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- (71) Applicant (for all designated States except US):
TOYOTA JIDOSHA KABUSHIKI KAISHA [JP/JP]; 1,
Toyota-cho, Toyota-shi, Aichi-ken, 471-8571 (JP).
- (72) Inventors; and
- (71) Applicants (for US only): TAKAGI, Isao [JP/JP]; c/o
TOYOTA JIDOSHA KABUSHIKI KAISHA, of 1,
Toyota-cho, Toyota-shi, Aichi-ken, 471-8571 (JP).
NOMURA, Mitsuhiro [JP/JP]; c/o TOYOTA JIDOSHA
KABUSHIKI KAISHA, of 1, Toyota-cho, Toyota-shi,
Aichi-ken, 471-8571 (JP).
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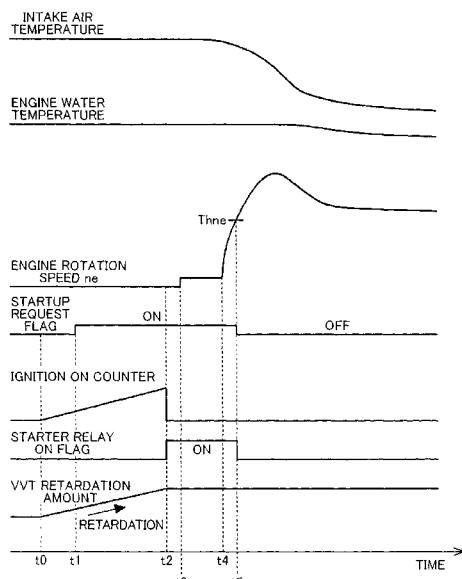
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FIG. 8



(57) Abstract: A startup control apparatus that starts an engine by performing cranking thereon includes: a variable valve timing mechanism capable of modifying at least a closing timing of an intake valve; and control portion which determines a temperature condition at a startup time, and when a pre-determined high temperature condition is established, retards the closing timing of the intake valve using the variable valve timing mechanism.

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APPARATUS FOR CONTROLLING A VARIABLE VALVE TIMING AT ENGINE START OF AN
INTERNAL COMBUSTION ENGINE

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

[0001] The invention relates to a startup control apparatus for an internal combustion engine installed in a vehicle or the like, and more particularly to control executed during startup on a variable valve timing mechanism capable of modifying an operation timing of an intake valve and an exhaust valve.

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2. Description of Related Art

[0002] In an internal combustion engine (also referred to as an engine hereafter) installed in a vehicle or the like, the use of a variable valve timing mechanism (also referred to as a VVT hereafter) that varies opening/closing timings of an intake valve is spreading. Further, practical realization of a so-called Atkinson cycle or Miller cycle, in which an expansion stroke of a cylinder is made longer than a compression stroke, is advancing. By lengthening the expansion stroke, combustion gas pressure can be converted into rotation of a crankshaft efficiently, leading to an improvement in engine efficiency.

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[0003] In a Miller cycle engine disclosed in Japanese Patent Application Publication No. 2010-084587 (JP 2010-084587 A), for example, a geometric compression ratio of a cylinder is increased to 13 or more, and in a normally used partial load operating region, a closing timing of an intake valve is retarded to at least a halfway point of a compression stroke by a VVT. As a result, pumping loss is reduced, and due to a reduction in an effective compression ratio, knocking is suppressed.

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[0004] Furthermore, in the engine described above, idling stop control is performed to stop the engine automatically in a predetermined condition. The engine may be restarted immediately after being stopped automatically, and therefore the closing timing of the intake valve is retarded to a maximum extent by the VVT. As a result, the

effective compression ratio becomes extremely low, and therefore, upon restarting of the engine, an air-fuel mixture is unlikely to self-ignite (pre-ignite) even when high-temperature intake air flows into the cylinder from an intake system.

5 [0005] When, on the other hand, the engine is stopped normally in response to an ignition operation by a driver or the like, rather than being stopped automatically during an idling stop, the closing timing of the intake valve is advanced to a maximum extent by the VVT. The purpose of this is to increase the effective compression ratio of the cylinder in consideration of a startability of the engine in a cold weather region.

10 [0006] As described in JP 2010-084587 A, the driver may restart the engine immediately after the stopping the engine normally, but during normal startup, fuel is supplied after purifying the high-temperature air by performing cranking a predetermined number of times, and therefore pre-ignition can be suppressed.

15 [0007] However, in a case where the driver restarts the engine immediately after stopping the engine normally, as described above, pre-ignition may occur during the predetermined number of cranking operations even when a fuel supply is stopped, leaving room for improvement. More specifically, the high-temperature air taken into the cylinder as a result of the cranking may intermix with fuel adhered to a wall surface of an intake port and fuel leaking from an injector to form an air-fuel mixture, and the air-fuel mixture may self-ignite during the cranking.

20 [0008] The reason why self-ignition occurs in this manner is that in the technique described in JP 2010-084587 A, it is assumed that a temperature condition at the time of startup is uniform regardless of whether the engine is stopped normally or automatically, and the VVT is controlled in accordance with this temperature condition. In other words, the reason for this self-ignition is believed to be that favorable VVT control corresponding
25 to the actual temperature condition at the time of startup cannot be realized.

SUMMARY OF THE INVENTION

[0009] The invention therefore provides a startup control apparatus for an internal combustion engine with which pre-ignition can be suppressed more reliably during startup

while securing favorable startability in the internal combustion engine.

