully opened becomes excessive, which degrades combustion stability.

SUMMARY OF THE DISCLOSURE

The present disclosure is made in view of solving the problem described above, and one purpose thereof is to provide an engine system, capable of avoiding lowering of combustion stability due to excessive exhaust gas recirculation (EGR) gas when a swirl control valve set to fully closed in a low load range is switched to fully opened.

According to one aspect of the present disclosure, an engine system is provided, which includes an engine, a swirl control valve, an EGR passage, an EGR gas adjusting mechanism, and a controller. The engine includes a cylinder defining a combustion chamber, a piston configured to reciprocate inside the cylinder, and a fuel injection valve configured to directly inject fuel into the cylinder. The swirl control valve is provided inside an intake passage and generates a swirl flow inside the cylinder when the swirl control valve closes, the intake passage being configured to supply intake air to the cylinder. The EGR passage recirculates exhaust gas of the engine as EGR gas to the intake passage. The EGR gas adjusting mechanism is provided to the EGR passage and controls an amount of EGR gas to be recirculated to the intake passage. The controller controls the fuel injection valve, the swirl control valve, and the EGR gas adjusting mechanism. When an engine load is at or below a given threshold, the controller controls the swirl control valve to close. While the engine load is at or below the threshold, the controller controls the EGR gas adjusting mechanism such that, at a fixed engine speed, an increase rate of the amount of EGR gas with respect to an increase in the engine load is lower in a first load range than in a second load range, the first load range higher than the second load range and including the threshold.

According to this configuration, in the low load range where the engine load is at or below the threshold, when the engine load is separated from the threshold (in the second load range), the controller controls to increase the amount of EGR gas as the engine load increases, whereas, when the engine load is near the threshold (in the first load range), the controller controls to avoid the increase in the amount of EGR gas corresponding to the increase in the engine load. Thus, even when an amount of internal EGR gas increases as described above during the switching of the swirl control valve (SCV) from fully closed to fully opened corresponding to shift of an operation state of the engine from the low load range to a high load range, the increase in an amount of external EGR gas corresponding to the engine load increase can accurately be suppressed. As a result, upon the switching of the SCV from fully closed to fully opened, the increase in the total amount of exhaust gas (i.e., the total amount of external EGR gas and internal EGR gas) introduced into the cylinder can be avoided, and combustion stability can be secured.

In the second load range, the controller may control the EGR gas adjusting mechanism to increase the amount of EGR gas as the engine load increases. On the other hand, in the first load range, the controller may control the EGR gas adjusting mechanism to keep the amount of EGR gas substantially constant regardless of the increase in the engine load.

According to this configuration, in the first load range, the controller adjusts the amount of EGR gas to be substantially constant regardless of the increase in the engine load. Thus, the amount of external EGR gas introduced into the cylinder when the SCV is switched from fully closed to fully opened can effectively be reduced, and combustion stability can certainly be secured.

When the engine load exceeds the threshold, the controller may control the swirl control valve to open, and control the EGR gas adjusting mechanism to reduce the amount of EGR gas as the engine load increases.

According to this configuration, in the high load range, since the controller reduces the amount of EGR gas as the engine load increases, an amount of fresh air introduced into the cylinder is increased and the engine output can be improved.

When the engine load is at or below the threshold, the controller may control the fuel injection valve to inject fuel all at once during an intake stroke of the engine. On the other hand, when the engine load exceeds the threshold, the controller may control the fuel injection valve to inject fuel a plurality of times from an intake stroke to a compression stroke of the engine.

According to this configuration, in the low load range, the controller executes the batch injection of fuel during an intake stroke, thereby homogeneous combustion appropriately being achieved in the engine. Moreover, in the high load range, the controller executes the split injection of fuel from an intake stroke to a compression stroke, thereby stratified-charge combustion appropriately being achieved in the engine.

The fuel injection valve may be provided incliningly with respect to an axial direction of the piston.

Furthermore, a crown surface of the piston may be formed to be substantially flat without a cavity.

The EGR gas adjusting mechanism may be an EGR valve.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a diagram schematically illustrating a configuration of an engine system according to one embodiment of the present disclosure.

