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Misumi et al.

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(54) **ENGINE SYSTEM**

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(73) Assignee: **Mazda Motor Corporation**, Hiroshima (JP)

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F01P 3/20	(2006.01)
F01P 7/14	(2006.01)

(52) **U.S. Cl.**

CPC ***F01P 7/167*** (2013.01); ***F01P 3/20*** (2013.01); *F01P 2007/146* (2013.01); *F01P 2025/62* (2013.01); *F01P 2037/02* (2013.01); *F01P 2060/08* (2013.01)

(58) **Field of Classification Search**

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See application file for complete search history.

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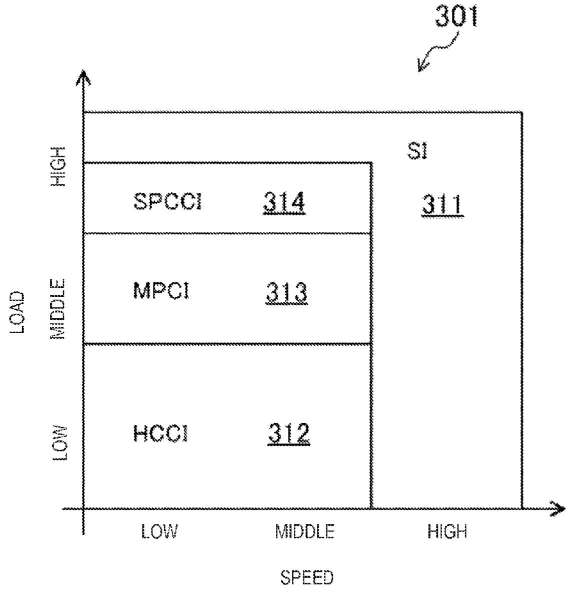
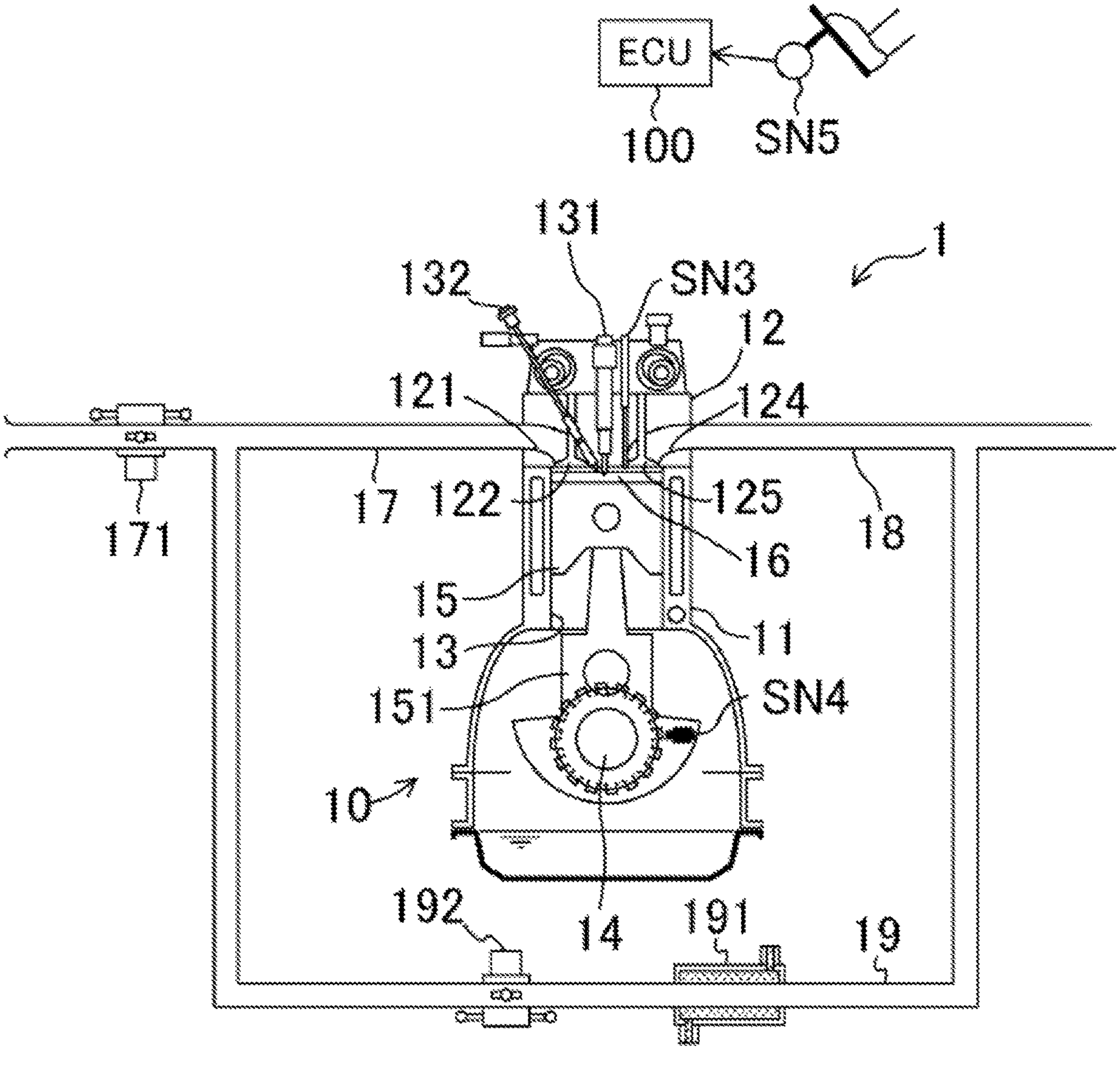
(57) **ABSTRACT**

An engine system is provided, including an engine having a water jacket, a circulation system that circulates coolant through the water jacket, and a controller. The circulation system includes a radiator passage including a heat exchanger, a bypass passage bypassing the heat exchanger, a flow rate control device, and a thermally-actuated valve connected to the radiator passage and that opens to allow the coolant to pass through the heat exchanger. When an engine load is below a first load, the controller controls the flow rate control device to adjust the coolant flow rate flowing through the water jacket according to the load, by closing the radiator passage and adjusting the coolant flow rate flowing through the bypass passage. When the load is above the first load, the controller controls the flow rate control device so that the coolant flows through each of the radiator passage and the bypass passage.

20 Claims, 10 Drawing Sheets




ECU
100
SN5
131
1
132
SN3
12
121
124
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16
15
11
13
151
SN4
10
14
192
191
19

FIG. 1

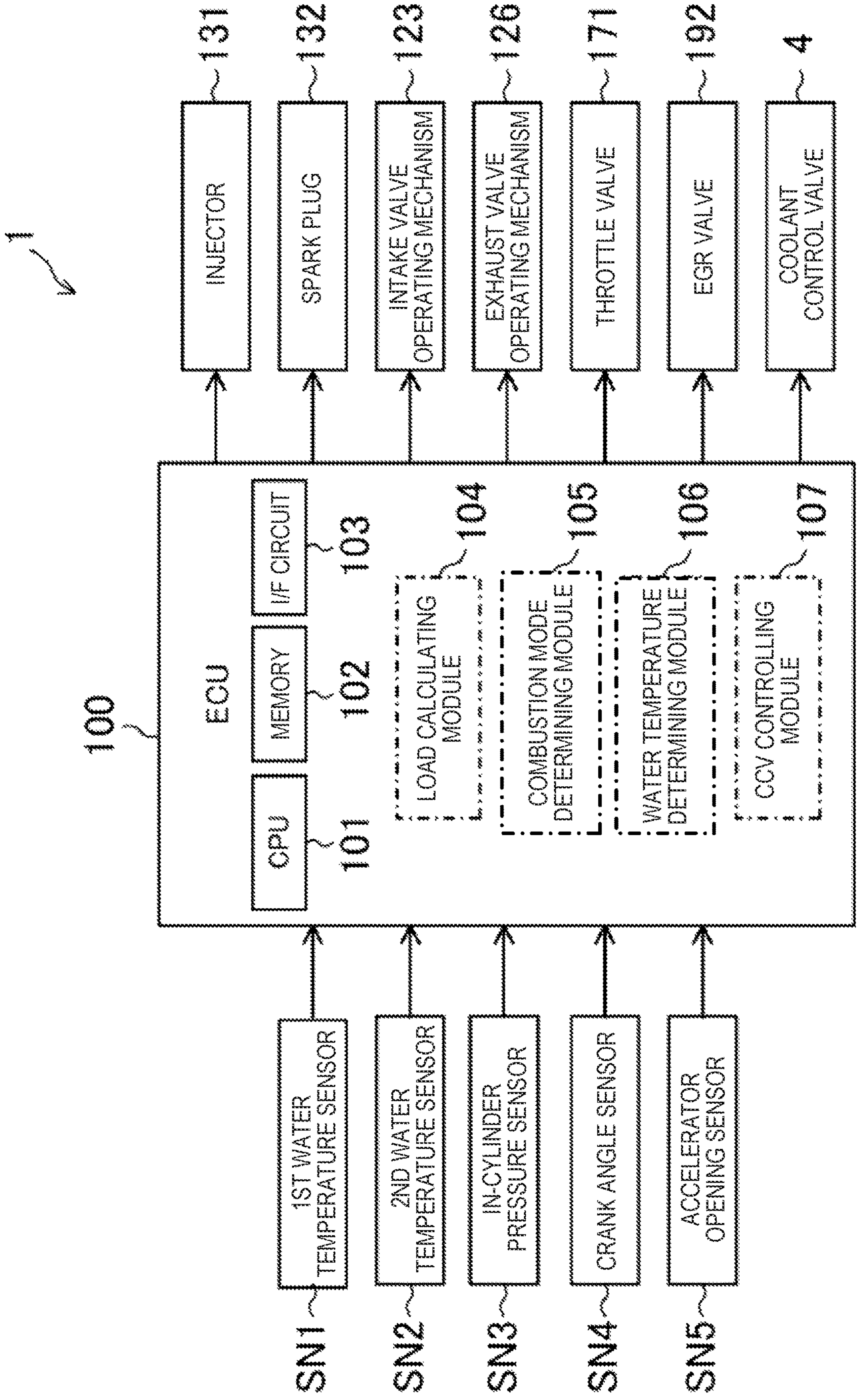

1
100
ECU
CPU
101
MEMORY
102
I/F CIRCUIT
103
LOAD CALCULATING MODULE
104
COMBUSTION MODE DETERMINING MODULE
105
WATER TEMPERATURE DETERMINING MODULE
106
CCV CONTROLLING MODULE
107
INJECTOR
131
SPARK PLUG
132
INTAKE VALVE OPERATING MECHANISM
123
EXHAUST VALVE OPERATING MECHANISM
126
THROTTLE VALVE
171
EGR VALVE
192
COOLANT CONTROL VALVE
4
1ST WATER TEMPERATURE SENSOR
SN1
2ND WATER TEMPERATURE SENSOR
SN2
IN-CYLINDER PRESSURE SENSOR
SN3
CRANK ANGLE SENSOR
SN4
ACCELERATOR OPENING SENSOR
SN5