[0010] According to an aspect of the invention, a temperature condition of an internal combustion engine is determined when the internal combustion engine is started rather than stopped, and a closing timing of an intake valve is modified in accordance with the temperature condition. More specifically, a startup control apparatus for an internal combustion engine, which starts an internal combustion engine by performing cranking thereon, includes: a variable valve timing mechanism capable of modifying at least a closing timing of an intake valve; and a control portion which determines a temperature condition at a startup time, and when a predetermined high temperature condition is established, retards the closing timing of the intake valve using the variable valve timing mechanism before the cranking is started.

[0011] According to this aspect of the invention, when the temperature condition of the internal combustion engine is high at the time of startup such that pre-ignition is likely to occur, the closing timing of the intake valve is retarded by the variable valve timing mechanism before the cranking is started. In other words, an effective compression ratio of a cylinder can be reduced as required on the basis of an actual engine temperature condition at the time of startup, and therefore pre-ignition can be suppressed more reliably while securing favorable startability.

[0012] Further, the control portion may further retard the closing timing of the intake valve as the temperature condition at the startup time is higher. Hence, when the temperature condition is comparatively low, the closing timing of the intake valve is retarded only slightly, and therefore the effective compression ratio does not decrease greatly, leading to an improvement in the startability. Further, the likelihood of pre-ignition increases steadily as the temperature increases, but by retarding the closing timing of the intake valve in accordance with the temperature condition so that the effective compression ratio decreases, pre-ignition can be suppressed more reliably.

[0013] Furthermore, the control portion may delay the start of the cranking as the temperature condition at the startup time is higher. In so doing, time required for the variable valve timing mechanism to perform the operation for retarding the closing timing

of the intake valve can be secured.

[0014] Since the closing timing of the intake valve is modified at the time of engine startup, the variable valve timing mechanism may be driven by an electric motor. A hydraulically driven variable valve timing mechanism operates rather sluggishly while
5 an oil pressure remains low immediately after engine startup. An electric variable valve timing mechanism, on the other hand, can be operated not only immediately after engine startup but also before startup, and therefore the cranking does not have to be delayed greatly.

[0015] In particular, when the internal combustion engine is installed in a vehicle,
10 the control portion may operate the variable valve timing mechanism to retard the closing timing of the intake valve in response to a predetermined operation performed by a driver of the vehicle before a cranking start operation is performed by the driver. In so doing, the delay in the cranking can be minimized such that there is substantially no delay in the cranking.

[0016] The startup control apparatus may further include a sensor for detecting a
15 temperature of at least one of a coolant and an intake air of the internal combustion engine, and the control portion may determine the temperature condition at the engine startup time from a signal output by the sensor. Hence, the actual temperature condition of the internal combustion engine at the time of startup can be determined precisely, thereby
20 ensuring that the effects of the invention can be secured.

[0017] The control portion may be configured to determine the temperature
condition at the engine startup time while taking into consideration not only the coolant temperature and the intake air temperature, but also at least one of an elapsed time following a preceding engine stoppage and an operation history up to the engine stoppage.
25 As a result, the temperature condition of the engine at the time of startup can be determined even more precisely, enabling a further improvement in the effects of the invention.

[0018] Moreover, when the internal combustion engine is stopped, the control portion may use the variable valve timing mechanism to control the closing timing of the

intake valve to a predetermined timing at which an effective compression ratio enabling cold startup in a cold weather region is obtained. In so doing, startability in a cold weather region can be secured in the internal combustion engine even when the variable valve timing mechanism malfunctions so as to become inoperable.

5 **[0019]** According to this aspect of the invention, the temperature condition of the internal combustion engine is determined when the internal combustion engine is started rather than stopped, and when the high temperature condition is determined, the variable valve timing mechanism is operated before the cranking is started. Therefore, the closing timing of the intake valve of the internal combustion engine can be controlled favorably in
10 accordance with the actual temperature condition at the time of startup, and as a result, pre-ignition can be suppressed more reliably while securing favorable startability in the internal combustion engine.

BRIEF DESCRIPTION OF THE DRAWINGS

15 **[0020]** Features, advantages, and technical and industrial significance of exemplary embodiments of the invention will be described below with reference to the accompanying drawings, in which like numerals denote like elements, and wherein:

FIG. 1 is a schematic view showing an example of an internal combustion engine (an engine) to which the invention is applied;

20 FIG. 2 is a sectional view showing a configuration of a VVT;

FIG. 3 is a sectional view taken along a III-III line in FIG. 2;

FIG. 4 is a block diagram showing a configuration of a control system of the engine;

FIG. 5 is a flowchart showing an example of engine startup control executed by an ECU, illustrating a VVT control routine;

25 FIG. 6 is a flowchart showing a starter motor control routine executed during the engine startup control;

FIG. 7A is a view illustrating a map used during the startup control on which a retardation amount of the VVT is set;

FIG. 7B is a view illustrating a map used during the startup control on which a

cranking delay is set; and

FIG. 8 is a timing chart showing an example of startup control, including the cranking delay and a VVT retardation operation implemented when a high temperature is determined.

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DETAILED DESCRIPTION OF EMBODIMENTS

[0021] An embodiment of the invention will be described below on the basis of the drawings.

[0022] First, referring to FIG. 1, an internal combustion engine (also referred to as an engine hereafter) to which the invention is applied will be described. An engine 1 according to this example is a four-cylinder gasoline engine installed in a vehicle. A piston 1c is housed to be capable of reciprocating vertically in each of four cylinders (only one cylinder is shown in FIG. 1) formed inside a cylinder block 1a. A water jacket is formed on the cylinder block 1a so as to surround the four cylinders, and a water temperature sensor 32 is disposed on the cylinder block 1a to detect a temperature of engine cooling water (a coolant).