FIG. **2** is a perspective view of an engine according to this embodiment.

FIG. **3** is a block diagram illustrating an electrical configuration of the engine system according to this embodiment.

FIG. **4** illustrates operation ranges of the engine according to this embodiment.

FIG. **5** is a map illustrating a relationship between an engine load and opening of an EGR valve according to this embodiment.

FIG. **6** is a flowchart illustrating control according to this embodiment.

DETAILED DESCRIPTION OF THE DISCLOSURE

Hereinafter, an engine system according to one embodiment of the present disclosure is described with reference to the accompanying drawings.

Configuration of Engine System

FIG. **1** is a diagram schematically illustrating a configuration of the engine system according to this embodiment. As illustrated in FIG. **1**, an engine system **100** includes an engine **1** mounted on a vehicle. The engine **1** is a gasoline engine to which fuel at least containing gasoline is supplied. In detail, the engine **1** includes a cylinder block **4** provided with cylinders **2** (note that, although one cylinder **2** is illustrated in FIG. **1**, for example, four cylinders **2** may be aligned in a row), a cylinder head **6** provided above the cylinder block **4**, and an oil pan **8** provided below the cylinder block **4** and storing lubricant therein. A piston **14** which is coupled to a crankshaft **12** via a connecting rod **10** is reciprocatably inserted into each cylinder **2**. The cylinder head **6**, the cylinder **2**, and the piston **14** define a combustion chamber **16** of the engine **1**.

Intake air is supplied to the engine **1** from an intake passage **40**. The intake passage **40** is provided thereon with a throttle valve **41** which is adjustable of an amount of intake air to be supplied to the engine **1**, and a surge tank **42** which temporality stores intake air to be supplied to the engine **1**. Further, part of the intake passage **40** constitutes an intake port **18** connected to the engine **1**.

Two independent intake ports **18** and two independent exhaust ports **20** are connected to the engine **1** for each cylinder **2**, and the intake ports **18** and the exhaust ports **20** are provided with intake valves **22** and exhaust valves **24** which open and close openings on the combustion chamber **16** side, respectively. Here, in response to opening of the intake valve **22** and descending of the piston **14**, a tumble flow (vertical (longitudinal) vortex) is generated by intake air flowed into the combustion chamber **16** from the intake port **18**.

Further, one of the two intake ports **18** for each cylinder **2** is provided with a swirl control valve (SCV) **43** which opens and closes a flow passage of the intake port **18**. Note that, in FIG. **1**, only one intake port **18** to which the SCV **43** is provided is illustrated, and the other intake port **18** without the SCV **43** is not illustrated. When the SCV **43** is closed, intake air is flowed into the combustion chamber **16** only from one of the two intake ports **18**, and therefore, a swirl flow (horizontal (transverse) vortex) is generated inside the combustion chamber **16**.

A lower surface of the cylinder head **6** of the engine **1** forms a ceiling **26** of the combustion chamber **16**. This ceiling **26** is a so-called pentroof type in which two opposing sloped surfaces are provided so as to extend from a central part of the ceiling **26** to a lower end of the cylinder head **6**. Further, the cylinder head **6** is attached, for each cylinder **2**, with a (direct injection) injector (fuel injection valve) **28** which directly injects fuel into the cylinder **2**. The injector **28** is provided incliningly with respect to an axial direction of the piston **14** (i.e., a moving direction of the piston **14**). In detail, the injector **28** is disposed such that its nozzle is oriented obliquely downwardly into the combustion chamber **16** from between the two intake ports **18** at a periphery of the ceiling **26** of the combustion chamber **16**.

Further, a spark plug **32** which forcibly ignites a mixture gas inside the combustion chamber **16** is attached to the cylinder head **6** of the engine **1** for each cylinder **2**. The spark plug **32** is disposed to extend downwardly from the central part of the ceiling **26** of the combustion chamber **16** while penetrating the cylinder head **6**. Moreover, the cylinder head **6** is provided with valve mechanisms **36** which drive the intake valves **22** and the exhaust valves **24** of each cylinder **2**, respectively. The valve mechanism **36** is, for example, a variable valve lift mechanism which can change a lift amount of each of the intake valve **22** and the exhaust valve **24**, or a variable valve phase mechanism which can change a rotational phase of a camshaft with respect to the crankshaft **12**.