FIG. 2

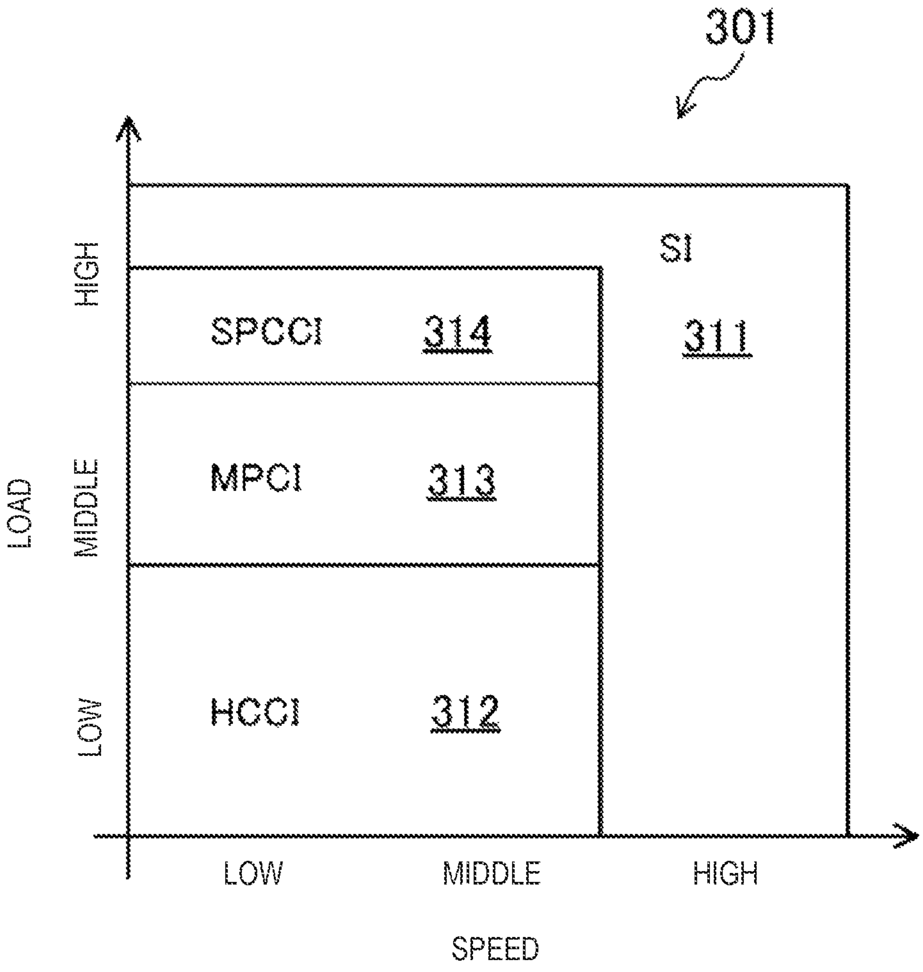

301
SI
311
SPCCI
314
MPCI
313
HCCI
312
LOAD
HIGH
MIDDLE
LOW
LOW
MIDDLE
HIGH
SPEED

FIG. 3

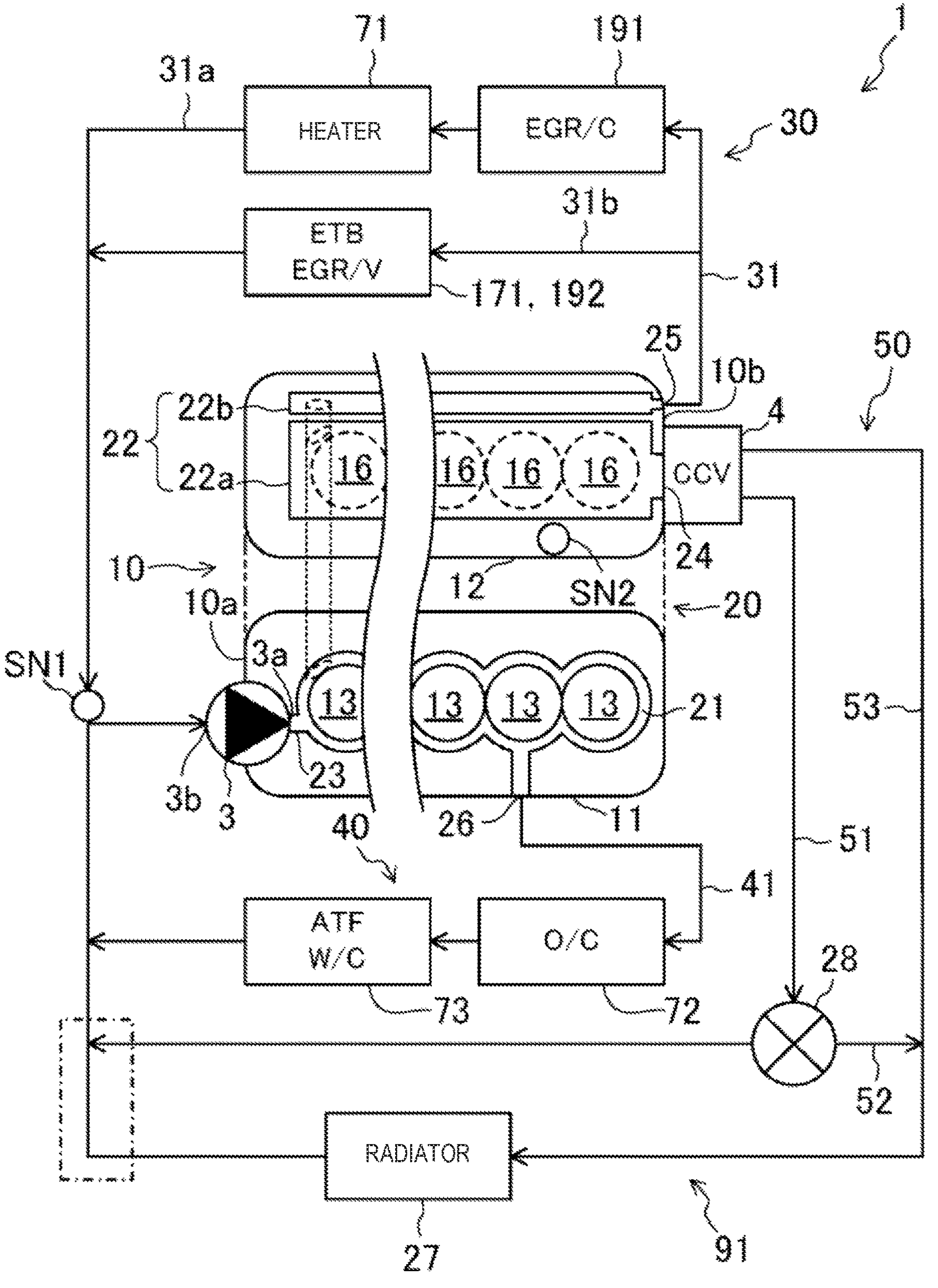

1
71
191
31a
HEATER
EGR/C
30
31b
ETB
EGR/V
171, 192
31
25
50
10b
22b
4
22
16
16
16
16
CCV
22a
24
10
12
SN2
20
10a
3a
SN1
13
13
13
13
21
23
3b
3
40
26
11
51
41
ATF
W/C
O/C
28
73
72
52
RADIATOR
27
91
53

FIG. 4

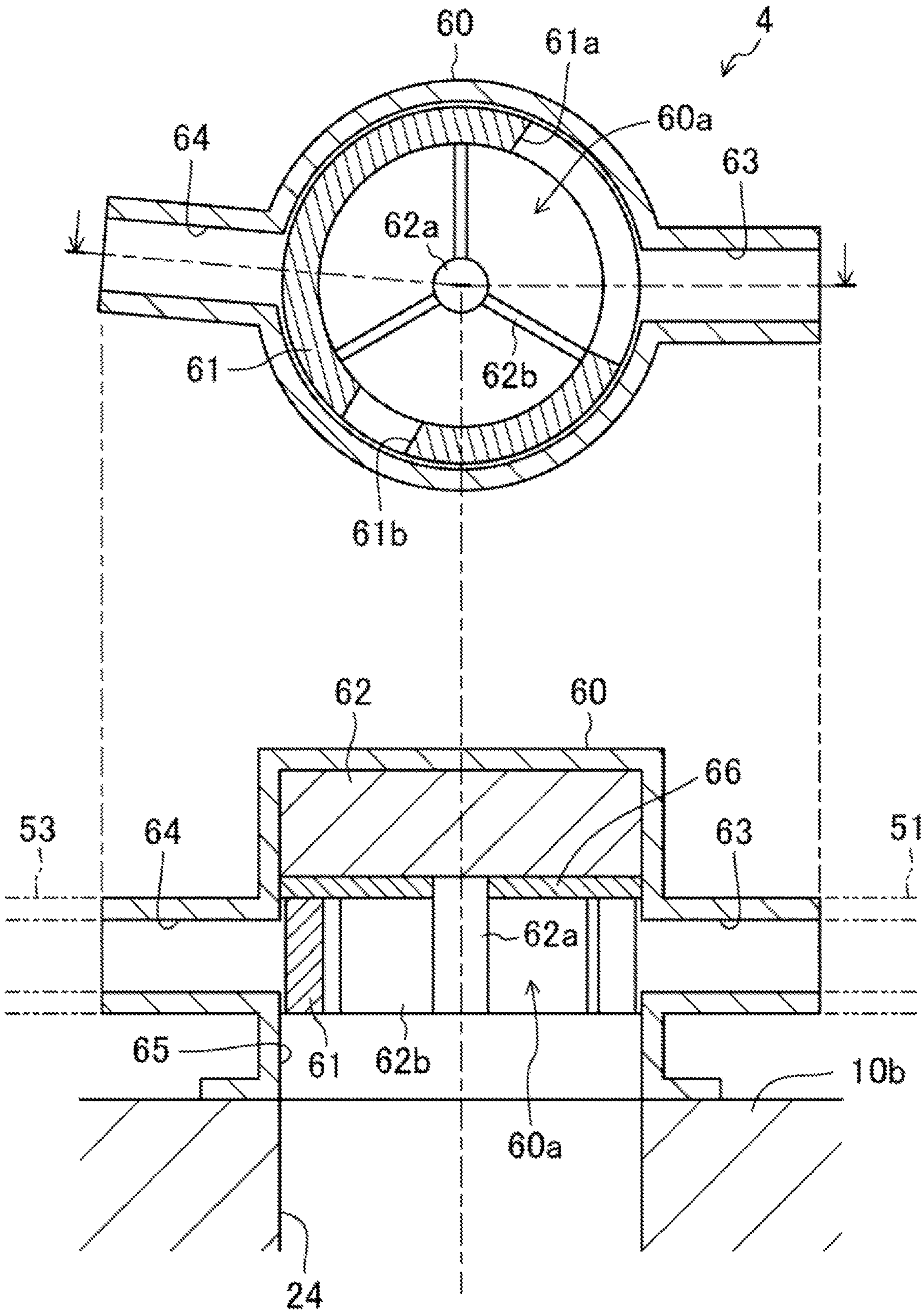

60
61a
4
60a
64
63
62a
61
62b
61b
62
60
66
53
64
63
51
62a
65
61
62b
10b
60a
24

FIG. 5

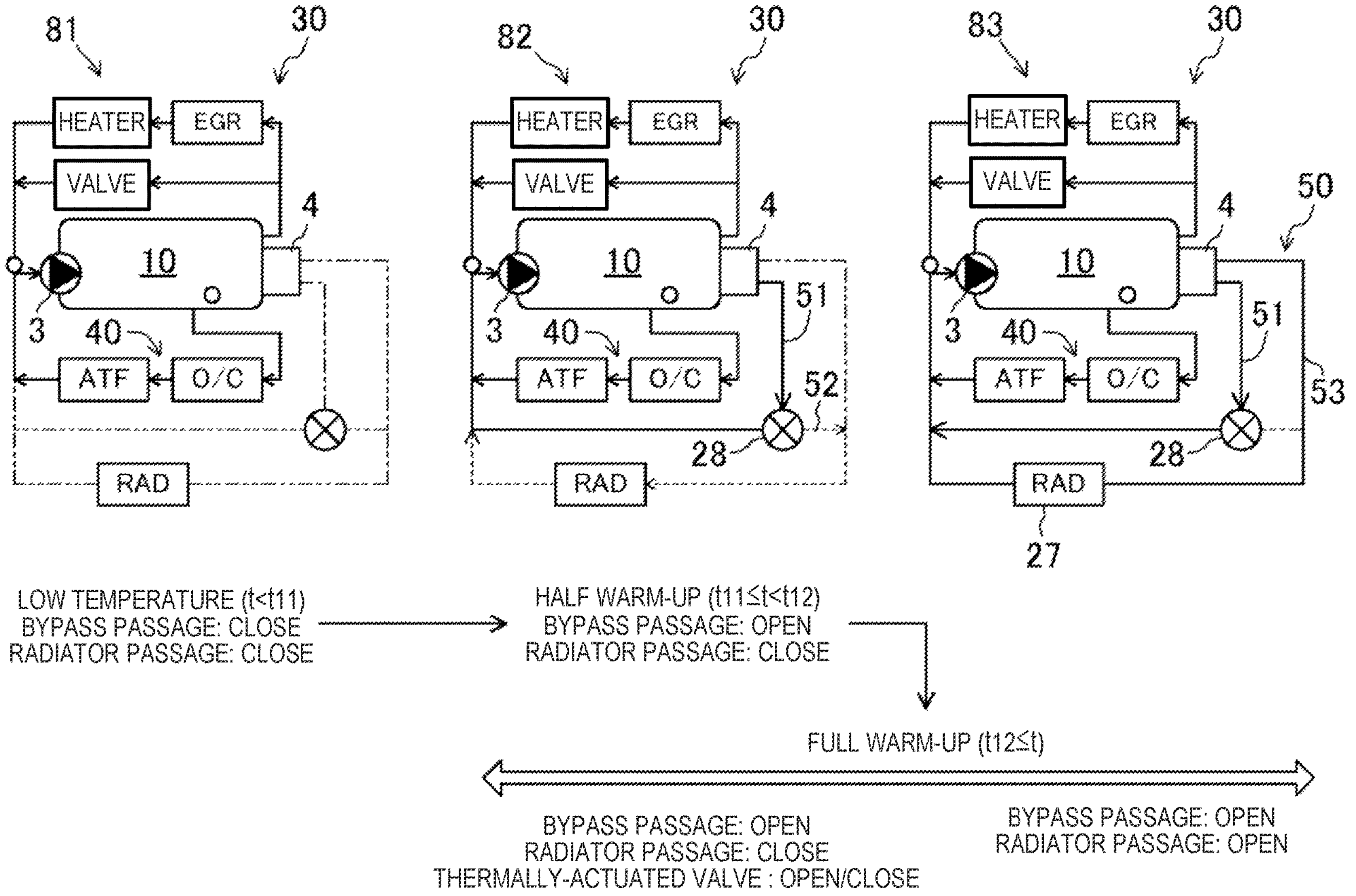
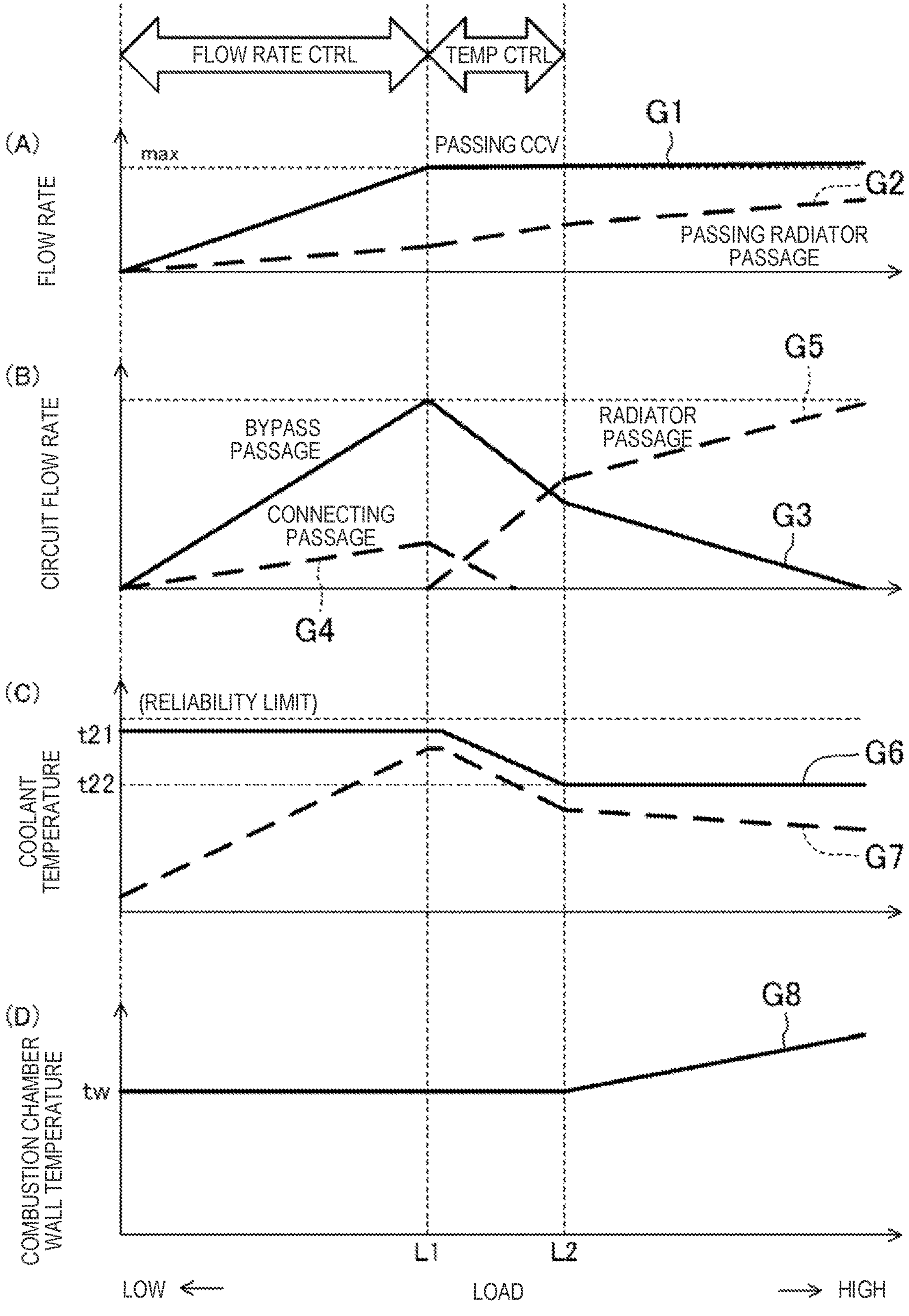