[0023] The reciprocating motion of the piston 1c in each of the four cylinders is converted into a rotary motion of a crankshaft 15 via a connecting rod 16. The crankshaft 15 is coupled to a transmission (not shown) via a torque converter (or a clutch) and so on such that an output of the engine 1 can be transmitted to a drive wheel of the vehicle via the transmission. The transmission may be a multistage automatic transmission that uses frictional engagement elements such as a clutch and a brake and a planetary gear mechanism, or a belt type continuously variable transmission, for example.

[0024] Further, a starter motor 10 that is activated when the engine 1 is started can be coupled to the crankshaft 15, and the crankshaft 15 can be rotated forcibly (i.e. cranked) by the starter motor 10. A signal rotor 17 is attached to the crankshaft 15, and a plurality of teeth (projections) 17a are provided on an outer peripheral surface of the signal rotor 17 at equal angular intervals. The signal rotor 17 is also provided with a missing tooth portion 17b from which two of the teeth 17a are missing.

[0025] A crank position sensor 31 that detects a crank angle is disposed near a side of the signal rotor 17. The crank position sensor 31 is an electromagnetic pickup, for example, that generates pulse-form signals corresponding to the teeth 17a of the signal rotor 17 while the crankshaft 15 rotates. An engine rotation speed n_e can be calculated from an output signal of the crank position sensor 31.

[0026] Further, an oil pan 18 for storing lubricating oil (engine oil) is provided in a lower portion of the cylinder block 1a so as to cover the crankshaft 15. The lubricating oil stored in the oil pan 18 is pumped up by an oil pump (not shown) when the engine 1 is operated, supplied to respective parts of the engine such as the piston 1c, the crankshaft 15, and the connecting rod 16, and used for lubrication, cooling, and so on of these parts.

[0027] Meanwhile, a cylinder head 1b is fastened to an upper end of the cylinder block 1a, and a combustion chamber 1d that is varied in volume by the reciprocating motion of the piston 1c is formed in each of the cylinders, respective upper ends of which are closed by the cylinder head 1b. A spark plug 3 is disposed in the cylinder head 1b for each cylinder so as to oppose the combustion chamber 1d, and an ignition timing of the spark plug 3 is regulated by an igniter 4. The igniter 4 is controlled by an electronic control unit (ECU) 200.

[0028] An intake passage 11 and an exhaust passage 12 respectively communicate with the combustion chamber 1d so that fresh air can be taken into the combustion chamber 1d and combustion gas can be discharged therefrom. A downstream side of the intake passage 11 (a downstream side of an intake air flow) is constituted by an intake port 11a and an intake manifold 11b, and a surge tank 11c is disposed on an upstream side thereof. Further, an air cleaner 7 that filters the intake air, a hot wire air flow meter 33, an intake air temperature sensor 34 (built into the air flow meter 33, for example), a throttle valve 5 for adjusting the intake air amount of the engine 1, and so on are disposed in the intake passage 11.

[0029] For example, the throttle valve 5 is provided on an upstream side of the surge tank 11c and driven by a throttle motor 6. An opening of the throttle valve 5 is detected by a throttle opening sensor 35 and feedback-controlled by the ECU 200 so that

an optimum intake air amount corresponding to an operating condition of the engine 1 is obtained.

[0030] Furthermore, an injector (a fuel injection valve) 2 is disposed in the intake port 11a for each cylinder. The respective injectors 2 are connected to a shared delivery pipe 101, and fuel is supplied thereto from a fuel supply system 100. The fuel supply system 100 includes, for example, a fuel supply pipe 102 connected to the delivery pipe 101, a fuel pump 103, a fuel tank 104, and so on.

[0031] The injectors 2 are controlled by the ECU 200 to inject fuel into the respective cylinders at a predetermined timing. The fuel injected into the intake port 11a from the injector 2 intermixes with the intake air, and a resulting air-fuel mixture is introduced into the combustion chamber 1d of each cylinder when an intake valve 13 is opened. The air-fuel mixture is ignited by the spark plug 3 in a final phase of a compression stroke of the cylinder so as to burn and explode, thereby generating high-temperature high-pressure combustion gas that pushes the piston 1c down and is then discharged into the exhaust passage 12 when an exhaust valve 14 is opened.

[0032] An upstream side of the exhaust passage 12 (an upstream side of an exhaust gas flow) is constituted by an exhaust port 12a and an exhaust manifold 12b, and a three-way catalyst 8 is disposed on a downstream side thereof. The three-way catalyst 8 purifies exhaust gas discharged into the exhaust passage 12 by performing oxidation of CO and HC contained in the exhaust gas and NOx reduction so as to turn the CO, HC and NOx into harmless CO₂, H₂O, and N₂.

[0033] A front air-fuel ratio sensor 37 having a linear characteristic with respect to an air-fuel ratio, for example, is disposed in the exhaust passage 12 on the upstream side of the three-way catalyst 8, and a rear O₂ sensor 38 constituted by a lambda sensor, for example, is disposed in the exhaust passage 12 on the downstream side of the three-way catalyst 8. Output signals from the front air-fuel ratio sensor 37 and the rear O₂ sensor 38 are fed back to the ECU 200 and used to control the air-fuel ratio.

[0034] Intake and discharge into and from the combustion chamber 1d are performed by opening and closing the intake valve 13 and the exhaust valve 14. The

intake valve 13 is provided between the intake port 11a and the combustion chamber 1d, and the exhaust valve 14 is provided between the exhaust port 12a and the combustion chamber 1d. The intake valve 13 and the exhaust valve 14 are opened and closed at respective predetermined timings by intake and exhaust camshafts 21, 22 that are rotated
5 by the crankshaft 15 via a timing chain or the like.