The intake passage **40** is connected to one side surface of the engine **1** as described above, whereas, on the other side surface, an exhaust passage **44** which discharges burnt gas (exhaust gas) from the combustion chamber **16** of each cylinder **2** is connected. The exhaust passage **44** is provided thereon with a catalyst **45** (in detail, a catalytic converter) which purifies exhaust gas. Moreover, the exhaust passage **44** is connected, on a downstream side of the catalyst **45**, to an exhaust gas recirculation (EGR) passage **46** which recirculates the exhaust gas to the intake passage **40**. The EGR passage **46** is provided thereon with an EGR cooler **47** which cools exhaust gas (EGR gas) to be recirculated, and an EGR valve **48** (EGR gas adjusting mechanism) which adjusts an amount of EGR gas to be recirculated to the intake passage **40**. The EGR passage **46**, the EGR cooler **47**, and the EGR valve **48** constitute an EGR system.

Next, FIG. **2** is a perspective view illustrating a detailed structure of the piston **14**, the injector **28**, and the spark plug **32** of the engine **1** according to this embodiment. As illustrated in FIG. **2**, the injector **28** is a multi-nozzle type having a plurality of nozzles **30**. The injector **28** is disposed such that an axial direction of the injector **28** inclines downwardly at a given angle with respect to a horizontal direction. Therefore, fuel spray injected from each nozzle **30** of the injector **28** spreads radially to obliquely downward from the periphery of the ceiling **26** of the combustion chamber **16**.

Further, a piston crown surface **14***a* which constitutes a top part of the piston **14** is formed as a convex which bulges at its central area. For example, at the center of the piston crown surface **14***a*, a flat surface **14***b* extending along a horizontal surface orthogonal to the axial direction of the piston **14** is formed over a comparatively wide range. The piston crown surface **14***a* is not formed with a so-called cavity.

Further, the piston crown surface **14***a* is provided with an injector side sloped surface **14***c* extending obliquely upward toward the center from an end part of the piston crown surface **14***a* on the injector **28** side, and a counter-injector side sloped surface **14***d* extending obliquely upward toward the center from an opposite end part of the piston crown surface **14***a*. i.e., on the farther side from the injector **28** (hereinafter, may be referred to as a “counter-injector side” as necessary). The injector side sloped surface **14***c* and the counter-injector side sloped surface **14***d* are formed along the ceiling **26** of the combustion chamber **16** (see FIG. **1**).

Further, in each end part of the piston crown surface **14***a* on the injector side and the counter-injector side, a horizontal surface **14***e* is formed. Moreover, the counter-injector side sloped surface **14***d* of the piston crown surface **14***a* is formed with exhaust valve recesses **14***f* which are concaved to avoid contact between the piston **14** and the exhaust valves **24**, respectively. Note that contact between the piston **14** and the intake valves **22** is avoided by the injector side sloped surface **14***c*, etc.

Next, FIG. **3** is a block diagram illustrating an electrical configuration of the engine system **100** according to this embodiment. PCM (Powertrain Control Module) **80** is comprised of a circuit, and is a controller based on a well-known microcomputer. The PCM **80** is provided with, for example, one or more microprocessor **80***a* (e.g., a CPU (Central Processing Unit)) which executes a program, memory **80***b* which is comprised of RAM (Random Access Memory) and/or ROM (Read Only Memory) and stores the program and data, and an I/O bus which inputs and outputs electric signals.

The PCM **80** is connected to various sensors. For example, the PCM **80** is mainly connected with an accelerator opening sensor **S1** and a crank angle sensor **S2**. The accelerator opening sensor **S1** detects an accelerator opening corresponding to a depressing amount of an accelerator pedal, and the crank angle sensor **S2** detects a rotational angle of the crankshaft **12** (corresponding to an engine speed). Detection signals outputted from these sensors **S1** and **S2** are inputted into the PCM **80**.