81
30
HEATER
EGR
VALVE
4
10
3
40
ATF
O/C
RAD
82
30
HEATER
EGR
VALVE
4
10
51
3
40
ATF
O/C
52
28
RAD
83
30
HEATER
EGR
VALVE
50
4
10
51
3
40
ATF
O/C
53
28
RAD
27
LOW TEMPERATURE (t<t11)
BYPASS PASSAGE: CLOSE
RADIATOR PASSAGE: CLOSE
HALF WARM-UP (t11≤t<t12)
BYPASS PASSAGE: OPEN
RADIATOR PASSAGE: CLOSE
FULL WARM-UP (t12≤t)
BYPASS PASSAGE: OPEN
RADIATOR PASSAGE: CLOSE
THERMALLY-ACTUATED VALVE : OPEN/CLOSE
BYPASS PASSAGE: OPEN
RADIATOR PASSAGE: OPEN

FIG. 6

FIG. 7


FLOW RATE CTRL
TEMP CTRL
(A)
FLOW RATE
max
PASSING CCV
G1
G2
PASSING RADIATOR PASSAGE
(B)
CIRCUIT FLOW RATE
BYPASS PASSAGE
RADIATOR PASSAGE
G5
CONNECTING PASSAGE
G3
G4
(C)
COOLANT TEMPERATURE
(RELIABILITY LIMIT)
t21
t22
G6
G7
(D)
COMBUSTION CHAMBER WALL TEMPERATURE
tw
G8
L1
L2
LOW
LOAD
HIGH

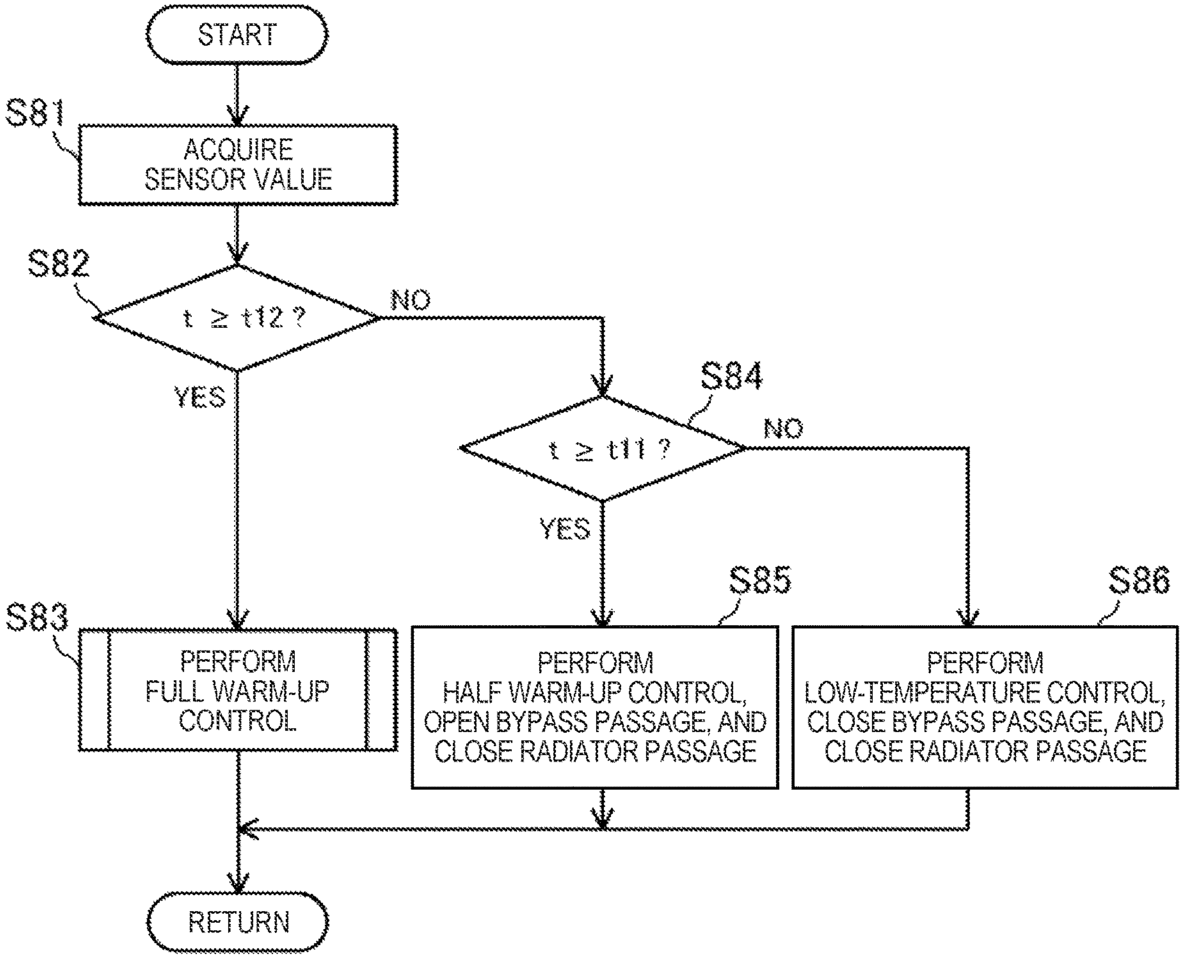

START
S81
ACQUIRE SENSOR VALUE
S82
t ≥ t12 ?
NO
YES
S84
t ≥ t11 ?
NO
YES
S83
PERFORM FULL WARM-UP CONTROL
S85
PERFORM HALF WARM-UP CONTROL, OPEN BYPASS PASSAGE, AND CLOSE RADIATOR PASSAGE
S86
PERFORM LOW-TEMPERATURE CONTROL, CLOSE BYPASS PASSAGE, AND CLOSE RADIATOR PASSAGE
RETURN

FIG. 8

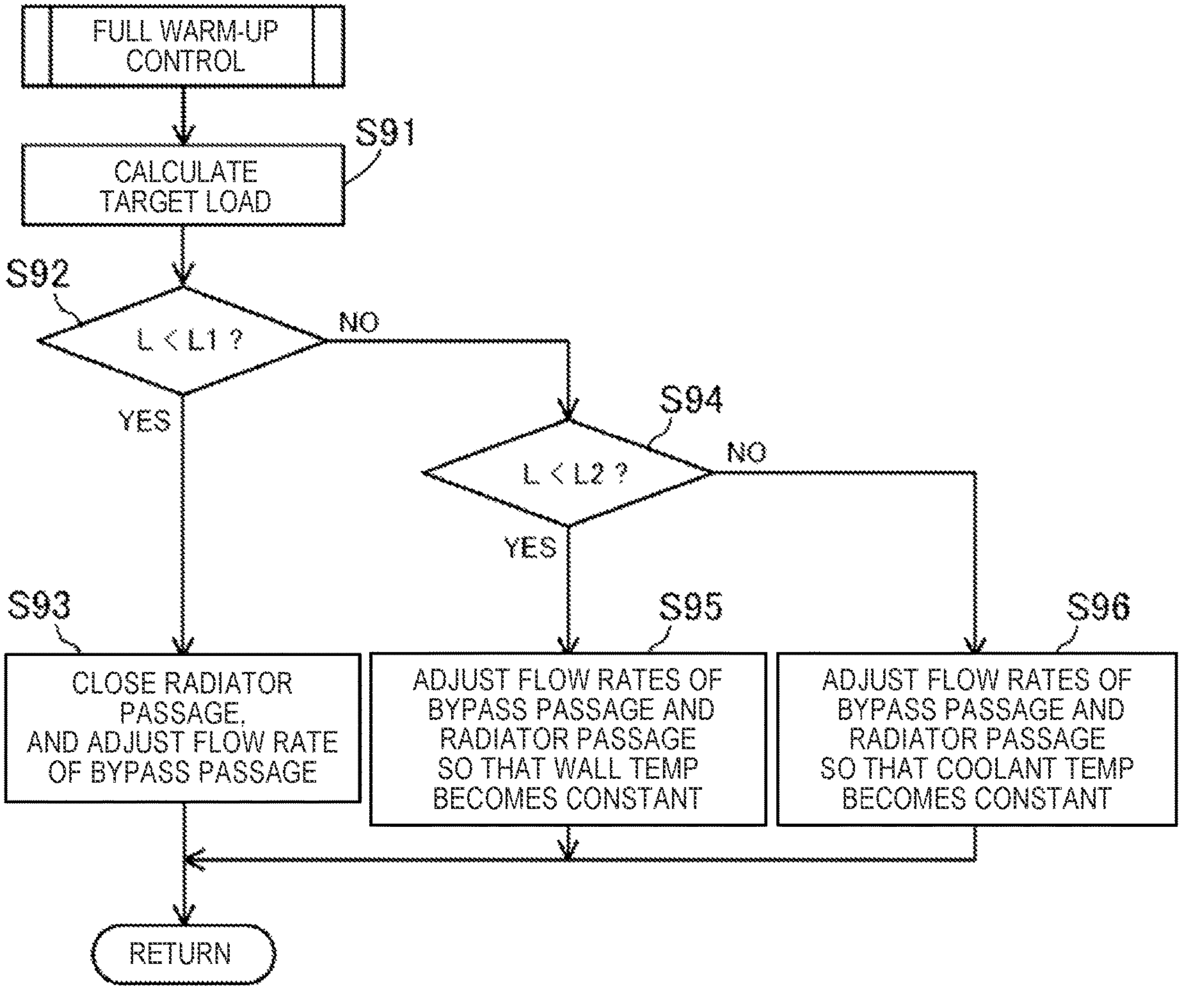
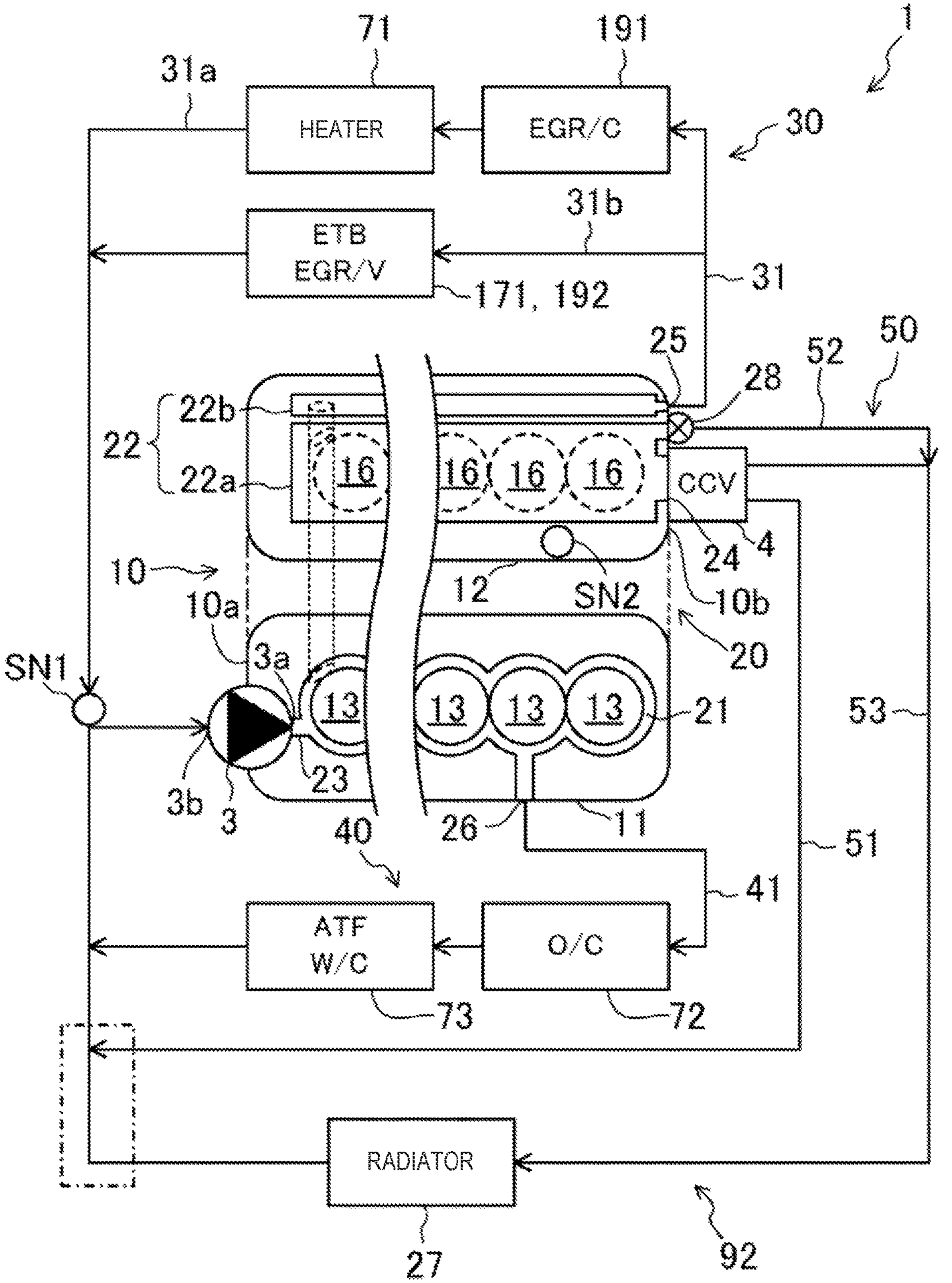

FULL WARM-UP CONTROL
S91
CALCULATE TARGET LOAD
S92
L < L1 ?
NO
YES
S94
L < L2 ?
NO
YES
S93
CLOSE RADIATOR PASSAGE, AND ADJUST FLOW RATE OF BYPASS PASSAGE
S95
ADJUST FLOW RATES OF BYPASS PASSAGE AND RADIATOR PASSAGE SO THAT WALL TEMP BECOMES CONSTANT
S96
ADJUST FLOW RATES OF BYPASS PASSAGE AND RADIATOR PASSAGE SO THAT COOLANT TEMP BECOMES CONSTANT
RETURN

FIG. 9


71
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22a
16
16
16
16
CCV
24
4
10
12
SN2
10b
10a
20
3a
SN1
13
13
13
13
21
53
23
3b
3
40
26
11
51
41
ATF
W/C
O/C
73
72
RADIATOR
27
92

FIG. 10

ENGINE SYSTEM

TECHNICAL FIELD

The disclosed technology relates to an engine system.

BACKGROUND OF THE DISCLOSURE

JP2016-128652A discloses a cooling device for an engine. This cooling device has a radiator path which circulates coolant between the engine and a radiator, and a radiator bypass path which bypasses the radiator and circulates the coolant. In the radiator bypass path, an ATF warmer which warms a heater core of an air-conditioner and lubrication oil of an automatic transmission is disposed.

The cooling device has a rotary flow rate control valve. The rotary flow rate control valve opens and closes the radiator path and the radiator bypass path according to a rotational position of a rotary valve body. Further, the rotary flow rate control valve has a radiator path connecting passage and a thermostat valve allocation passage. The radiator path connecting passage is connected to the radiator path. A thermostat valve is provided to the thermostat valve allocation passage. When opening the thermostat valve, the coolant flows into the radiator path from the thermostat valve allocation passage.