[0035] More specifically, the intake and exhaust camshafts 21, 22 are respectively rotated at 1/2 the rotation speed of the crankshaft 15 so as to complete a single revolution in the time required for the piston 1c to reciprocate twice. In other words, the respective camshafts 21, 22 perform a single revolution in the time required for the crankshaft 15 to
10 perform two revolutions (i.e. to rotate 720°) and the piston 1c to perform an intake stroke, a compression stroke, an expansion stroke, and an exhaust stroke. The intake valve 13 opens during the intake stroke of each cylinder, while the exhaust valve 14 opens during the exhaust stroke.

[0036] A cam position sensor 39 that generates a pulse-form signal when the
15 piston 1c of a specific cylinder (a first cylinder, for example) reaches compression top dead center (TDC) is provided in the vicinity of the intake camshaft 21 that rotates in the manner described above. The cam position sensor 39 is constituted by an electromagnetic pickup, similarly to the aforesaid crank position sensor 31, which outputs a pulse-form signal when a single tooth (not shown) formed on a rotor outer periphery of the intake
20 camshaft 21 passes by.

[0037] Furthermore, in this embodiment, an electric variable valve timing mechanism (abbreviated to VVT 40 hereafter) to be described below is attached to the intake camshaft 21. Hence, a rotary phase of the intake camshaft 21, which uses the rotation of the crankshaft 15 as a reference, can be varied continuously, with the result that
25 the opening and closing timings of the intake valve 13 can be modified continuously to an advancement side and a retardation side.

[0038] The engine 1 according to this embodiment operates on a so-called Atkinson cycle (Miller cycle), in which a geometric compression ratio (a ratio between volumes of the combustion chamber 1d when the piston 1c is at TDC and bottom dead

center) of each cylinder is set at a high value between 12 and 14, and in a frequently used partial load operating region, the closing timing of the intake valve 13 is retarded by the VVT 40 to at least a halfway point of the compression stroke.

[0039] In this embodiment, as shown in FIGS. 2 and 3, the VVT 40 (not shown in FIG. 1) is disposed on an end portion of the intake camshaft 21. FIG. 2 is a sectional view showing an internal structure of the VVT 40, and FIG. 3 is a sectional view taken along a III-III line in FIG. 2. A similar VVT may be disposed in the exhaust camshaft 22.

[0040] In the example shown in the drawings, the VVT 40 is driven by an electric motor 42 (referred to simply as a motor hereafter) that is controlled by the ECU 200. As shown in FIG. 2, the electric motor 42 is a three-phase motor constituted by a motor shaft 44, bearings 46, a rotation speed sensor 47, a stator 50, and so on. The motor shaft 44 is supported by the two bearings 46 to be capable of rotating about an axis O. A disc-shaped rotor portion 45 that projects outward in a radial direction is fixed to the motor shaft 44, and a plurality of magnets 45a are embedded in an outer peripheral wall of the rotor portion 45.

[0041] The stator 50, meanwhile, is disposed on an outer peripheral side of the motor shaft 44, and includes a plurality of coils arranged at equal intervals around the axis O of the motor shaft 44. Each coil is formed by winding a winding 52 around a core 51, and when a current flows to the coil upon reception of a current supply from a drive circuit 108, the coil forms a rotating magnetic field on the outer peripheral side of the motor shaft 44, thereby generating rotary torque. The rotation speed sensor 47 is disposed in the vicinity of the rotor portion 45, and detects a rotation speed (to be referred to as a motor rotation speed hereafter) of the motor shaft 44 by sensing an intensity of a magnetic field formed by each magnet 45a.

[0042] As shown in both FIG. 2 and FIG. 3, the VVT 40 further includes a phase variation mechanism 60. The phase variation mechanism 60 includes a sprocket 62, a ring gear 63, an eccentric shaft 64, a planetary gear 65, an output shaft 66, and so on. The sprocket 62 is disposed on an outer peripheral side of the output shaft 66 coaxially therewith so as to be capable of rotating relative to the output shaft 66 about the same axis

O as the motor shaft 44.

[0043] When the rotation of the crankshaft 15 is transmitted to the sprocket 62 by a chain or the like, the sprocket 62 rotates about the axis O in a clockwise direction of FIG. 3 while maintaining a rotary phase relative to the crankshaft 15. The ring gear 63 is constituted by an internal gear and fixed to an inner peripheral wall of the sprocket 62 coaxially therewith so as to rotate integrally with the sprocket 62.

[0044] The eccentric shaft 64 is coupled fixedly to the motor shaft 44 so as to be disposed eccentrically relative to the axis O, and rotates integrally with the motor shaft 44. The planetary gear 65 is an external gear capable of a planetary motion, which is disposed on an inner peripheral side of the ring gear 63 so as to mesh therewith. The planetary gear 65 is supported on an outer peripheral wall of the eccentric shaft 64 coaxially therewith, and is capable of rotating relative to the eccentric shaft 64 about an eccentric axis P.

[0045] Furthermore, the output shaft 66 is fixed to the intake camshaft 21 coaxially therewith by a bolt, and rotates integrally with the intake camshaft 21 about the same axis O as the motor shaft 44. An annular plate-shaped engagement portion 67 centering on the axis O is formed on the output shaft 66, and a plurality of engagement holes 68 are provided in the engagement portion 67 at equal intervals around the axis O. A plurality of engagement projections 69 are provided in the planetary gear 65 at equal intervals about the eccentric axis P so as to oppose the engagement holes 68, and the respective engagement projections 69 project to the shaft 66 side so as to penetrate the corresponding engagement holes 68.