The PCM **80** calculates, based on the detection signals inputted from the sensors S**1** and S**2**, a control amount of each device in accordance with a control logic defined in advance. The control logic is stored in the memory **80***b*. The control logic includes calculating a target amount and/or the control amount by using a map stored in the memory **80***b*. The PCM **80** outputs control signals related to the calculated control amounts mainly to the injector **28**, the spark plug **32**, the SCV **43**, and the EGR valve **48**.

Control Contents

Next, control contents executed by the PCM **80** according to this embodiment are described. Basically, the PCM **80** switches the opening and closing of the SCV **43** corresponding to a change in an operation state of the engine **1**, that is, switches the SCV **43** from fully closed to fully opened, or from fully opened to fully closed. According to this, whether to introduce the swirl flow into the combustion chamber **16** by the SCV **43** is switched according to the operation state of the engine **1**.

First, with reference to FIG. **4**, the operation ranges of the engine **1** in which the SCV **43** is set to fully closed or fully opened are described. FIG. **4** illustrates the operation ranges of the engine **1** defined by the engine speed indicated by the horizontal axis and the engine load indicated by the vertical axis. In an operation range R**1** where the engine speed is at or below a speed threshold N**1** (e.g., 2,500 rpm) and the engine load is at or below a load threshold L**1**, the SCV **43** is set to fully closed, that is, the engine **1** is operated using the swirl flow generated by closing the SCV **43**. In addition, in the operation range R**1**, the injector **28** injects fuel all at once (batch injection) during an intake stroke of the engine **1** in the state where the swirl flow is generated, and thus homogeneous combustion being achieved in the engine **1**.

On the other hand, in an operation range R**2** where the engine speed exceeds the speed threshold N**1** or the engine load exceeds the load threshold L**1**, the SCV **43** is set to fully opened, that is, the engine **1** is operated without using the swirl flow. Further, when the engine speed is at or below the speed threshold N**1** in the operation range R**2**, the injector **28** dividedly injects fuel a plurality of times (split injection) during an intake stroke and a compression stroke of the engine **1**, and thus stratified-charge combustion is achieved in the engine **1**. In contrast, in a range where the engine speed exceeds the speed threshold N**1** in the operation range R**2**, the injector **28** injects fuel all at once (batch injection) during an intake stroke of the engine **1**, and thus homogeneous combustion is achieved in the engine **1**.

Note that FIG. **4** illustrates an example in which the speed threshold N**1** and the load threshold L**1** are fixed values, respectively. However, in other examples, the speed threshold N**1** may be lowered as the engine load increases, or the load threshold L**1** may be lowered as the engine speed increases. Moreover, below, the operation range R**1** may suitably be referred to as a “low-load range R**1**,” and the operation range R**2** may suitably be referred to as a “high-load range R**2**.”

As described above, in the low-load range R**1**, the PCM **80** controls the SCV **43** to fully close so that a swirl flow is generated inside the combustion chamber **16**. Moreover, from the viewpoint of reducing a pumping loss of the engine **1**, in the low-load range R**1**, the PCM **80** basically controls the EGR valve **48** to increase the amount of EGR gas to be recirculated to the intake passage **40** from the EGR passage **46**.

Here, when the SCV **43** is switched from fully closed to fully opened corresponding to the shift of the operation state of the engine **1** from the low-load range R**1** to the high-load range R**2**, a state where only one intake port **18** communicates with each cylinder **2** is shifted to a state where two intake ports **18** communicate with the cylinder **2**. Therefore, while the SCV **43** is switched from fully closed to fully opened, a blown back amount (backflow amount) of exhaust gas to the intake passage **40** during a valve overlap period where both of the intake valve **22** and the exhaust valve **24** open increases compared with before the switching (the fully closed state of the SCV **43**). According to this, during an intake stroke of the engine **1**, an amount of exhaust gas (internal EGR gas) introduced into the combustion chamber **16** together with fresh air increases. As a result, when a comparatively large amount of EGR gas (external EGR gas) is recirculated from the EGR passage **46** in the low-load range R**1** as described above, the total amount of exhaust gas (i.e., the total amount of external EGR gas and internal EGR gas) introduced into the combustion chamber **16** upon the switching of the SCV **43** from fully closed to fully opened becomes excessive, which degrades combustion stability.