When the engine is warm with the coolant at a temperature above a given temperature, the rotary flow rate control valve rotates the rotary valve body to a rotational position where the coolant flows into each of the radiator bypass path and the thermostat valve allocation passage. Since the thermostat valve opens while the engine is warm, the coolant flows into the radiator path from the thermostat valve allocation passage.

When the temperature of the coolant further increases, the rotary flow rate control valve rotates the rotary valve body to a rotational position where the coolant flows to all of the radiator bypass path, the thermostat valve allocation passage, and the radiator path connecting passage. Further, the rotational position of the rotary valve body is adjusted so that a flow rate of the coolant to the radiator path increases as a temperature of the coolant, an engine load, and/or an engine speed increase.

The combustion chamber becomes high in the temperature after the engine has been fully warmed up. In order to cool the combustion chamber, a passage through which the coolant cooled by the radiator flows (a so-called "water jacket") is provided to a part around the combustion chamber, such as a cylinder bore and a cylinder head, which constitute the engine body, which is also provided to the cooling device disclosed in JP2016-128652A.

Meanwhile, in the engine combustion control, the temperature inside the combustion chamber (in-cylinder temperature) is one of the important factors. The in-cylinder temperature requires a more precise control as the combustion control becomes more advanced. For example, in order to stably control compression ignition combustion, it is necessary to accurately control the in-cylinder temperature at a temperature higher than that of spark ignition combustion. In addition, since the heat generated inside the combustion chamber varies according to the engine load, the in-cylinder temperature also varies.

In the in-cylinder temperature control, a wall temperature of the combustion chamber is one of the important factors. It is demanded that the wall temperature of the combustion chamber is adjusted with good response to the change in the engine load.

The cooling device disclosed in JP2016-128652A lowers the temperature of the coolant by increasing the flow rate of the coolant which flows through the radiator path, when the temperature of the coolant becomes high. When the temperature of the coolant changes, the heat exchanging quantity between the coolant and the combustion chamber changes. If the heat exchanging quantity is changed according to the heat generated inside the combustion chamber, the wall temperature of the combustion chamber can be adjusted.

However, since the calorific capacity of the coolant is large, it requires a long period of time to change the temperature of the coolant. It is difficult for the temperature adjustment of the coolant to adjust the wall temperature of the combustion chamber with good response to the change in the engine load.

SUMMARY OF THE DISCLOSURE

The technology disclosed herein adjusts a wall temperature of a combustion chamber with high response according to a load of an engine.

The present inventers have completed the technology disclosed herein by paying attention to the adjustment of the wall temperature of the combustion chamber by changing a flow rate of coolant which flows through a water jacket to change a heat transfer coefficient between the coolant and the combustion chamber, without changing a temperature of the coolant.

According to one aspect of the present disclosure, an engine system is provided, which includes an engine having a water jacket formed around a combustion chamber, a circulation system that is attached to the engine and circulates coolant through the water jacket, and a controller configured to control the circulation system according to an operating state of the engine. The circulation system includes a radiator passage including a heat exchanger, a bypass passage bypassing the heat exchanger, a flow rate control device that adjusts a flow rate of coolant flowing through the water jacket by adjusting a flow rate of coolant flowing through each of the radiator passage and the bypass passage, and a thermally-actuated valve that is connected to the radiator passage and opens to allow the coolant to pass through the heat exchanger. The controller is electrically connected to the flow rate control device. The controller controls the flow rate control device to adjust the flow rate of the coolant flowing through the water jacket according to a load of the engine, by closing the radiator passage and adjusting the flow rate of the coolant flowing through the bypass passage, when the load is below a first load. The controller controls the flow rate control device so that the coolant flows through each of the radiator passage and the bypass passage, when the load is above the first load.

According to this configuration, the coolant passing through the water jacket of the engine exchanges heat with the combustion chamber. The coolant circulates through the water jacket by the circulation system.

The circulation system includes the thermally-actuated valve which opens when the coolant reaches a given temperature. When the thermally-actuated valve opens, part of the coolant passes through the heat exchanger, and thus, the coolant temperature decreases. By the thermally-actuated valve, the coolant temperature is maintained at a specific temperature corresponding to a valve-opening temperature of the thermally-actuated valve.

When the load is below the first load, the flow rate control device closes the radiator passage, and thus the coolant flows through the bypass passage. Further, the flow rate control device adjusts the flow rate of the coolant. Therefore, the flow rate of the coolant which flows through the water jacket changes. The flow rate of the coolant can be changed by the flow rate control device more promptly compared with the temperature of the coolant. Thus, the flow rate control device can adjust the flow rate of the coolant which flows through the water jacket with high response to the change of the load.

As the flow rate of the coolant which flows through the water jacket becomes lower, the heat transfer coefficient decreases, and as the flow rate of the coolant which flows through the water jacket increases, the heat transfer coefficient increases. The heat generated inside the combustion chamber changes according to the engine load. Therefore, since the controller changes, through the flow rate control device, the flow rate of the coolant which flows through the water jacket according to the engine load, the engine system can adjust the wall temperature of the combustion chamber with high response.

When the load is above the first load, the heat generated inside the combustion chamber relatively increases. The controller makes the coolant flow through each of the radiator passage and the bypass passage through the flow rate control device. For example, by increasing the flow rate of the coolant which flows through the radiator passage, the coolant temperature decreases. When the load is above the first load, the wall temperature of the combustion chamber becomes suitable.

When the load is below the first load, the controller may increase the flow rate of the coolant flowing through the water jacket as the load increases.

As the engine load increases, the heat generated inside the combustion chamber also increases. As the load increases, the flow rate of the coolant flowing through the water jacket increases, and thus, the heat transfer coefficient increases. The wall temperature of the combustion chamber is maintained at the suitable temperature.

When the load is above the first load, the controller may adjust a temperature of the coolant flowing through the water jacket according to the load by adjusting the flow rate of the coolant flowing through the bypass passage and the flow rate of the coolant flowing through the radiator passage.

When the flow rate of the coolant which flows through the radiator passage increases, the coolant temperature decreases. Although the heat generated inside the combustion chamber also increases as the load increases, the wall temperature of the combustion chamber becomes suitable by adjusting the temperature of the coolant flowing through the water jacket according to the load.

When the load is above the first load, the controller may reduce the flow rate of the coolant flowing through the bypass passage, and increase the flow rate of the coolant flowing through the radiator passage, as the load increases.

When the flow rate of the coolant flowing through the radiator passage increases, the coolant temperature decreases. By reducing the coolant temperature when the load is high and the heat generated inside the combustion chamber is also high, the wall temperature of the combustion chamber becomes suitable. On the other hand, when the flow rate of the coolant flowing through the radiator passage decreases, the coolant temperature increases. By increasing the coolant temperature when the load is low and the heat generated inside the combustion chamber is low, the wall temperature of the combustion chamber becomes suitable.

When the load is above the first load, the controller may set the flow rate of the coolant flowing through the water jacket at a maximum flow rate.

When the load becomes above the first load, the heat generated inside the combustion chamber increases. By making the flow rate of the coolant flowing through the water jacket the maximum flow rate, the wall temperature of the combustion chamber becomes suitable when the heat generated inside the combustion chamber is high.

Both when the load is below the first load and when the load is above the first load, the controller may maintain the wall temperature of the combustion chamber at a constant temperature.

The ideal wall temperature of the combustion chamber when the engine load is low, does not necessarily match with the ideal wall temperature of the combustion chamber when the engine load is high. Changing the wall temperature of the combustion chamber according to the load is ideal. However, since the calorific capacity of the wall part of the combustion chamber is large, it is difficult to change the temperature of the wall part of the combustion chamber in a short period of time.

According to this configuration, both when the load is below the first load and when the load is above the first load, the wall temperature of the combustion chamber is maintained at a permissible specific temperature. More specifically, when the load is below the first load, while maintaining the temperature of the coolant constant by using the thermally-actuated valve, the flow rate of the coolant which flows through the water jacket is adjusted according to the load, and therefore, the wall temperature of the combustion chamber can be maintained at the specific temperature. On the other hand, when the load is above the first load, by adjusting the flow rate of the coolant which flows through the bypass passage and the flow rate of the coolant which flows through the radiator passage so that the temperature of the coolant which flows through the water jacket is adjusted according to the load, the wall temperature of the combustion chamber can be maintained at the same specific temperature. As a result, even when the engine load becomes below the first load or above the first load, the wall temperature of the combustion chamber becomes suitable.

When the load is above the first load, the controller may lower a temperature of the coolant flowing through the water jacket to a temperature below a valve-opening temperature of the thermally-actuated valve.

When the load is high, the heat generated inside the combustion chamber is large. By relatively lowering the temperature of the coolant flowing through the water jacket, the wall temperature of the combustion chamber becomes suitable.

When the load is low, the heat generated inside the combustion chamber is small. When the load is below the first load, the coolant temperature is defined by the valve-opening temperature of the thermally-actuated valve as described above. By setting the valve-opening temperature of the thermally-actuated valve at the relatively high temperature, the temperature of the coolant flowing through the water jacket relatively increases, and thus, the wall temperature of the combustion chamber becomes suitable.

When the load is above the first load and below a second load, the controller may increase the flow rate of the coolant flowing through the radiator passage to lower the temperature of the coolant flowing through the water jacket as the load increases. When the load is above the second load, the controller may increase the flow rate of the coolant flowing through the radiator passage to maintain the temperature of the coolant flowing through the water jacket constant as the load increases.

When the load is above the first load and below the second load (i.e., a middle load), the temperature of the coolant flowing through the water jacket decreases as the load increases. The wall temperature of the combustion chamber can be maintained at a constant temperature with respect to the load increase. When the load is above the second load (i.e., a high load), the temperature of the coolant flowing through the water jacket becomes constant as the load increases. The wall temperature of the combustion chamber becomes suitable.

The engine may have a spark plug that forcibly ignites an air-fuel mixture. When the load is below the first load, the air-fuel mixture inside the combustion chamber may combust without the forcible ignition of the spark plug, and when the load is above the first load, the air-fuel mixture inside the combustion chamber may combust by the forcible ignition of the spark plug.

When the air-fuel mixture inside the combustion chamber combusts without the forcible ignition (i.e., combusts by self-ignition), the wall temperature of the combustion chamber likely becomes low because the thermal efficiency of the engine improves. However, in view of stabilizing the combustion, it is preferable to maintain the wall temperature of the combustion chamber at a relatively high temperature. As described above, it may be configured so that, by setting the valve-opening temperature of the thermally-actuated valve at the relatively high temperature, the temperature of the coolant flowing through the water jacket relatively increases, and the wall temperature of the combustion chamber becomes high.

As described above, the flow rate of the coolant which flows through the water jacket is adjusted according to the load. By this, the heat transfer coefficient changes corresponding to the heat generated inside the combustion chamber, and the wall temperature of the combustion chamber is maintained at the suitable temperature.

When the air-fuel mixture inside the combustion chamber combusts by the forcible ignition, the wall temperature of the combustion chamber becomes relatively higher due to the thermal efficiency being lowered, and the wall temperature of the combustion chamber being excessively high may cause abnormal combustion, such as knocking. Thus, when the air-fuel mixture combusts by the forcible ignition, the controller controls the flow rate control device so that the coolant flows into each of the radiator passage and the bypass passage. In this manner, the coolant temperature relatively decreases, and the wall temperature of the combustion chamber becomes suitable.

The flow rate control device may be installed at a location branching into the bypass passage and the radiator passage, or a location where the bypass passage and the radiator passage are joined. The circulation system may further have a connecting passage connecting the bypass passage to the radiator passage. The thermally-actuated valve may open and close the connecting passage.

According to this configuration, while the radiator passage is closed, when the coolant temperature increases and the thermally-actuated valve opens, the coolant flows to the radiator passage from the bypass passage. Thus, the coolant temperature decreases. By this thermally-actuated valve, the coolant temperature can be maintained at the given temperature.

The flow rate control device may be installed at a location branching into the bypass passage and the radiator passage, or a location where the bypass passage and the radiator passage are joined. The circulation system may further have a connecting passage bypassing the flow rate control device and connecting the water jacket to the radiator passage. The thermally-actuated valve may open and close the connecting passage.

According to this configuration, while the radiator passage is closed by the flow rate control device, when the coolant temperature increases and the thermally-actuated valve opens, the coolant bypasses the flow rate control device and flows to the radiator passage. Thus, the coolant temperature decreases. Also in this case, by this thermally-actuated valve, the coolant temperature can be maintained at the given temperature.

The flow rate control device may include a housing provided with a first port that is connected to the bypass passage, a second port that is connected to the radiator passage, and a third port that communicates with each of the first port and the second port. The flow rate control device may include a rotary valve body rotatably accommodated in the housing, intervening between the first port, the second port, and the third port, and having a first water flow opening that communicates with the first port and a second water flow opening that communicates with the second port. The flow rate control device may further include an actuator that rotates the rotary valve body to change openings of the first water flow opening and the second water flow opening so as to adjust the flow rate of the coolant which flows through each of the first port and the second port.

The flow rate control device having the rotary valve body can selectively close the bypass passage and/or the radiator passage, and can adjust the flow rate of the bypass passage and the flow rate of the radiator passage. The engine system provided with the flow rate control device can realize the flow rate adjustment of the water jacket described above with the simple configuration.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates an exemplary engine system.

FIG. **2** is a block diagram of the exemplary engine system.

FIG. **3** illustrates an exemplary control map of the engine system.

FIG. **4** illustrates an exemplary circulation system.

FIG. **5** illustrates an exemplary flow rate control device.

FIG. **6** illustrates an exemplary control of the circulation system.

FIG. **7** illustrates an exemplary control of the circulation system.

FIG. **8** illustrates an exemplary control procedure of the circulation system.

FIG. **9** illustrates an exemplary control procedure of the circulation system.

FIG. **10** illustrates an exemplary circulation system.

DETAILED DESCRIPTION OF THE DISCLOSURE

Hereinafter, one embodiment of an engine system is described with reference to the accompanying drawings. The engine system described herein is merely illustration.

Example Configuration of Engine System

FIGS. **1** and **2** illustrate one example of a configuration of an engine system **1**. The engine system **1** is mounted on an automobile. The engine system **1** is provided with an engine **10** which is an internal combustion engine. When the engine **10** operates, the automobile travels. Note that the automobile may be an automobile on which only the engine **10** is mounted as a propelling power source, or may be a hybrid vehicle on which the engine **10** and an electric motor are mounted.

The engine **10** is provided with a cylinder block **11** and a cylinder head **12**. A plurality of cylinders **13** are formed in the cylinder block **11**. The engine **10** is a multi-cylinder engine.

The plurality of cylinders **13** are lined up along a crankshaft **14** (also see FIG. **4**). A piston **15** is inserted in each cylinder **13**. The piston **15** is coupled to the crankshaft **14** via a connecting rod **151**. The piston **15**, the cylinder **13**, and the cylinder head **12** form a combustion chamber **16**.

An intake port **121** which communicates with each cylinder **13** is formed in the cylinder head **12**. An intake valve **122** disposed at the intake port **121** opens and closes the intake port **121**. An intake valve operating mechanism **123** (see FIG. **2**) opens and closes the intake valve **122** at a given timing. The intake valve operating mechanism **123** is a variable valve operating mechanism which can vary a valve timing and/or a valve lift.