[0046] In the VVT 40 having the structure described above, when the motor shaft 44 does not rotate relative to the sprocket 62, the planetary gear 65 rotates in the clockwise direction of FIG. 3 integrally with the sprocket 62 in response to the rotation of the crankshaft 15 while maintaining its meshing position with the ring gear 63. At this time, the engagement projections 69 are pressed against respective inner peripheral walls of the engagement holes 68 in a rotation direction, and therefore the output shaft 66 rotates in the clockwise direction of FIG. 3 without rotating relative to the sprocket 62. As a result, the

rotary phase of the intake camshaft 21 relative to the crankshaft 15 is maintained.

[0047] On the other hand, when the motor shaft 44 rotates relative to the sprocket 62 in a counter-clockwise direction of FIG. 3, the planetary gear 65 performs the planetary motion so as to vary its meshing position with the ring gear 63 while rotating relative to the eccentric shaft 64 in the clockwise direction of FIG. 3. At this time, a force by which the engagement projections 69 are pressed against the engagement holes 68 in the rotation direction increases, and therefore the output shaft 66 is advanced relative to the sprocket 62. As a result, the rotary phase of the intake camshaft 21 varies to the advancement side.

[0048] Conversely, when the motor shaft 44 rotates relative to the sprocket 62 in the clockwise direction of FIG. 3, the planetary gear 65 performs the planetary motion so as to vary its meshing position with the ring gear 63 while rotating relative to the eccentric shaft 64 in the counter-clockwise direction of FIG. 3. At this time, the engagement projections 69 are pressed against the engagement holes 68 in an anti-rotation direction, and therefore the output shaft 66 is retarded relative to the sprocket 62. As a result, the rotary phase of the intake camshaft 21 varies to the retardation side.

[0049] As shown in FIG. 4, the ECU 200 includes a central processing unit (CPU) 201, a read only memory (ROM) 202, a random access memory (RAM) 203, a backup RAM 204, and so on.

[0050] The ROM 202 stores various control programs, maps referred to when executing the various control programs, and so on. The CPU 201 executes various calculation processing on the basis of the various control programs and maps stored in the ROM 202. Further, the RAM 203 is a memory for temporarily storing calculation results obtained by the CPU 201, data input from respective sensors, and so on, while the backup RAM 204 is a non-volatile memory that stores data and the like to be saved when the engine 1 is stopped, for example.

[0051] The CPU 201, the ROM 202, the RAM 203, and the backup RAM 204 are connected to each other by a bus 207, and also connected to an input interface 205 and an output interface 206.

[0052] Various sensors including the crank position sensor 31, the water

temperature sensor 32, the air flow meter 33, the intake air temperature sensor 34, the throttle opening sensor 35, an accelerator depression amount sensor 36 that outputs a detection signal corresponding to a depression amount of an accelerator pedal, the front air-fuel ratio sensor 37, the rear O₂ sensor 38, and the cam position sensor 39 are connected
5 to the input interface 205.

[0053] An ignition switch 48 for switching a main power supply of the vehicle ON and OFF, and a starter switch 49 used by a driver of the vehicle to perform an operation relating to startup of the engine 1 are also connected to the input interface 205. When the ignition switch 48 is switched ON, control of the engine 1 by the ECU 200 is
10 started, and when the starter switch 49 is switched ON, cranking of the engine 1 by the starter motor 10 is started.

[0054] Meanwhile, the injectors 2 of the respective cylinders, the igniters 4 of the spark plugs 3 of the respective cylinders, the throttle motor 6 of the throttle valve 5, the starter motor 10, the VVT 40 of the intake camshaft 21, and so on, for example, are
15 connected to the output interface 206.

[0055] On the basis of signals from the various sensors and switches described above, the ECU 200 executes various types of control on the engine 1, including drive control of the injector 2 (fuel injection amount and injection timing control), control of the ignition timing of the spark plug 3, drive control of the throttle motor 6 (throttle opening
20 control), and operation control of the VVT 40 (phase control of the intake valve 13). The ECU 200 also executes engine startup control to be described below.

[0056] In other words, the startup control apparatus for an internal combustion engine according to the invention is realized by a program relating to the engine startup control to be described below, which is executed by the ECU 200.

[0057] First, in the engine 1 according to this embodiment, fuel injected by the injector 2 immediately before an operation is stopped may adhere to a wall surface of the intake port 11a (including a rear surface of the intake valve 13), and after the engine 1 is stopped, fuel may leak from the injector 2. Therefore, even if fuel is not injected when the engine 1 is restarted, high-temperature air taken into the cylinder by the cranking may

intermix with the fuel adhered to the wall surface and the leaked fuel, thereby forming an air-fuel mixture that may self-ignite (in other words, pre-ignition may occur).

[0058] Hence, a temperature condition of the engine 1 is determined at the time of startup, and when a predetermined high temperature condition is established, the closing timing of the intake valve 13 is retarded by the VVT 40 before the cranking is started. In so doing, an effective compression ratio of the cylinder can be reduced, and as a result, pre-ignition can be prevented. An example of this engine startup control will be described below with reference to flowcharts shown in FIGS. 5 and 6.