In this embodiment, the PCM **80** executes control to suppress the degradation in combustion stability due to the excessive EGR gas when the SCV **43** is switched from the fully closed to fully opened. In detail, while the operation range is the low-load range R**1** where the engine load is at or below the load threshold L**1**, the PCM **80** controls the EGR valve **48** such that, at a fixed speed, an increase rate of the EGR gas amount with respect to the increase in the engine load is lower in a first load range than in a second load range. The first load range is higher than the second load range, and includes the load threshold L**1**. That is, in the low-load range R**1**, when the engine load is separated from the load threshold L**1**, the PCM **80** controls the EGR valve **48** to increase the amount of EGR gas as the engine load increases. On the other hand, when the engine load is near the load threshold L**1**, the PCM **80** controls the EGR valve **48** to avoid the increase in the amount of EGR gas corresponding to the increase in the engine load (typically, maintain the EGR gas amount substantially constant regardless of the increase in the engine load).

Here, a basic concept of the control according to this embodiment is described with reference to FIG. **5**. FIG. **5** illustrates a map of an EGR valve opening (vertical axis) applied according to the engine load (horizontal axis) at a certain engine speed (e.g., 1,500 rpm). As illustrated in FIG. **5**, in this embodiment, in a range on the lower load side within the low-load range R**1** (in detail, in a second load range R**1***b* at or below a given load L**2** in the low-load range R**1**), the PCM **80** gradually increases the EGR valve opening so as to increase the EGR gas amount corresponding to the increase in the engine load (see an arrow A**1**), in view of reducing the pumping loss of the engine **1**.

Particularly, in this embodiment, in a range on the higher load side within the low-load range R**1** (in detail, in a first load range R**1***a* between the given load L**2** and the load threshold L**1** (i.e., higher than the given load L**2** and lower than the load threshold L**1**)), the PCM **80** reduces the increase rate of the EGR valve opening with respect to the increase in the engine load (see an arrow A**2**), compared with in the second load range R**1***b*. In more detail, in the first load range R**1***a*, the PCM **80** keeps the EGR valve opening substantially constant regardless of the engine load increase. According to this, even when the amount of internal EGR gas increases during the switching of the SCV **43** from fully closed to fully opened corresponding to the shift of the operation state of the engine **1** from the low-load range R**1** to the high-load range R**2**, the increase in the amount of external EGR gas corresponding to the increase in the engine load can accurately be suppressed. As a result, upon the switching of the SCV **43** from fully closed to fully opened, the increase in the total amount of exhaust gas (i.e., the total amount of external EGR gas and internal EGR gas) introduced into the combustion chamber **16** can be suppressed, and combustion stability can be secured.

Note that in a range on a further lower load side within the second load range R**1***b*, in order to give priority to securing combustion stability, the EGR valve opening is set to zero so as not to introduce EGR gas into the combustion chamber **16**. On the other hand, in the high-load range R**2**, in view of improving an engine output by increasing an amount of fresh air, the PCM **80** gradually reduces the EGR valve opening so as to lower the EGR gas amount as the engine load increases (see an arrow A**3**).

Next, a control flow related to this embodiment is described with reference to FIG. **6**. FIG. **6** is a flowchart illustrating the control according to this embodiment. This control is repeatedly executed by the PCM **80** at a given cycle. First, at Step S**11**, the PCM **80** acquires various information. For example, the PCM **80** at least acquires the detection signals of the accelerator opening sensor S**1** and the crank angle sensor S**2** described above.

Next, at Step S**12**, the PCM **80** identifies, based on the information acquired at Step S**11**, the current operation state of the engine **1** (in detail, the current engine speed and the current engine load). Here, the PCM **80** acquires the engine speed based on the crank angle (the rotational angle of the crankshaft **12**) corresponding to the detection signal of the crank angle sensor S**2**. Moreover, the PCM **80** acquires a target torque of the vehicle based on the accelerator opening corresponding to the detection signal of the accelerator opening sensor S**1**, and then, calculates the engine load corresponding to the target torque.

Next, at Step S**13**, the PCM **80** determines a valve state (fully closed or fully opened) to be set for the SCV **43** based on the operation state of the engine **1** identified at Step S**12**. For example, when the engine speed and the engine load belong to the low-load range R**1**, the PCM **80** determines the valve state as fully closed, and, when the engine speed and the engine load belong to the high-load range R**2**, the PCM **80** determines the valve state as fully opened.