An exhaust port **124** which communicates with each cylinder **13** is formed in the cylinder head **12**. An exhaust valve **125** disposed at the exhaust port **124** opens and closes the exhaust port **124**. An exhaust valve operating mechanism **126** opens and closes the exhaust valve **125** at a given timing. The exhaust valve operating mechanism **126** is a variable valve operating mechanism which can vary a valve timing and/or a valve lift.

An injector **131** is attached to the cylinder head **12** for every cylinder **13**. The injector **131** injects fuel directly into the cylinder **13**. A spark plug **132** is attached to the cylinder head **12** for every cylinder **13**. The spark plug **132** forcibly ignites an air-fuel mixture inside the cylinder **13**.

An intake passage **17** is connected to one side surface of the engine **10**. The intake passage **17** communicates with the intake port **121**. A throttle valve **171** is disposed at the intake passage **17**. The throttle valve **171** adjusts an introducing amount of air into the cylinder **13**. An exhaust passage **18** is connected to the other side surface of the engine **10**. The exhaust passage **18** communicates with the exhaust port **124**.

An exhaust gas recirculation (EGR) passage **19** is connected between the intake passage **17** and the exhaust passage **18**. The EGR passage **19** recirculates part of exhaust gas to the intake passage **17**. An EGR cooler **191** is disposed at the EGR passage **19**. The EGR cooler **191** cools the exhaust gas. An EGR valve **192** is disposed at the EGR passage **19**. The EGR valve **192** adjusts a flow rate of exhaust gas which flows through the EGR passage **19**.

The engine system **1** is provided with an ECU (Engine Control Unit) **100** for operating the engine **10**. The ECU **100** is a controller based on a well-known microcomputer, which includes a CPU (Central Processing Unit) **101**, memory **102**, and an I/F (interface) circuit **103**. The CPU **101** executes a program. The memory **102** is, for example, comprised of RAM (Random Access Memory) and/or ROM (Read Only Memory), and stores the program and data. The I/F circuit **103** inputs and outputs an electric signal. The ECU **100** is one example of a controller.

The ECU **100** is connected to various kinds of sensors SN**1**-SN**5**. The sensors SN**1**-SN**5** output signals to the ECU **100**. The sensors include the following sensors:

First water temperature sensor SN**1**: It outputs a signal corresponding to a temperature of coolant which flows into the engine **10**, in a circulation system **91** of the coolant (described later);

Second water temperature sensor SN**2**: It is attached to the engine **10**, and outputs a signal corresponding to a temperature of coolant which flows inside the engine **10**;

In-cylinder pressure sensor SN**3**: It is attached to the cylinder head **12**, and outputs a signal corresponding to a pressure inside each cylinder **13**;

Crank angle sensor SN**4**: It is attached to the engine **10**, and outputs a signal corresponding to a rotation angle of the crankshaft **14**; and

Accelerator opening sensor SN**5**: It is attached to an accelerator pedal mechanism, and outputs a signal corresponding to an operating amount of the accelerator pedal.

The ECU **100** determines an operating state of the engine **10** based on the signals from the sensors SN**1**-SN**5**, and then calculates a controlled variable of each device according to control logic defined beforehand. The control logic is stored in the memory **102**. The control logic includes calculating targeted amounts and/or controlled variables by using a map stored in the memory **102**. The ECU **100** outputs electric signals according to the calculated controlled variables to the injector **131**, the spark plug **132**, the intake valve operating mechanism **123**, the exhaust valve operating mechanism **126**, the throttle valve **171**, the EGR valve **192**, and a coolant control valve **4** (described later).

In more detail, the ECU **100** has a load calculating module **104**, a combustion mode determining module **105**, a water temperature determining module **106**, and a CCV controlling module **107** executed by the CPU **101** to perform their respective functions. These modules are stored in the memory **102** as software modules.

The load calculating module **104** calculates a target load of the engine **10** based on the output signal of the accelerator opening sensor SN**5**. The combustion mode determining module **105** determines an operating range of the engine **10** in a base map **301** (described later, see FIG. **3**) based on the load of the engine **10** and the output signal of the crank angle sensor SN**4**, and determines a combustion mode corresponding to the operating range. The water temperature determining module **106** determines a temperature of coolant which flows through a water jacket **20** (see FIG. **4**) around the combustion chamber **16** based on the output signal of the second water temperature sensor SN**2**. The CCV controlling module **107** cools the engine **10** by controlling the coolant control valve **4** according to the operating state of the engine **10**.

(Engine Operation Control Map)

FIG. **3** illustrates the base map **301** according to the control of the engine **10**. The base map **301** is stored in the memory **102** of the ECU **100**. The illustrated base map **301** is for a case of the engine **10** being fully warmed up.

The base map **301** is defined by the load and engine speed of the engine **10**. The base map **301** is roughly divided into four ranges according to the load and the engine speed. In more detail, a first range **311** includes a range from the low load to high load at a high speed, and a range of the high load at a low speed and a middle speed. A second range **312** is a low-load range at the low speed and the middle speed. A third range **313** is a range from the low load to the middle load at the low speed and the middle speed. A fourth range **314** is a range from the middle load to the high load at the low speed and the middle speed. Note that the low-speed range, the middle-speed range, and the high-speed range may be a low-speed range, a middle-speed range, and a high-speed range when the entire operating range of the engine **10** is divided in the engine speed direction into three substantially equal ranges.

Next, operation of the engine **10** in each range is briefly described. The ECU **100** determines the operating range according to the target load for the engine **10** and the engine speed of the engine **10**, and the ECU **100** changes the open-and-close operation of the intake valve **122** and the exhaust valve **125**, the fuel injection timing, and the existence of the forcible ignition, according to the determined operating range. Therefore, the combustion mode of the engine **10** changes between SI (Spark Ignition) combustion, HCCI (Homogeneous Charge Compression Ignition) Combustion, MPCI (Multiple Premixed fuel injection Compression Ignition) combustion, and SPCCI (Spark Controlled Compression Ignition) combustion.

(SI Combustion)

When the operating state of the engine **10** is in the first range **311**, the ECU **100** carries out flame propagation combustion of the air-fuel mixture inside the cylinder **13**. The intake valve operating mechanism **123** opens the intake valve **122** at a given timing and/or by a given lift, and the exhaust valve operating mechanism **126** opens the exhaust valve **125** at a given timing and/or by a given lift. The injector **131** injects fuel into the cylinder **13** during an intake stroke and/or a compression stroke. The spark plug **132** ignites the air-fuel mixture near a compression top dead center.

(HCCI Combustion)

When the operating state of the engine **10** is in the second range **312**, the ECU **100** carries out compression ignition combustion of the air-fuel mixture inside the cylinder **13**. The intake valve operating mechanism **123** opens the intake valve **122** at a given timing and/or by a given lift, and the exhaust valve operating mechanism **126** opens the exhaust valve **125** at a given timing and/or by a given lift. The injector **131** injects fuel into the cylinder **13** during an intake stroke. The spark plug **132** does not ignite the air-fuel mixture. The air-fuel mixture carries out compression self-ignition and combusts near a compression top dead center.

(MPCI Combustion)

When the operating state of the engine **10** is in the third range **313**, the ECU **100** carries out compression ignition combustion of the air-fuel mixture inside the cylinder **13**. The intake valve operating mechanism **123** opens the intake valve **122** at a given timing and/or by a given lift, and the exhaust valve operating mechanism **126** opens the exhaust valve **125** at a given timing and/or by a given lift. The injector **131** injects fuel into the cylinder **13** during an intake stroke and a compression stroke. The injector **131** performs a divided injection. The spark plug **132** does not ignite the air-fuel mixture. The air-fuel mixture carries out compression self-ignition and combusts near a compression top dead center.

By the divided injection, the air-fuel mixture inside the cylinder **13** becomes heterogeneous. In this regard, the MPCI combustion differs from the HCCI combustion in which a homogeneous air-fuel mixture is formed. The MPCI combustion allows a control of a timing of the compression self-ignition when the load of the engine **10** is relatively high.

(SPCCI Combustion)

When the operating state of the engine **10** is in the fourth range **314**, the ECU **100** carries out flame propagation combustion of part of the air-fuel mixture inside the cylinder **13**, and carries out compression ignition combustion of the remaining air-fuel mixture. The intake valve operating mechanism **123** opens the intake valve **122** at a given timing and/or by a given lift, and the exhaust valve operating mechanism **126** opens the exhaust valve **125** at a given timing and/or by a given lift. The injector **131** injects fuel into the cylinder **13** during a compression stroke. The spark plug **132** ignites the air-fuel mixture near a compression top dead center. The air-fuel mixture starts flame propagation combustion. The temperature inside the cylinder **13** becomes high due to generation of combustion heat, and the pressure inside the cylinder **13** increases due to flame propagation. Accordingly, unburnt mixture gas carries out, for example, compression self-ignition after a compression top dead center to start combustion. The flame propagation combustion and the compression ignition combustion progress in parallel after the compression ignition combustion is started.

(Configuration of Circulation System)

Next, a configuration of the circulation system **91** which the engine system **1** has is described with reference to FIG. **4**. The circulation system **91** is a device which is attached to the engine **10** and circulates the coolant through the water jacket **20**.

The water jacket **20** is formed inside the engine **10**. The water jacket **20** constitutes a circuit which is connected to the circulation system **91** and through which the coolant is circulated as well as the circulation system **91**. The water jacket **20** has an in-block jacket **21** and an in-head jacket **22**. The in-block jacket **21** is formed in the cylinder block **11** so that it spreads along the outer circumference of each cylinder **13**.

The in-head jacket **22** is formed in the cylinder head **12**. The in-head jacket **22** communicates with the in-block jacket **21** (see broken lines in FIG. **4**). The in-head jacket **22** has a first jacket **22***a* and a second jacket **22***b*. The first jacket **22***a* and the second jacket **22***b* are independent from each other.

The first jacket **22***a* is formed so that it extends along an upper part of a plurality of lined-up combustion chambers **16**. The coolant which flows through the first jacket **22***a* mainly exchanges heat (mainly, cools) with the combustion chamber **16**. In detail, the coolant which flows through the first jacket **22***a* exchanges heat with the atmosphere inside the combustion chamber **16** via a wall surface of the combustion chamber **16**.

The second jacket **22***b* is formed so that it extends along a circumference part of the exhaust ports **124** of the plurality of lined-up cylinders **13**. The coolant which flows through the second jacket **22***b* mainly exchanges heat (mainly, cools) with the exhaust port **124** where hot exhaust gas flows.

A water pump **3** is installed in the cylinder block **11**, at an end of the engine **10** (inflow-side end part **10***a*). The water pump **3** constitutes a part of the circulation system **91**.

The water pump **3** is a mechanical pump in which a rotation shaft of the pump is connected with the crankshaft **14** of the engine **10** via a pulley, a belt, etc. The water pump **3** operates by a driving force of the engine **10**. Note that the water pump **3** may be an electric rotary pump which can operate independently from the engine **10**.

The in-block jacket **21** is connected with a discharge port **3***a* of the water pump **3** via a coolant introducing passage **23**. Therefore, the coolant discharged from the water pump **3** flows into the in-block jacket **21** through the coolant introducing passage **23**. The coolant which flowed into the in-block jacket **21** flows into the in-head jacket **22**. In detail, it dividedly flows into the first jacket **22***a* and the second jacket **22***b*.

The coolant control valve (CCV) **4** (an example of a "flow rate control device" in the disclosed art) is installed in the cylinder head **12**, at an end (outflow-side end part **10***b*) opposite from the inflow-side end part **10***a* of the engine **10**. The coolant control valve **4** constitutes a part of the circulation system **91**.

A third port **65** (see FIG. **5**) of the coolant control valve **4** is connected with the first jacket **22***a* via a first coolant deriving passage **24**. Therefore, the coolant which flows through the first jacket **22***a* flows out of the engine **10** through the first coolant deriving passage **24**, and flows into the coolant control valve **4** (the details of the coolant control valve **4** will be described later).

A second coolant deriving passage **25** which communicates with the second jacket **22***b* is formed in a part of the outflow-side end part **10***b*, on the exhaust side of the cylinder head **12**. Therefore, the coolant which flows through the second jacket **22***b* flows out of the engine **10** through the second coolant deriving passage **25**, and flows into a second circulation flow passage **31** (described later).

A third coolant deriving passage **26** which communicates with the in-block jacket **21** is formed in a part of the outflow-side end part **10***b*, on the intake side of the cylinder block **11**. Therefore, part of the coolant which flows through the in-block jacket **21** flows out of the engine **10** through the third coolant deriving passage **26**, and flows into a third circulation flow passage **41** (described later).

The circulation system **91** includes, in addition to the water pump **3** and the coolant control valve **4** which are described above, a radiator **27** (an example of a "heat exchanger" in the disclosed art), and a thermally-actuated valve (thermostat valve) **28**. Further, the engine system **1** including the circulation system **91** roughly includes, as passages through which the coolant is circulated, a second circuit **30**, a third circuit **40**, and a first circuit **50**.

(Second Circuit)

The second circuit **30** has the second circulation flow passage **31** which is provided with a passage which branches into two (a first branch passage **31***a* and a second branch passage **31***b*). In the first branch passage **31***a*, the EGR cooler **191** and a heater **71** are disposed. The heater **71** is built into an air-conditioner which adjusts air inside a vehicle cabin. In the second branch passage **31***b*, the throttle valve (Electric Throttle Body: ETB) **171** and the EGR valve **192** are disposed. An upstream end of the second circulation flow passage **31** is connected to the second coolant deriving passage **25**. A downstream end of the second circulation flow passage **31** is connected to a suction port **3***b* of the water pump **3** in a state where it is joined to the first circuit **50** and the third circuit **40**.

Inside of the engine **10**, the in-block jacket **21**, the second jacket **22***b*, and the second coolant deriving passage **25** constitute a passage of the second circuit **30**. Therefore, in the second circuit **30**, coolant which flowed through the in-block jacket **21** and the second jacket **22***b* among the coolant discharged from the water pump **3** dividedly flows into the first branch passage **31***a* and the second branch passage **31***b*. Then, it returns to the water pump **3** after being joined.

The coolant which flows through the second circuit **30** exchanges heat with the engine **10** (mainly, with the exhaust port **124**). Further, it also exchanges heat with the EGR cooler **191**, the heater **71**, the throttle valve **171**, and the EGR valve **192**.

(Third Circuit)

The third circuit **40** has the third circulation flow passage **41** in which an oil cooler **72** and an automatic transmission fluid (ATF) heat exchanger **73** are installed. The oil cooler **72** is installed in a system which circulates and supplies lubricating oil to the engine **10**. The ATF heat exchanger **73** is installed in a system which circulates and supplies hydraulic fluid of an automatic transmission. An upstream end of the third circulation flow passage **41** is connected to the third coolant deriving passage **26**. A downstream end of the third circulation flow passage **41** is connected to the suction port **3***b* of the water pump **3** in a state where it is joined to the first circuit **50** and the second circuit **30**.