[0059] First, a startup VVT control routine shown in FIG. 5 is started (Start) when the ignition switch 48 is switched ON (IG-SW ON). Then, in step ST101, the engine water temperature and the intake air temperature are detected from the respective output signals of the water temperature sensor 32 and the intake air temperature sensor 34, and mainly on the basis of these detection results, a determination is made as to whether or not a predetermined high temperature condition in which pre-ignition is likely to occur is established upon startup of the engine 1.

[0060] In step ST101, for example, a determination is made as to whether or not a pre-ignition condition constituted by four following conditions is established. When the determination is affirmative (YES), the routine advances to step ST102, and when the determination is negative (NO), the routine advances to step ST106, to be described below. The pre-ignition condition is established when: 1) the engine water temperature equals or exceeds a predetermined water temperature determination value; 2) the intake air temperature of the engine 1 equals or exceeds a predetermined intake air temperature determination value; 3) an elapsed time following a preceding stoppage of the engine 1 is less than a predetermined determination time; 4) at least a predetermined high load condition was reached between a preceding engine startup and the preceding engine stoppage, and so on.

[0061] As regards the four conditions, a temperature of the combustion chamber 1d in the cylinder is higher as the engine water temperature increases, leading to an increase in the temperature of the intake air charged into the combustion chamber 1d and a

corresponding increase in the likelihood of pre-ignition occurring during the compression stroke. When the temperature of the intake air itself is high, needless to say the likelihood of pre-ignition increases. The temperature of the combustion chamber 1d also is higher as the elapsed time following the preceding engine stoppage decreases, and when at least
5 the predetermined high load condition is reached prior to the preceding engine stoppage, a site having a particularly high temperature (a heat spot) may exist in the combustion chamber 1d.

[0062] Therefore, when all of the four conditions are established, for example, it can be determined that pre-ignition is likely to occur during startup. Note that the
10 determination as to whether or not the pre-ignition condition is established may be made by any one of the four conditions, or combining any of the four conditions in various combinations, or by adding further conditions. Moreover, as regards the water temperature determination value, the intake air temperature determination value, and the
15 determination time, values of an engine water temperature, an intake air temperature, and an elapsed time following the preceding engine stoppage at which pre-ignition is likely to occur during startup may be obtained in advance by experiments, simulations, and so on, and a combination of values based on the obtained values may be set as the water temperature determination value, the intake air temperature determination value, and the
20 determination time.

[0063] When it is determined as a result of the determination that the pre-ignition condition is established (YES), the routine advances to step ST102, where a value of a pre-ignition flag F is set at 1 ($F \leftarrow 1$). The routine then advances to step ST103, where the VVT 40 is operated to the retardation side in order to retard the closing timing of the intake valve 13. An amount by which the VVT 40 is operated to the retardation side (a VVT
25 retardation amount) is determined in accordance with the engine water temperature (a startup water temperature) and the intake air temperature by referring to a VVT retardation amount map shown in FIG. 7A, for example.

[0064] On the map shown in the drawing, the VVT retardation amount is increased as the engine water temperature and the intake air temperature increase. The

closing timing of the intake valve 13 is retarded accordingly, leading to a reduction in the effective compression ratio of the cylinder, and as a result, a cylinder internal temperature does not reach a self-ignition temperature of the air-fuel mixture even at TDC. Hence, retardation amounts of the VVT 40 are set in accordance with the engine water temperature and the intake air temperature by experiments, calculations, and so on, whereupon resulting set values are mapped and stored thus in the ROM 202 of the ECU 200.

[0065] Note that the effective compression ratio at which the cylinder internal temperature does not reach the self-ignition temperature of the air-fuel mixture is set at an effective compression ratio at which a temperature increase caused by heat received from the cylinder wall and compression during the compression stroke does not cause the cylinder internal temperature to reach the self-ignition temperature, also taking into consideration effects of the intake air temperature at engine startup, a charging amount into the cylinder, latent heat generated by fuel evaporation, a specific heat ratio of the air-fuel mixture, and so on. This effective compression ratio may be set to have a predetermined margin. Further, the VVT retardation amount is not limited to the map described above, and may be determined in accordance with only one of the engine water temperature and the intake air temperature, or set at a fixed value.

[0066] Returning to the flowchart of FIG. 5, in step ST104, a determination is made as to whether or not the engine rotation speed n_e calculated from the output signal of the crank position sensor 31 has reached a predetermined startup completion determination value Th_{ne} (500 rpm, for example; see FIG. 8). When the determination is negative (NO), the routine enters standby, but when the engine rotation speed n_e has reached the determination value Th_{ne} such that the determination is affirmative (YES), the value of the flag F is set at 0 ($F \leftarrow 0$) in step ST105, whereupon the startup VVT control routine is terminated.

[0067] Further, when it is determined in step ST101 that the pre-ignition condition is not established (NO) such that the routine advances to step ST106, the VVT 40 is not operated, and the startup VVT control routine is terminated (End) while maintaining the VVT position at the time of the preceding engine stoppage, or in other

words keeping the closing timing of the intake valve 13 in a condition established at the time of the preceding engine stoppage. In this embodiment, when the engine 1 is stopped, the VVT 40 is normally controlled to control the closing timing of the intake valve 13 to a predetermined timing (approximately after top dead center (ATDC) 60 to 70° CA, for example) so that an effective compression ratio enabling cold startup is obtained.

[0068] Next, referring to FIG. 6, a startup starter control routine will be described. Similarly to the startup VVT control routine described above, this routine is started (Start) when the ignition switch 48 is switched ON (IG-SW ON). First, in step ST201, a determination is made as to whether or not the starter switch 49 has been switched ON (starter SW ON?). When the determination is negative (NO), the routine enters standby, and when the determination is affirmative (YES), the routine advances to step ST202.