Next, at Step S**14**, the PCM **80** determines the EGR valve opening to be set for the EGR valve **48** based on the operation state of the engine **1** identified at Step S**12**. For example, the PCM **80** determines the EGR valve opening to be applied at the current engine load with reference to the map as illustrated in FIG. **5**. Note that since the map illustrated in FIG. **5** is defined for each engine speed, the map corresponding to the current engine speed is selected. Then, the PCM **80** proceeds to Step S**15**.

Next, at Step S**15**, the PCM **80** controls the SCV **43** and the EGR valve **48** based on the valve state of the SCV **43** determined at Step S**13**, and the EGR valve opening determined at Step S**14**. In this case, the PCM **80** controls the EGR valve **48** to be the determined valve opening. Moreover, when the valve state of the SCV **43** determined at Step S**13** is different from the current valve state, the PCM **80** switches the valve state of the SCV **43**, that is, switches the SCV **43** from fully closed to fully opened, or from fully opened to fully closed. On the other hand, when the valve state of the SCV **43** determined at Step S**13** is the same as the current valve state, the PCM **80** maintains the valve state of the SCV **43**. Then, the PCM **80** ends the flow illustrated in FIG. **6**.

Operation and Effects

Next, operation and effects of the engine system **100** according to this embodiment are described.

In this embodiment, in the low-load range R**1** where the engine load is at or below the load threshold L**1** at which the SCV **43** is switched from fully closed to fully opened, the

PCM **80** controls the EGR valve **48** such that, at the fixed speed, the increase rate of the EGR gas amount with respect to the increase in the engine load is lower in the first load range R**1***a* than in the second load range R**1***b*. The first load range R**1***a* is higher than the second load range R**1***b*, and includes the load threshold L**1**. According to this, even when the internal EGR gas amount increases during the switching of the SCV **43** from fully closed to fully opened corresponding to the shift of the operation state of the engine **1** from the low-load range R**1** to the high-load range R**2**, the increase in the external EGR gas amount corresponding to the engine load increase can accurately be suppressed. As a result, upon the switching of the SCV **43** from fully closed to fully opened, the increase in the total amount of exhaust gas (i.e., the total amount of external EGR gas and internal EGR gas) introduced into the combustion chamber **16** can be suppressed, and combustion stability can be secured.

Further, according to this embodiment, in the first load range R**1***a*, the PCM **80** controls the EGR valve **48** such that the amount of EGR gas becomes substantially constant regardless of the increase in the engine load. According to this, the amount of external EGR gas introduced into the combustion chamber **16** when the SCV **43** is switched from fully closed to fully opened can effectively be reduced, and the combustion stability can certainly be secured.

Further, according to this embodiment, in the high-load range R**2**, since the PCM **80** controls the EGR valve **48** to reduce the amount of EGR gas as the engine load increases, the amount of fresh air introduced into the combustion chamber **16** is increased and the engine output can be improved.

Further, according to this embodiment, in the low-load range R**1**, the PCM **80** executes the batch injection of fuel during an intake stroke, thereby the homogeneous combustion appropriately being achieved in the engine **1**. Moreover, in the high-load range R**2** (at or below the speed threshold N**1**), the PCM **80** executes the split injection of fuel from an intake stroke to a compression stroke, thereby the stratified-charge combustion appropriately being achieved in the engine **1**.

It should be understood that the embodiments herein are illustrative and not restrictive, since the scope of the invention is defined by the appended claims rather than by the description preceding them, and all changes that fall within metes and bounds of the claims, or equivalence of such metes and bounds thereof, are therefore intended to be embraced by the claims.