Inside of the engine **10**, the in-block jacket **21** and the third coolant deriving passage **26** constitute a passage of the third circuit **40**. Therefore, in the third circuit **40**, among the coolant discharged from the water pump **3**, part of the coolant which flows through the in-block jacket **21** flows through the third circulation flow passage **41** and returns to the water pump **3**. The coolant which flows through the third circuit **40** exchanges heat with the oil cooler **72** and the ATF heat exchanger **73**.

(First Circuit)

The first circuit **50** has a bypass passage **51**, a connecting passage **52**, and a radiator passage **53**. Inside of the engine **10**, the in-block jacket **21**, the first jacket **22***a*, and the first coolant deriving passage **24** constitute a passage of the first circuit **50**.

The passage of the first circuit **50** branches to the bypass passage **51** and the radiator passage **53** at the coolant control valve **4**. The downstream ends of the bypass passage **51** and the radiator passage **53** are connected to the suction port **3***b* of the water pump **3** in a state where they are joined to the second circuit **30** and the third circuit **40**.

The radiator **27** is provided to the radiator passage **53**. The radiator **27** is installed behind a front grille of the automobile. The coolant which flows through the radiator **27** exchanges heat mainly with outside air flow caused by the automobile traveling. The coolant radiates the heat and is cooled by flowing through the radiator passage **53**.

Therefore, the radiator passage **53** cools, by the radiator **27**, the coolant which is discharged from the water pump **3** and is heated by exchanging heat while flowing through the in-block jacket **21** and the first jacket **22***a*, and recirculates it to the in-block jacket **21** and the first jacket **22***a*.

The bypass passage **51** is a passage which bypasses the radiator passage **53**. The bypass passage **51** is shorter than the radiator passage **53**. Only the thermally-actuated valve **28** is provided to the bypass passage **51**. The thermally-actuated valve **28** is connected by the radiator passage **53** via the connecting passage **52** in a state where the upstream side and the downstream side of the bypass passage **51** always communicate with each other.

Therefore, the bypass passage **51** recirculates to the in-block jacket **21** and the first jacket **22***a* the coolant which was discharged from the water pump **3** and exchanged heat while flowing through the in-block jacket **21** and the first jacket **22***a*, without cooling the coolant by the radiator **27**.

The thermally-actuated valve **28** is a known device which opens and closes at a high temperature set beforehand. The thermally-actuated valve **28** has a valve body which is biased in a closing direction by an elastic force of a spring. The thermally-actuated valve **28** opens and closes by the valve body being displaced according to an action of wax. The thermally-actuated valve **28** of the engine system **1** is set so that its valve-opening temperature is higher than a valve-opening temperature of a conventional thermally-actuated valve.

When the thermally-actuated valve **28** opens, the bypass passage **51** communicates the radiator passage **53** via the connecting passage **52**. Therefore, when the thermally-actuated valve **28** opens, part of the coolant which flows through the bypass passage **51** passes through the connecting passage **52**, and flows into the radiator passage **53**.

(Coolant Control Valve)

FIG. **5** illustrates the coolant control valve **4**. The coolant control valve **4** is a valve which can adjust a flow rate of the coolant, and is comprised of a housing **60**, a rotary valve body **61**, and an actuator **62**.

A cylindrical flow-dividing chamber **60***a* is provided inside the housing **60**. The cylindrical rotary valve body **61** is rotatably accommodated in the flow-dividing chamber **60***a*. A first port **63** and a second port **64** are formed in the housing **60** so that they extend radially outward from a given position in an outer circumference of the flow-dividing chamber **60***a*. The first port **63** is connected to the bypass passage **51**. The second port **64** is connected to the radiator passage **53**.

One end of the flow-dividing chamber **60***a* is opened. This opening constitutes the third port **65** through which the coolant flows into the flow-dividing chamber **60***a*. Further, the housing **60** is attached to the cylinder head **12** so that the third port **65** is coaxially connected to the first coolant deriving passage **24**. Therefore, a circumferential wall of the rotary valve body **61** intervenes between the third port **65** and each of the first port **63** and the second port **64**.

A first water flow opening **61***a* and a second water flow opening **61***b* are formed at given positions of the circumferential wall of the rotary valve body **61**. The first water flow opening **61***a* has a length in the circumferential direction longer than the second water flow opening **61***b*, and has a relatively large opening area. Depending on the rotational position of the rotary valve body **61**, the third port **65** communicates or does not communicate with the first port **63** and the second port **64** via the first water flow opening **61***a* and the second water flow opening **61***b*, respectively. Further, when communicating with the ports, an opening between each of the first port **63** and the second port **64** and the third port **65** varies depending on the rotational position of the rotary valve body **61**.

The other end of the flow-dividing chamber **60***a* is sealed with a closure wall **66**. The actuator **62** is accommodated inside the housing **60**, on the opposite side of the flow-dividing chamber **60***a* with respect to the closure wall **66**. A rotation shaft **62***a* of the actuator **62** projects into the flow-dividing chamber **60***a* through a shaft hole which opens at the center of the closure wall **66**. The rotary valve body **61** is attached via support arms **62***b* to the rotation shaft **62***a* projected into the flow-dividing chamber **60***a*. The ECU **100** outputs a control signal to the actuator **62**. By the ECU **100** controlling the actuator **62**, the rotary valve body **61** is rotated.

Returning to FIG. **4**, the first water temperature sensor SN**1** is disposed at a passage where the first circuit **50**, the second circuit **30**, and the third circuit **40** join and flow into the water pump **3**. The second water temperature sensor SN**2** is disposed at the first jacket **22***a*. The first water temperature sensor SN**1** measures a temperature of coolant which flows into the engine **10**. The second water temperature sensor SN**2** measures a temperature of coolant which flows into the water jacket **20** (more accurately, into the first jacket **22***a*). These sensors SN**1** and SN**2** are utilized for a coolant control and a combustion control. For example, when performing the advanced combustion control, the second water temperature sensor SN**2** is utilized for estimating the wall temperature of the combustion chamber **16**. The second water temperature sensor SN**2** is utilized for controlling the actuator **62**.

In this circulation system **91**, the ECU **100** controls the coolant control valve **4** based on the measurement of the second water temperature sensor SN**2**. This adjusts a flow rate of the coolant which flows through the first circuit **50** (i.e., the bypass passage **51** and the radiator passage **53**). Note that the flow of the coolant in the connecting passage **52** is automatically adjusted by the thermally-actuated valve **28**.

The coolant which flows through the circulation system **91** is mainly cooled by the radiator **27** installed in the radiator passage **53**. The temperature of the coolant is adjusted.

That is, the main object of the circulation system **91** is the first circuit **50**. The flow rate and the temperature of the coolant in each of the second circuit **30** and the third circuit **40** change according to an adjustment of the flow rate and the temperature of the coolant in the first circuit **50**. In this circulation system **91**, although the first circuit **50** is essential, the second circuit **30** and the third circuit **40** are not essential.

(How Coolant Flows)

As described above, the coolant which flows through the first jacket **22***a* mainly exchanges heat with the wall part of the combustion chamber **16** to cool the wall part of the combustion chamber **16**. In this engine system **1**, a plurality of ways for the coolant to flow are set according to the temperature of the coolant which flows through the first jacket **22***a* (the measurement of the second water temperature sensor SN2) in order to stably and efficiently perform the combustion control of the engine **10**. FIG. **6** illustrates a flowing state of each circuit in the engine system **1** according to the temperature of the coolant.

In the coolant control valve **4**, the actuator **62** is controlled to adjust the flow rate of the coolant which flows through both the first port **63** and the second port **64**. That is, the opening of each of the first water flow opening **61***a* and the second water flow opening **61***b* is changed so that the rotary valve body **61** is at the given rotational position.

"Low Temperature" is a so-called state during "cold start," such as immediately after the engine **10** is started. "Low Temperature" is a state where a temperature t of the coolant which flows through the first jacket **22***a* is below a first switching temperature t**11** (for example, 40° C.). "Full Warm-up" is a state where the engine **10** is warmed up to a temperature suitable for operation, and is a so-called state after "warmed up." "Full Warm-up" is a state where the temperature t of the coolant which flows through the first jacket **22***a* is at or above a second switching temperature t**12** (for example, 80° C.). "Half Warm-up" is a state between "Low Temperature" and "Full Warm-up" (i.e., it is a transition state). "Half Warm-up" is a state where the temperature t of the coolant which flows through the first jacket **22***a* is at or above the first switching temperature t**11** and below the second switching temperature t**12**, and it is a state where the coolant temperature t is from 40° C. to 80° C.

As illustrated by a left state **81** in FIG. **6**, the coolant neither flows into the bypass passage **51** nor the radiator passage **53** during "Low Temperature" (both the flow rates are zero). That is, in the first circuit **50**, the circulation of the coolant is not performed. At this time, in the coolant control valve **4**, the rotary valve body **61** is set at a rotational position where both the first port **63** and the second port **64** do not communicate with the third port **65**.

Since the coolant does not flow into the radiator passage **53**, the coolant will not be cooled by the radiator **27**. Therefore, the coolant rises promptly in the temperature. Further, the combustion chamber **16** is not cooled by the circulation of the coolant. The combustion chamber **16** can be promptly heated by the combustion heat. Since the engine **10** promptly rises to the temperature state suitable for combustion, fuel efficiency can be improved. At this time, the coolant discharged from the water pump **3** circulates through the second circuit **30** and the third circuit **40**.

As illustrated by a center state **82** in FIG. **6**, during "Half Warm-up," although the coolant flows into the bypass passage **51**, the coolant does not flow into the radiator passage **53** (the flow rate of the radiator passage **53** is zero). That is, in the first circuit **50**, the coolant only circulates through the bypass passage **51**. At this time, in the coolant control valve **4**, the rotary valve body **61** is set at a rotational position where only the first port **63** communicates with the third port **65**. The opening of the first water flow opening **61***a* is fully open, for example.

Since the coolant does not flow into the radiator passage **53**, the coolant promptly rises in the temperature. On the other hand, since the coolant flows into the bypass passage **51**, the coolant flows into the first jacket **22***a*. The bypass passage **51** is short. Further, since the coolant control valve **4** is set to be fully opened, most of the coolant flows through the bypass passage **51** and the first jacket **22***a*.

The combustion chamber **16** can be promptly heated by the circulating coolant. Since the coolant is circulated, the combustion chamber **16** and its circumference can be heated uniformly. Since the engine **10** promptly rises to the temperature state suitable for combustion, fuel efficiency can be improved.

Note that, at this time, the remainder of the coolant discharged from the water pump **3** circulates through the second circuit **30** and the third circuit **40** (similar during "Full Warm-up"). The temperature of the coolant during "Half Warm-up" is lower than the valve-opening temperature of the thermally-actuated valve **28**. Therefore, the thermally-actuated valve **28** is in a fully closed state. Part of the coolant will not flow into the radiator passage **53** from the bypass passage **51**.

During "Full Warm-up," the engine **10** reaches the temperature state suitable for combustion. The engine **10** after fully warmed up changes the combustion mode according to the load and the engine speed, as described above. This engine system **1** controls the circulation system **91** so that the wall temperature of the combustion chamber **16** becomes a temperature suitable for the combustion mode. During "Full Warm-up," the state **82** illustrated in the center of FIG. **6** and a state **83** illustrated in the right of FIG. **6** are switched according to the operating state of the engine **10**. The state **82** is a state where the bypass passage **51** is opened and the radiator passage **53** is closed, as described above. However, since the temperature of the coolant rises during "Full Warm-up," the coolant may flow through the radiator passage **53** by the thermally-actuated valve **28** being opened, as will be described later. The state **83** is a state where the circulation of the coolant is performed using the entire first circuit **50** by opening both the bypass passage **51** and the radiator passage **53**.

In more detail, during "Full Warm-up," as illustrated by the center state **82**, in the coolant control valve **4**, the rotary valve body **61** is set at a rotational position so that the first port **63** communicates with the third port **65**, and the second port **64** does not communicate with the third port **65**. Further, according to the load of the engine **10**, the flow rate of the coolant is adjusted at the first port **63** (bypass passage **51**).

During "Full Warm-up," as illustrated by the right state **83**, the coolant flows into both the bypass passage **51** and the radiator passage **53**. In that case, in the coolant control valve **4**, the rotary valve body **61** is set at a rotational position so that both the first port **63** and the second port **64** communicate with the third port **65**. Further, according to the load of the engine **10**, the flow rate of the coolant is adjusted at both the first port **63** (bypass passage **51**) and the second port **64** (radiator passage **53**).

(How Coolant Flows when Fully Warmed Up)

FIG. **7** illustrates a concrete example of how the coolant flows when fully warmed up. In FIG. **7**, charts (A) to (D) illustrate changes in main properties according to the load of the engine **10**.

Chart (A) illustrates change G**1** in the flow rate of the coolant which passes through the coolant control valve **4**, and change G**2** in the flow rate of the coolant which passes through the radiator passage **53**. Chart (B) illustrates the details of the change in the flow rate of the coolant which flows through the first circuit **50**, that is, change G**3** in the flow rate of the coolant which flows into the bypass passage **51** from the coolant control valve **4**, change G**4** in the flow rate of the coolant which flows through the connecting passage **52**, and change G**5** in the flow rate of the coolant which flows into the radiator passage **53** from the coolant control valve **4**.

Chart (C) illustrates change G**6** in the temperature of the coolant which flows through the first jacket **22***a*, and change G**7** in the temperature of the coolant which flows into the water pump **3**. In other words, changes in the measurements of the second water temperature sensor SN**2** and the first water temperature sensor SN**1** are illustrated. Chart (D) illustrates change G**8** in the wall temperature of the combustion chamber **16**.

The load range of the engine **10** is divided, in association with the control of the coolant, into three ranges comprised of a range below a first load L**1**, a range above a second load L**2**, and a range above the first load L**1** and below the second load L**2**. Each chart of FIG. **7** corresponds to the case where the engine speed of the engine **10** is the low speed or the middle speed. The range below the first load L**1** roughly corresponds to a range where the engine **10** performs HCCI combustion or MPCI combustion. The range above the second load L**2** roughly corresponds to a range where the engine **10** performs SI combustion. The range above the first load L**1** and below the second load L**2** roughly corresponds to a range where the engine **10** performs SPCCI combustion. Note that the first load L**1** and the second load L**2** may or may not be in agreement with the load at which the combustion mode is switched.

Further, in this engine system **1**, the flow rate control of the coolant is performed in the range below the first load L**1**, and the temperature control of the coolant is performed in the range above the first load L**1** and below the second load L**2**. Therefore, in the range where the load of the engine **10** is low and middle, the wall temperature of the combustion chamber **16** is maintained to a specific constant temperature (see G**8**).