[0069] In step ST202, a determination is made as to whether or not the value of the pre-ignition flag F is 0 ($F = 0?$). When the determination is affirmative (YES), the routine advances to step ST203, where a starter relay is switched ON in order to start the cranking. When the determination is negative (NO), on the other hand, the routine advances to step ST204, where a determination is made as to whether or not a cranking delay has elapsed.

[0070] More specifically, at the same time as the ignition switch 48 is switched ON, a counter (an ignition ON counter) is activated in the ECU 200. When a value of the counter has not reached a set value, it is determined that the delay has not elapsed (NO), and the routine enters standby. When the counter value reaches the set value, on the other hand, it is determined that the delay has elapsed (YES), whereupon the routine advances to step ST203 in order to switch the starter relay ON.

[0071] In other words, when the value of the pre-ignition flag F is 1 such that the high temperature condition in which pre-ignition is likely to occur is established at the time of startup of the engine 1, activation of the starter motor 10, or in other words the start of the cranking, is delayed for a predetermined time even after the ignition switch 48 is switched ON. This delay is set in advance on a cranking delay map shown in FIG. 7B, for example, in accordance with an end time of the operation of the VVT 40 in the startup

VVT control routine described above.

[0072] The map shown in FIG. 7B is stored in the ROM 202 of the ECU 200 and set similarly to the VVT retardation amount map described above such that the cranking delay is increased steadily as the engine water temperature and the intake air temperature increase. For example, an operation time of the VVT 40 required to reach a target VVT retardation amount is set by experiments, calculations, and so on and then mapped. Note that the cranking may be started by feeding back an actual operating condition of the VVT 40 instead of using a map.

[0073] After retarding the closing timing of the intake valve 13 in this manner, the cranking is started, whereupon fuel injection by the injector 2 and ignition control by the spark plug 3 are performed in order to start the engine 1. Note that the fuel injection amount and the ignition timing are determined on the basis of various conditions (the engine water temperature, the intake air temperature, and so on) at the time of engine startup using a startup injection amount map and a startup ignition timing map, for example.

[0074] In step ST205 of the flowchart shown in FIG. 6, a determination is made as to whether or not the engine rotation speed n_e has reached the determination value Th_{ne} , and when the determination is negative (NO), the routine enters standby. When the engine rotation speed n_e has reached the determination value Th_{ne} such that the determination is affirmative (YES), the routine advances to step ST206, where the starter relay is switched OFF, thereby halting the cranking performed by the starter motor 10. The startup starter control routine is then terminated (End).

[0075] FIG. 8 shows startup of the engine 1 (i.e. increasing of the engine rotation speed n_e and so on) in a case where the high temperature condition is established such that the cranking is delayed and the closing timing of the intake valve 13 is retarded, in association with variation in the intake air temperature and the engine water temperature, an ON operation of the ignition switch 48 (an ignition ON counter), an ON operation of the starter switch 49 (a startup request flag), activation of the starter motor 10 (a starter relay ON flag), and the operation of the VVT 40 (the VVT retardation amount).

[0076] As shown in an upper section of the drawing, when the ignition switch 48 is switched ON (time t_0) in a condition where the intake air temperature and the engine water temperature are high, the ignition ON counter of the ECU 200 is started and the VVT 40 is operated to the retardation side such that the VVT retardation amount gradually increases, as shown in a lower section of the drawing. In other words, the opening timing of the intake valve 13 are retarded.

[0077] In this case, the starter relay ON flag is not raised even when the starter switch 49 is subsequently switched ON such that the startup request flag is raised (time t_1), as shown in an intermediate section of the drawing, and as a result, the start of the cranking is delayed (the engine rotation speed does not increase). The ignition ON counter reaches a set value at substantially the same time as the VVT retardation amount reaches a target value (time t_2), whereupon the starter relay ON flag is raised.

[0078] Hence, when the starter motor 10 is activated such that cranking of the engine 1 is started, the engine rotation speed n_e increases to a predetermined rotation speed (approximately 200 rpm, for example) at time t_3 , i.e. at a slight delay. Further, although not shown in the drawing, fuel is supplied to the four cylinders and ignited in a predetermined order. At this time, as described above, the closing timing of the intake valve 13 is sufficiently retarded by retarding the VVT 40, leading to a considerable reduction in the effective compression ratio of the cylinder, and therefore pre-ignition is avoided.

[0079] Moreover, the VVT retardation amount is set precisely on the basis of the intake air temperature and the engine water temperature, and therefore the effective compression ratio does not decrease excessively, meaning that favorable startability is maintained. Hence, when the air-fuel mixture is burned in the cylinder that is ignited first and the cylinder that is ignited second, for example, the rotation of the crankshaft 15 is accelerated, with the result that the engine rotation speed n_e increases rapidly after starting to rise (time t_4).

[0080] When the increasing engine rotation speed n_e reaches the determination value Th_{ne} (time t_5), the startup request flag and the starter relay ON flag are switched

OFF, indicating completion of the startup control. Further, the intake air temperature is reduced rapidly by an inflow of outside air into the intake passage 11, while the engine water temperature is reduced gently by the cooling water flowing through the water jacket. Thereafter, retardation control of the VVT 40 is terminated quickly and normal control
5 corresponding to the operating condition of the engine 1 is resumed.

[0081] Hence, in the startup control apparatus for the engine 1 according to this embodiment, the intake VVT 40 is positioned on the advancement side when the engine 1 is stopped, and when the high temperature condition is determined mainly on the basis of the intake air temperature and the engine water temperature at the time of startup thereafter,
10 the VVT 40 is operated to retard the closing timing of the intake valve 13 before cranking is started. In so doing, the effective compression ratio of the cylinder can be reduced, and as a result, pre-ignition can be avoided.