DESCRIPTION OF REFERENCE CHARACTERS

1 Engine
2 Cylinder
14 Piston
14*a* Piston Crown Surface
16 Combustion Chamber
18 Intake Port
28 Injector (Fuel Injection Valve)
32 Spark Plug
40 Intake Passage
43 Swirl Control Valve (SCV)
44 Exhaust Passage
45 Catalyst
46 EGR Passage
48 EGR Valve (EGR Gas Adjusting Mechanism)
80 PCM (Controller)
100 Engine System

What is claimed is:

1. An engine system, comprising:
an engine including:
a cylinder defining a combustion chamber;
a piston configured to reciprocate inside the cylinder; and
a fuel injection valve configured to directly inject fuel into the cylinder;
a swirl control valve provided inside an intake passage and configured to generate a swirl flow inside the cylinder when the swirl control valve closes, the intake passage being configured to supply intake air to the cylinder;
an exhaust gas recirculation (EGR) passage configured to recirculate exhaust gas of the engine as EGR gas to the intake passage;
an EGR gas adjusting mechanism provided to the EGR passage and configured to control an amount of EGR gas to be recirculated to the intake passage; and
a controller configured to control the fuel injection valve, the swirl control valve, and the EGR gas adjusting mechanism,
wherein when an engine load is at or below a given threshold, the controller controls the swirl control valve to close, and
wherein while the engine load is at or below the threshold, the controller controls the EGR gas adjusting mechanism such that, at a fixed engine speed, an increase rate of the amount of EGR gas with respect to an increase in the engine load is lower in a first load range than in a second load range, the first load range being higher than the second load range and including the threshold.

2. The engine system of claim **1**, wherein in the second load range, the controller controls the EGR gas adjusting mechanism to increase the amount of EGR gas as the engine load increases, and in the first load range, the controller controls the EGR gas adjusting mechanism to keep the amount of EGR gas substantially constant regardless of the increase in the engine load.

3. The engine system of claim **2**, wherein when the engine load exceeds the threshold, the controller controls the swirl control valve to open and controls the EGR gas adjusting mechanism to reduce the amount of EGR gas as the engine load increases.

4. The engine system of claim **3**, wherein when the engine load is at or below the threshold, the controller controls the fuel injection valve to inject fuel all at once during an intake stroke of the engine, and when the engine load exceeds the threshold, the controller controls the fuel injection valve to inject fuel a plurality of times from an intake stroke to a compression stroke of the engine.

5. The engine system of claim **4**, wherein the fuel injection valve is provided inclininglv with respect to an axial direction of the piston.

6. The engine system of claim **5**, wherein a crown surface of the piston is formed to be substantially flat without a cavity.

7. The engine system of claim **1**, wherein when the engine load exceeds the threshold, the controller controls the swirl control valve to open and controls the EGR gas adjusting mechanism to reduce the amount of EGR gas as the engine load increases.

8. The engine system of claim **1**, wherein when the engine load is at or below the threshold, the controller controls the fuel injection valve to inject fuel all at once during an intake stroke of the engine, and when the engine load exceeds the threshold, the controller controls the fuel injection valve to inject fuel a plurality of times from an intake stroke to a compression stroke of the engine.

9. The engine system of claim **1**, wherein the fuel injection valve is provided incliningly with respect to an axial direction of the piston.

10. The engine system of claim **1**, wherein a crown surface of the piston is formed to be substantially flat without a cavity.

11. The engine system of claim **2**, wherein when the engine load is at or below the threshold, the controller controls the fuel injection valve to inject fuel all at once during an intake stroke of the engine, and when the engine load exceeds the threshold, the controller controls the fuel injection valve to inject fuel a plurality of times from an intake stroke to a compression stroke of the engine.

12. The engine system of claim **2**, wherein the fuel injection valve is provided incliningly with respect to an axial direction of the piston.

13. The engine system of claim **2**, wherein a crown surface of the piston is formed to be substantially flat without a cavity.

14. The engine system of claim **3**, wherein the fuel injection valve is provided incliningly with respect to an axial direction of the piston.

15. The engine system of claim **3**, wherein a crown surface of the piston is formed to be substantially flat without a cavity.

16. The engine system of claim **4**, wherein a crown surface of the piston is formed to be substantially flat without a cavity.

17. The engine system of claim **1**, wherein the EGR gas adjusting mechanism is an EGR valve.

18. The engine system of claim **2**, wherein the EGR gas adjusting mechanism is an EGR valve.

19. The engine system of claim **6**, wherein the EGR gas adjusting mechanism is an EGR valve.

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