That is, in order to realize the compression self-ignition combustion without forcible ignition, like HCCI combustion or MPCI combustion, it is necessary to accurately control the temperature inside the combustion chamber **16** (in-cylinder temperature) at a temperature higher than SI combustion. On the other hand, SPCCI combustion is combustion accompanied by forcible ignition though part of the air-fuel mixture combusts by compression ignition, and the temperature inside the combustion chamber **16** is permitted to be lower than that of HCCI combustion or MPCI combustion. On the contrary, if the temperature inside the combustion chamber **16** is too high, the air-fuel mixture may carry out self-ignition before forcible ignition is performed, or a rate of the self-ignition combustion may become too large in the SPCCI combustion where flame propagation combustion and self-ignition combustion are combined. That is, if the temperature inside the combustion chamber **16** is too high, stable SPCCI combustion will not be realized.

Therefore, it is ideal to change the wall temperature of the combustion chamber **16** according to the switching of the combustion mode. However, since the calorific capacity of the wall part of the combustion chamber **16** is large, it is difficult to change the wall temperature of the combustion chamber **16** with sufficient response to the switching of the combustion mode or the change in the load. Thus, in the range from the low load to the middle load, the engine system **1** maintains the wall temperature of the combustion chamber **16** at the specific constant temperature. This specific temperature is an intermediate temperature between an optimal temperature for HCCI combustion or MPCI combustion and an optimal temperature for SPCCI combustion, is a temperature permissible in the execution of HCCI combustion or MPCI combustion, and is a temperature also permissible in the execution of SPCCI combustion. Even if the combustion mode is switched or the load is changed, the wall temperature of the combustion chamber **16** becomes a suitable temperature by maintaining the wall temperature of the combustion chamber **16** at the constant temperature.

However, if the load of the engine **10** is low, the combustion heat increases in general, and if the load of the engine **10** increases, the combustion heat decreases in general. In order to maintain the constant wall temperature of the combustion chamber **16** regardless of the load of the engine **10**, it is necessary to adjust the heat exchanging quantity by the coolant with high response to the occurring combustion heat.

For example, in order to adjust the heat exchanging quantity, it is possible to adjust the temperature of the coolant according to the load of the engine **10**. However, since the calorific capacity of the coolant is large, it requires a long period of time to raise or lower the temperature of the coolant. It is difficult to adjust the temperature of the coolant with high response to the change in the load of the engine **10**.

Thus, this engine system **1** adjusts the flow rate of the coolant which flows through the first port **63** and the first jacket **22***a* by using the coolant control valve **4** according to the load of the engine **10**, while keeping the temperature of the coolant constant at a given temperature. Since the adjustment of the flow rate can be changed with high response, the heat transfer coefficient by the coolant can be adjusted with high response against the occurring combustion heat, and, as a result, the wall temperature of the combustion chamber **16** can be maintained constant.

(Range Below First Load L**1**)

As illustrated in FIG. **7**, in the range below the first load L**1**, the coolant control valve **4** adjusts the flow rate of the coolant which flows through the bypass passage **51** without the coolant flowing to the radiator passage **53** (see G**3**, G**5**).

Since the radiator passage **53** is closed, the temperature of the coolant is determined by a valve-opening temperature of the thermally-actuated valve **28**. The valve-opening temperature of the thermally-actuated valve **28** is set at a comparatively high temperature. The temperature of the coolant which flows through the first jacket **22***a* is constant at a first target temperature t**21**, regardless of the load (see G**6**). The first target temperature t**21** is a temperature near the reliability limit temperature of the engine **10**. By setting the temperature of the coolant at the comparatively high temperature, in the range below the first load L**1**, the wall temperature of the combustion chamber **16** can be maintained at the comparatively high temperature (that is, a target temperature tw). When the wall temperature of the combustion chamber **16** is high, it is advantageous to stabilize the compression self-ignition combustion without forcible ignition like HCCI combustion or MPCI combustion. Note that, in the example of the drawing, in the range below the first load L**1**, the temperature of the coolant which flows into the engine **10** gradually rises as the load of the engine **10** increases (see G**7**).

In the range below the first load L**1**, the coolant control valve **4** adjusts the flow rate so that the flow rate of the coolant which flows through the bypass passage **51** becomes less when the load of the engine **10** is low, and the flow rate of the coolant which flows through the bypass passage **51** becomes more when the load of the engine **10** is high.

At this time, in the coolant control valve **4**, the actuator **62** is controlled so that the rotary valve body **61** is located at a rotational position where the third port **65** does not communicate with the second port **64** and the third port **65** communicates with the first port **63**. Further, according to the load of the engine **10**, the opening between the third port **65** and the first port **63** is adjusted.

Note that, in the range below the first load L**1**, the flow rate of the coolant which flows through the connecting passage **52** when the thermally-actuated valve **28** is opened changes corresponding to the change in the flow rate of the coolant which flows through the bypass passage **51** (see G**4**).

Here, in the example of the drawing, although the load of the engine **10** and the flow rate of the coolant have a linear relationship, it is not limited to the linear relationship.

The flow rate of the coolant which flows through the first jacket **22***a* corresponds to the flow rate of the coolant which flows through the bypass passage **51**. Therefore, when the load of the engine **10** is low, the flow rate of the coolant which flows through the first jacket **22***a* is small, and when the load of the engine **10** is high, the flow rate of the coolant which flows through the first jacket **22***a* is large. In the example of FIG. **7**, when the load of the engine **10** is the first load L**1**, the flow rate of the coolant which flows through the first jacket **22***a* becomes the maximum flow rate (see G**1**). Note that when the load of the engine **10** is the first load L**1**, the flow rate of the coolant which flows through the first jacket **22***a* may be below the maximum flow rate.

When the flow rate of the coolant which flows through the first jacket **22***a* is small, the heat transfer coefficient with the combustion chamber **16** falls. Therefore, even if the combustion heat decreases, the wall temperature of the combustion chamber **16** can be adjusted to a high temperature. When the flow rate of the coolant which flows through the first jacket **22***a* is large, the heat transfer coefficient with the combustion chamber **16** increases. Therefore, even if the combustion heat increases, the wall temperature of the combustion chamber **16** can be adjusted to a low temperature.

In this way, while maintaining the temperature of the coolant constant by using the thermally-actuated valve **28** (see G**6**), the flow rate of the coolant which flows through the first jacket **22***a* is fluctuated using the coolant control valve **4** with high response according to the load of the engine **10** (see G**1**, G**3**). Therefore, the wall temperature of the combustion chamber **16** can be held constant at the target temperature tw (see G**8**).

(Range Above First Load L**1** and Below Second Load L**2**)

The flow rate of the coolant which flows through the coolant control valve **4** (i.e., the flow rate of the coolant which flows through the first circuit **50**) reaches an upper limit at the first load L**1** (see G**1**). That is, the flow rate control cannot be performed at the load above the first load L**1**. Thus, in the range above the first load L**1** and below the second load L**2**, the temperature control of the coolant is performed. The wall temperature of the combustion chamber **16** is held at the target temperature tw by gradually allowing the coolant which flows through the bypass passage **51** to flow to the radiator passage **53** as the load of the engine **10** increases, to cool the coolant.

In detail, in a state where the flow rate of the coolant which flows through the first circuit **50** is held at the maximum flow rate, the coolant control valve **4** gradually increases the flow rate of the coolant which flows through the radiator passage **53**, while gradually reducing the flow rate of the coolant which flows through the bypass passage **51**, as the load of the engine **10** increases (see G**1**, G**2**, G**3**, and G**5**). In the range above the first load L**1** and below the second load L**2**, the coolant control valve **4** adjusts the temperature of the coolant which flows through the first jacket **22***a* by adjusting the flow rate of the coolant which flows through the radiator passage **53**. Note that if the load of the engine **10** is above the first load L**1**, the flow rate of the coolant which flows through the radiator passage **53** exceeds the flow rate of the coolant which flows through the bypass passage **51**. The load of the engine **10** at which the flow rate is reversed changes according to the operating environments of the engine **10** (for example, ambient temperature, wind quantity during the vehicle traveling, etc.).

The coolant control valve **4** controls the actuator **62** so that the rotary valve body **61** is located at a rotational position where the third port **65** communicates with both the first port **63** and the second port **64**. Further, according to the load of the engine **10**, the opening between the third port **65** and each of the first port **63** and the second port **64** is adjusted.

Thus, the temperature of the coolant which flows through the first jacket **22***a* and the temperature of the coolant which flows into the engine **10** become lower as the load of the engine **10** increases (see G**6** and G**7**). When the load of the engine **10** increases to increase the combustion heat, since the temperature of the coolant which flows through the first jacket **22***a* is low even if the flow rate of the coolant is constant, the cooling quantity by the coolant which flows through the first jacket **22***a* can be maintained. Further, since the flow rate of the coolant which flows through the first circuit **50** is the maximum flow rate, it is advantageous to cool the combustion chamber **16**. As a result, also in the range above the first load L**1** and below the second load L**2**, the wall temperature of the combustion chamber **16** can be held at the target temperature tw (see G**8**).

In order to suppress the excessive rise in the temperature of the combustion chamber **16**, in this cooling system, a second target temperature t**22** (for example, 88° C.) lower than the first target temperature t**21** is set as a target temperature of the coolant which flows through the first jacket **22***a*. The temperature control is performed until the temperature of the coolant which flows through the first jacket **22***a* reaches the second target temperature t**22**.

Note that, as illustrated in G**5** of FIG. **7**, when the temperature of the coolant reaches the second target temperature t**22**, the flow rate of the coolant which flows through the radiator passage **53** is below the maximum flow rate. If the flow rate of the coolant which flows through the radiator passage **53** is further increased, the temperature of the coolant can be further reduced. That is, even if the load of the engine **10** exceeds L**2**, it is possible to maintain the wall temperature of the combustion chamber **16** at the target temperature tw.

Thus, the engine system **1** can maintain the wall temperature of the combustion chamber **16** constant over the wide range from the low load to the middle load of the engine **10**, by the combination of the flow rate control and the temperature control. Since the wall temperature of the combustion chamber **16** is maintained at the suitable temperature even if the combustion mode is switched between HCCI combustion, MPCI combustion, and SPCCI combustion corresponding to the change in the load of the engine **10**, each combustion is stably performed.

The coolant control valve **4** having the rotary valve body **61** can selectively close the bypass passage **51** and/or the radiator passage **53**, and can adjust the flow rate of the bypass passage **51** and the flow rate of the radiator passage **53**. The engine system **1** provided with the coolant control valve **4** can realize the flow rate adjustment of the water jacket **20** described above with the simple configuration.

Note that in the range above the first load L**1** and below the second load L**2**, the coolant which flows into the radiator passage **53** through the connecting passage **52** gradually decreases and will not flow as the load of the engine **10** increases (see G**4**). In detail, the temperature of the coolant which flows into the bypass passage **51** from the coolant control valve **4** gradually decreases from the first target temperature t**21**. In connection with it, the temperature of the coolant which flows through the thermally-actuated valve **28** also decreases. Therefore, in the range above the first load L**1** and below the second load L**2**, the thermally-actuated valve **28** gradually closes, and it will become fully closed. Therefore, the coolant which flows into the radiator passage **53** through the connecting passage **52** gradually decreases, and will not flow.

Although in the example of FIG. **7** a proportional relationship exists between the flow rate reduction of the coolant which flows through the bypass passage **51** and the flow rate increase of the coolant which flows through the radiator passage **53**, there is no necessity of being the proportional relationship. In the range above the first load L**1** and below the second load L**2**, the flow rate of the coolant which flows through the coolant control valve **4** may be below the upper limit.

(Range Above Second Load L**2**)

In the range above the second load L**2**, the adjustment is performed in the coolant control valve **4** so that the temperature of the coolant which flows through the first jacket **22***a* is held at the second target temperature t**22**. In detail, the actuator **62** is controlled, and the adjustment is made so that the opening between the third port **65** and the second port **64** becomes large, and the opening between the third port **65** and the first port **63** becomes small, as the load of the engine **10** increases. Thus, the coolant which flows through the radiator passage **53** gradually increases, and the coolant which flows through the bypass passage **51** gradually decreases (see G**3** and G**5**). By doing so, the temperature of the coolant which flows through the first jacket **22***a* can be held at the second target temperature t**22** (see G**6**).

In the range where SI combustion is performed, it becomes possible to suppress abnormal combustion, such as knocking, by relatively lowering the temperature of the coolant.

In the range above the first load L**1** and below the second load L**2**, in order to maintain the wall temperature of the combustion chamber **16** constant, the temperature of the coolant which flows through the first jacket **22***a* is positively lowered as the load of the engine **10** increases. Therefore, with respect to the increase in the load of the engine **10**, a degree of change in the flow rate of the coolant which flows into the bypass passage **51** from the coolant control valve **4**, and a degree of change in the flow rate of the coolant which flows into the radiator passage **53** from the coolant control valve **4** are relatively large. That is, slopes of G**3** and G**5** are larger.

On the other hand, in the range above the second load L**2**, in order to hold the temperature of the coolant at the second target temperature t**22**, with respect to the increase in the load of the engine **10**, a degree of change in the flow rate of the coolant which flows into the bypass passage **51** from the coolant control valve **4**, and a degree of change in the flow rate of the coolant which flows into the radiator passage **53** from the coolant control valve **4** are relatively small. That is, the slopes of G**3** and G**5** are small, and the slopes of G**3** and G**5** change at the second load L**2**.

Note that in the range above the second load L**2**, the proportional relationship between the flow rate reduction of the coolant which flows through the bypass passage **51** and the flow rate increase of the coolant which flows through the radiator passage **53** is not essential. In the range above the second load L**2**, the flow rate of the coolant which flows through the coolant control valve **4** may be below the upper limit.

In the range above the second load L**2**, the flow rate of the coolant which flows through the first jacket **22***a* is the maximum, and the temperature of the coolant is held at the second target temperature t**22**. Since the heat occurring inside the combustion chamber **16** increases as the load of the engine **10** increases, the wall temperature of the combustion chamber **16** gradually rises as the load of the engine **10** increases (see G**8**).

Note that in the range above the second load L**2**, since the temperature of the coolant is maintained at the second target temperature t**22**, the thermally-actuated valve **28** is fully closed. The coolant does not flow into the connecting passage **52**. The bypass passage **51** and the radiator passage **53** constitute mutually independent passages.

Next, a control executed by the ECU **100** for cooling of the engine **10** is described with reference to FIGS. **8** and **9**.

FIG. **8** is a flowchart for switching between a cold state, a half warmed up state, and a fully warmed up state of the engine **10**. First, at Step S**81** after the start, the ECU **100** acquires signal values outputted from various kinds of the sensors SN**1**-SN**5**. The subsequent Step S**82**, the ECU **100** determines whether the temperature t of the coolant is at or above the second switching temperature t**12** based on the signal from the second water temperature sensor SN**2**. If the temperature t of the coolant is at or above the second switching temperature t**12**, the process shifts from Step S**82** to Step S**83**. At Step S**83**, the ECU **100** executes a full warm-up control. The details of the full warm-up control is described with reference to FIG. **9**.

If the temperature of the coolant is below the second switching temperature t**12**, the process shifts from Step S**82** to Step S**84**. At Step S**84**, the ECU **100** determines whether the temperature t of the coolant is at or above the first switching temperature t**11**. If the temperature t of the coolant is at or above the first switching temperature t**11**, the process shifts from Step S**84** to Step S**85**. At Step S**85**, the ECU **100** executes a half warm-up control. As described above, the ECU **100** opens the bypass passage **51** and closes the radiator passage **53**, through the coolant control valve **4**.

If the temperature t of the coolant is below the first switching temperature t**11**, the process shifts from Step S**84** to Step S**86**. At Step S**86**, the ECU **100** executes a low-temperature control. As described above, the ECU **100** closes the bypass passage **51** and closes the radiator passage **53**, through the coolant control valve **4**.

FIG. **9** illustrates a flow of the full warm-up control at Step S**83**. At Step S**91** after the start, the ECU **100** calculates the target load of the engine **10** based on the signal values outputted from the sensors SN**1**-SN**5**. At the subsequent Step S**92**, the ECU **100** determines whether the target load L is below the first load L**1**. If the target load L is below the first load L**1**, the process shifts from Step S**92** to Step S**93**. At Step S**93**, the ECU **100** executes a flow rate control. That is, the ECU **100** closes the radiator passage **53** through the coolant control valve **4**, and adjusts the flow rate of the bypass passage **51** according to the load of the engine **10**.

If the target load L is above the first load L**1**, the process shifts from Step S**92** to Step S**94**. At Step S**94**, the ECU **100** determines whether the target load L is below the second load L**2**. If the target load L is below the second load L**2**, the process shifts from Step S**94** to Step S**95**. At Step S**95**, the ECU **100** executes a temperature control. That is, the ECU **100** adjusts the flow rates of the radiator passage **53** and the bypass passage **51** through the coolant control valve **4** according to the load of the engine **10** so that the wall temperature of the combustion chamber **16** becomes constant.

If the target load L is above the second load L**2**, the process shifts from Step S**94** to Step S**96**. At Step S**96**, the ECU **100** adjusts the flow rates of the radiator passage **53** and the bypass passage **51** through the coolant control valve **4** according to the load of the engine **10** so that the temperature of the coolant becomes constant.

(Modification of Circulation System)

FIG. **10** illustrates a circulation system **92** according to a modification. This circulation system **92** differs from the circulation system **91** of FIG. **4** in the position of the thermally-actuated valve **28**.

In detail, the thermally-actuated valve **28** is attached to the outflow-side end part **10***b* of the engine **10**, instead of the bypass passage **51**. A downstream end of the first jacket **22***a* provided to the cylinder head **12** branches into two. The coolant control valve **4** and the thermally-actuated valve **28** are connected to the first jacket **22***a*.

The thermally-actuated valve **28** is connected by the radiator passage **53** via the connecting passage **52**. In more detail, the connecting passage **52** is connected to a part of the radiator passage **53** upstream of the radiator **27**.

Note that this circulation system **92** does not have the connecting passage which connects the bypass passage **51** to the radiator passage **53** in the circulation system **91** of FIG. **4**.

How the coolant flows in the circulation system **92** is the same as the circulation system **91** of FIG. **4**. That is, if the temperature t of the coolant is in “Low Temperature” state below the first switching temperature t**11**, the coolant neither flows into the bypass passage **51** nor the radiator passage **53** (both the flow rates are zero). At this time, in the coolant control valve **4**, the rotary valve body **61** is set at the rotational position where both the first port **63** and the second port **64** do not communicate with the third port **65**. Further, the thermally-actuated valve **28** is closed. Therefore, in the first circuit **50**, the circulation of the coolant is not performed.

If the temperature t of the coolant is in "Half Warm-up" state at or above the first switching temperature t**11** and below the second switching temperature t**12**, although the coolant flows to the bypass passage **51**, it does not flow to the radiator passage **53** (the flow rate of the radiator passage **53** is zero). At this time, in the coolant control valve **4**, the rotary valve body **61** is set at the rotational position where only the first port **63** communicates with the third port **65**. The opening of the first water flow opening **61***a* is fully open, for example. Further, since the temperature of the coolant is low, the thermally-actuated valve **28** is closed. In the first circuit **50**, the circulation of the coolant is performed only in the bypass passage **51**.

If the temperature t of the coolant is in "Full Warm-up" state at or above the second switching temperature t**12**, the circulation system **92** is controlled according to the load.

Concretely, when the operating state of the engine **10** is in the range below the first load L**1**, the flow rate control is performed. The temperature of the coolant is kept constant by the thermally-actuated valve **28**. The coolant control valve **4** opens the bypass passage **51** and closes the radiator passage **53**. Note that the coolant may pass through the radiator **27** by the thermally-actuated valve **28** being opened. The coolant control valve **4** adjusts the flow rate of the coolant which flows through the bypass passage **51** according to the load of the engine **10**. Therefore, the wall temperature of the combustion chamber **16** is maintained at the target temperature tw.

The temperature control is performed when the operating state of the engine **10** is in the range above the first load L**1** and below the second load L**2**. The coolant control valve **4** opens both the bypass passage **51** and the radiator passage **53**. In more detail, the coolant control valve **4** reduces the flow rate of the coolant which flows through the bypass passage **51** and increases the flow rate of the coolant which flows through the radiator passage **53**, as the load of the engine **10** increases. Therefore, the wall temperature of the combustion chamber **16** is maintained at the target temperature tw.

When the operating state of the engine **10** is in the range above the second load L**2**, the coolant control valve **4** adjusts the flow rates of the coolant which flows through the bypass passage **51** and the radiator passage **53** so that the temperature t of the coolant becomes constant at the second target temperature t**22**. In more detail, the coolant control valve **4** reduces the flow rate of the coolant which flows through the bypass passage **51** and increases the flow rate of the coolant which flows through the radiator passage **53**, as the load of the engine **10** increases. The thermally-actuated valve **28** is closed.

Since the engine system **1** provided with the circulation system **92** performs the flow rate control in the range below the first load L**1**, it can change the flow rate of the coolant which flows through the first jacket **22***a* with high response to the load of the engine **10** changing, and can keep the wall temperature of the combustion chamber **16** constant.

Further, since the wall temperature of the combustion chamber **16** can be maintained at the target temperature tw by performing the temperature control in the range above the first load L**1** and below the second load L**2**, the wall temperature of the combustion chamber **16** does not change even if the load of the engine **10** changes between the first load L**1** and the second load L**2**. It can stably perform HCCI combustion and MPCI combustion without forcible ignition, and can also stably perform SPCCI combustion accompanied by forcible ignition.

The circulation system **92** does not provide the thermally-actuated valve **28** to downstream of the coolant control valve **4**. The connecting passage **52** is a passage which bypasses the coolant control valve **4**. For this reason, even if the coolant control valve **4** has failed, such as valve adhesion, the thermally-actuated valve **28** can be opened to cool the coolant by the radiator **27** when the temperature of the coolant reaches the valve-opening temperature of the thermally-actuated valve **28**. Since the circulation system **92** can suppress that the temperature of the coolant becomes excessively high, it is advantageous to improve the reliability of the engine system **1**.

Other Embodiments

Note that in the circulation system **91** of FIG. **4**, the position of the coolant control valve **4** may be changed. In detail, the coolant control valve **4** may be provided at a location where the bypass passage **51** and the radiator passage **53** join (a location surrounded by a one-dot chain line of FIG. **4**). In this configuration, the upstream end of the bypass passage **51** and the upstream end of the radiator passage **53** are connected mutually-independently to the first jacket **22***a*. Further, the connecting passage **52** may connect the bypass passage **51** to a location of the radiator passage **53** downstream of the radiator **27**, and the thermally-actuated valve **28** may be provided so as to open and close the connecting passage **52**.

Similarly, in the circulation system **92** of FIG. **10**, the position of the coolant control valve **4** may be changed. In detail, the coolant control valve **4** may be provided at a location where the bypass passage **51** and the radiator passage **53** join (a location surrounded by a one-dot chain line of FIG. **10**). In this configuration, the upstream end of the bypass passage **51** and the upstream end of the radiator passage **53** are connected mutually-independently to the first jacket **22***a*. Further, the connecting passage **52** may connect a part of the radiator passage **53** downstream of the radiator **27** and a part upstream of the water pump **3** so as to bypass the coolant control valve **4**, and the thermally-actuated valve **28** may be provided so as to open and close the connecting passage **52**.

Further, the flow rate control device is not limited to be comprised of the coolant control valve **4** having the rotary valve body **61**. The flow rate control device may be comprised of a first flow rate control valve which adjusts the flow rate of the coolant which flows through the bypass passage **51**, and a second flow rate control valve which adjusts the flow rate of the coolant which flows through the radiator passage **53** and is independent from the first flow rate control valve.

FIG. **3** illustrates one example of the control of the engine system **1**. The engine system **1** does not need to switch the combustion mode. Even if the engine system **1** switches the combustion mode, this switching is not limited to the example of FIG. **3**.

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 System
10	Engine
16	Combustion Chamber
100	ECU (Controller)
22*a*	First Jacket (Water Jacket)
27	Radiator (Heat Exchanger)
28	Thermally-actuated Valve
4	Coolant Control Valve (Flow Rate Control Device)
51	Bypass Passage
52	Connecting Passage
53	Radiator Passage
91	Circulation System
92	Circulation System

What is claimed is:

1. An engine system, comprising:

an engine having a water jacket formed around a combustion chamber;

a circulation system that is attached to the engine and circulates coolant through the water jacket; and

a controller configured to control the circulation system according to an operating state of the engine,

wherein the circulation system includes:

- a radiator passage including a heat exchanger;
- a bypass passage bypassing the heat exchanger;
- a flow rate control device that adjusts a flow rate of coolant flowing through the water jacket by adjusting a flow rate of coolant flowing through each of the radiator passage and the bypass passage; and
- a thermally-actuated valve that is connected to the radiator passage and opens to allow the coolant to pass through the heat exchanger,

wherein the controller is electrically connected to the flow rate control device,

wherein the controller controls the flow rate control device to adjust the flow rate of the coolant flowing through the water jacket according to a load of the engine, by closing the radiator passage and adjusting the flow rate of the coolant flowing through the bypass passage, when the load is below a first load, and

wherein the controller controls the flow rate control device so that the coolant flows through each of the radiator passage and the bypass passage, when the load is above the first load.

2. The engine system of claim **1**, wherein when the load is below the first load, the controller increases the flow rate of the coolant flowing through the water jacket as the load increases.

3. The engine system of claim **2**, wherein when the load is above the first load, the controller adjusts a temperature of the coolant flowing through the water jacket according to the load by adjusting the flow rate of the coolant flowing through the bypass passage and the flow rate of the coolant flowing through the radiator passage.

4. The engine system of claim **3**, wherein when the load is above the first load, the controller reduces the flow rate of the coolant flowing through the bypass passage and increases the flow rate of the coolant flowing through the radiator passage, as the load increases.

5. The engine system of claim **4**, wherein when the load is above the first load, the controller sets the flow rate of the coolant flowing through the water jacket at a maximum flow rate.

6. The engine system of claim **5**, wherein both when the load is below the first load and when the load is above the first load, the controller maintains a wall temperature of the combustion chamber at a constant temperature by adjusting the flow rate of the coolant flowing through the water jacket.

7. The engine system of claim **6**, wherein, when the load is above the first load, the controller lowers a temperature of the coolant flowing through the water jacket to a temperature below a valve-opening temperature of the thermally-actuated valve.

8. The engine system of claim **4**,

wherein when the load is above the first load and below a second load, the controller increases the flow rate of the coolant flowing through the radiator passage to lower the temperature of the coolant flowing through the water jacket as the load increases, and

wherein when the load is above the second load, the controller increases the flow rate of the coolant flowing through the radiator passage to maintain the temperature of the coolant flowing through the water jacket constant as the load increases.

9. The engine system of claim **8**,

wherein the engine includes a spark plug that forcibly ignites an air-fuel mixture,

wherein when the load is below the first load, the air-fuel mixture inside the combustion chamber combusts without the forcible ignition of the spark plug, and

wherein when the load is above the first load, the air-fuel mixture inside the combustion chamber combusts by the forcible ignition of the spark plug.

10. The engine system of claim **9**,

wherein the flow rate control device is installed at a location branching into the bypass passage and the radiator passage, or a location where the bypass passage and the radiator passage are joined,

wherein the circulation system further includes a connecting passage connecting the bypass passage to the radiator passage, and

wherein the thermally-actuated valve opens and closes the connecting passage.

11. The engine system of claim **9**,

wherein the flow rate control device is installed at a location branching into the bypass passage and the radiator passage, or a location where the bypass passage and the radiator passage are joined,

wherein the circulation system further includes a connecting passage bypassing the flow rate control device and connecting the water jacket to the radiator passage, and

wherein the thermally-actuated valve opens and closes the connecting passage.

12. The engine system of claim **1**, wherein when the load is above the first load, the controller adjusts a temperature of the coolant flowing through the water jacket according to the load by adjusting the flow rate of the coolant flowing through the bypass passage and the flow rate of the coolant flowing through the radiator passage.

13. The engine system of claim **12**, wherein when the load is above the first load, the controller reduces the flow rate of the coolant flowing through the bypass passage and increases the flow rate of the coolant flowing through the radiator passage, as the load increases.

14. The engine system of claim **13**,

wherein when the load is above the first load and below a second load, the controller increases the flow rate of the coolant flowing through the radiator passage to lower the temperature of the coolant flowing through the water jacket as the load increases, and

wherein when the load is above the second load, the controller increases the flow rate of the coolant flowing through the radiator passage to maintain the temperature of the coolant flowing through the water jacket constant as the load increases.

15. The engine system of claim **1**, wherein when the load is above the first load, the controller sets the flow rate of the coolant flowing through the water jacket at a maximum flow rate.

16. The engine system of claim **1**, wherein both when the load is below the first load and when the load is above the first load, the controller maintains a wall temperature of the combustion chamber at a constant temperature by adjusting the flow rate of the coolant flowing through the water jacket.

17. The engine system of claim **16**, wherein, when the load is above the first load, the controller lowers a temperature of the coolant flowing through the water jacket to a temperature below a valve-opening temperature of the thermally-actuated valve.

18. The engine system of claim **1**,

wherein the engine includes a spark plug that forcibly ignites an air-fuel mixture,

wherein when the load is below the first load, the air-fuel mixture inside the combustion chamber combusts without the forcible ignition of the spark plug, and

wherein when the load is above the first load, the air-fuel mixture inside the combustion chamber combusts by the forcible ignition of the spark plug.

19. The engine system of claim **1**,

wherein the flow rate control device is installed at a location branching into the bypass passage and the radiator passage, or a location where the bypass passage and the radiator passage are joined,

wherein the circulation system further includes a connecting passage connecting the bypass passage to the radiator passage, and

wherein the thermally-actuated valve opens and closes the connecting passage.

20. The engine system of claim **1**,

wherein the flow rate control device is installed at a location branching into the bypass passage and the radiator passage, or a location where the bypass passage and the radiator passage are joined,

wherein the circulation system further includes a connecting passage bypassing the flow rate control device and connecting the water jacket to the radiator passage, and

wherein the thermally-actuated valve opens and closes the connecting passage.

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