[0082] In other words, the effective compression ratio of the cylinder can be reduced as required on the basis of the actual temperature condition at the time of startup
15 of the engine 1, and therefore pre-ignition can be avoided more reliably while securing favorable startability. At a comparatively low temperature, startability can be secured by increasing the effective compression ratio without greatly retarding the closing timing of the intake valve 13, and by steadily retarding the closing timing of the intake valve 13 so as to reduce the effective compression ratio as the temperature increases, pre-ignition can be
20 avoided reliably.

[0083] The VVT 40 is operated during startup and is therefore constituted by an electric mechanism. Moreover, the VVT 40 is operated in response to an operation (a predetermined operation) of the ignition switch 48 before the starter switch 49 is switched ON, or in other words before a cranking start operation is performed. Hence, the delay
25 from the ON operation of the starter switch 49 to the start of cranking is small, and therefore a driver is unlikely to experience discomfort.

[0084] As noted above, by positioning the VVT 40 on the advancement side when the engine 1 is stopped, startability is secured effectively in the engine 1 in a cold weather region. If the VVT 40 is controlled to the retardation side when the engine 1 is stopped

and the engine 1 is subsequently restarted in extremely cold weather (approximately -10°C , for example), the VVT 40 may malfunction so as to become inoperable, leading to a dramatic reduction in the startability of the engine 1.

[0085] In this embodiment, the VVT 40 is operated to the retardation side in accordance with the intake air temperature and the engine water temperature when the pre-ignition condition is established at the time of startup of the engine 1, whereby the closing timing of the intake valve 13 is retarded by a steadily greater retardation amount as the temperature increases. However, the invention is not limited thereto, and the VVT retardation amount may be varied in accordance with either one of the engine water temperature and the intake air temperature. Further, the VVT 40 may be retarded to a fixed value when the pre-ignition condition is established.

[0086] Further, in this embodiment, the pre-ignition condition is determined immediately after the ignition switch 48 is switched ON, and when the condition is established, the VVT 40 is operated to the retardation side before the starter switch 49 is switched ON. However, the invention is not limited thereto, and the VVT 40 may be operated using a predetermined operation such as an operation of the starter switch 49, for example, as a trigger.

[0087] Furthermore, in this embodiment, the VVT 40 is controlled to the advancement side when the engine 1 is stopped, thereby advancing the closing timing of the intake valve 13 so that an effective compression ratio enabling cold startup in a cold weather region is obtained. However, the invention is not limited thereto, and the VVT 40 may be controlled to any position other than a maximum retardation position when the engine 1 is stopped.

[0088] Moreover, in this embodiment, an example in which the invention is applied to startup control of the port injection type engine 1 was described, but the invention is not limited thereto, and may be applied to startup control of an in-cylinder direct injection type engine or startup control of an engine including both port injection and in-cylinder injection type fuel injection valves.

[0089] Furthermore, in this embodiment, a case in which the invention is applied

to a four-cylinder engine was described, but the invention is not limited thereto, and may be applied to startup control of an engine having another number of cylinders, such as a six-cylinder engine, for example. The invention may also be applied to startup control of an in-line multi-cylinder engine or a V type multi-cylinder engine.

5 **[0090]** The invention can be applied as a startup control apparatus for an internal combustion engine (an engine), and is capable of suppressing pre-ignition during startup while securing favorable startability. The invention is therefore particularly effective when installed in a passenger vehicle or the like.

CLAIMS:

1. A startup control apparatus for an internal combustion engine, which starts an internal combustion engine by performing cranking thereon, comprising:

a variable valve timing mechanism capable of modifying at least a closing timing of an intake valve; and

a control portion which determines a temperature condition at a startup time, and when a predetermined high temperature condition is established, retards the closing timing of the intake valve using the variable valve timing mechanism before the cranking is started.

2. The startup control apparatus for an internal combustion engine according to claim 1, wherein the control portion further retards the closing timing of the intake valve as the temperature condition at the startup time is higher.

3. The startup control apparatus for an internal combustion engine according to claim 1 or 2, wherein the control portion delays the start of the cranking as the temperature condition at the startup time is higher.

4. The startup control apparatus for an internal combustion engine according to any one of claims 1 to 3, wherein the variable valve timing mechanism is driven by an electric motor.

5. The startup control apparatus for an internal combustion engine according to any one of claims 1 to 4, wherein the internal combustion engine is installed in a vehicle, and the control portion operates the variable valve timing mechanism to retard the closing timing of the intake valve in response to a predetermined operation performed by a driver of the vehicle before a cranking start operation is performed by the driver.

6. The startup control apparatus for an internal combustion engine according to any one of claims 1 to 5, further comprising a sensor for detecting a temperature of at least one of a coolant and an intake air of the internal combustion engine,

wherein the control portion determines the temperature condition at the engine startup time from a signal output by the sensor.

7. The startup control apparatus for an internal combustion engine according to claim 6, wherein the control portion determines the temperature condition at the engine startup time while taking into consideration at least one of an elapsed time following a preceding engine stoppage and an operation history up to the engine stoppage at the engine startup time.

8. The startup control apparatus for an internal combustion engine according to any one of claims 1 to 7, wherein, when the internal combustion engine is stopped, the control portion uses the variable valve timing mechanism to control the closing timing of the intake valve to a predetermined timing at which an effective compression ratio enabling cold startup in a cold weather region is obtained.

FIG. 1

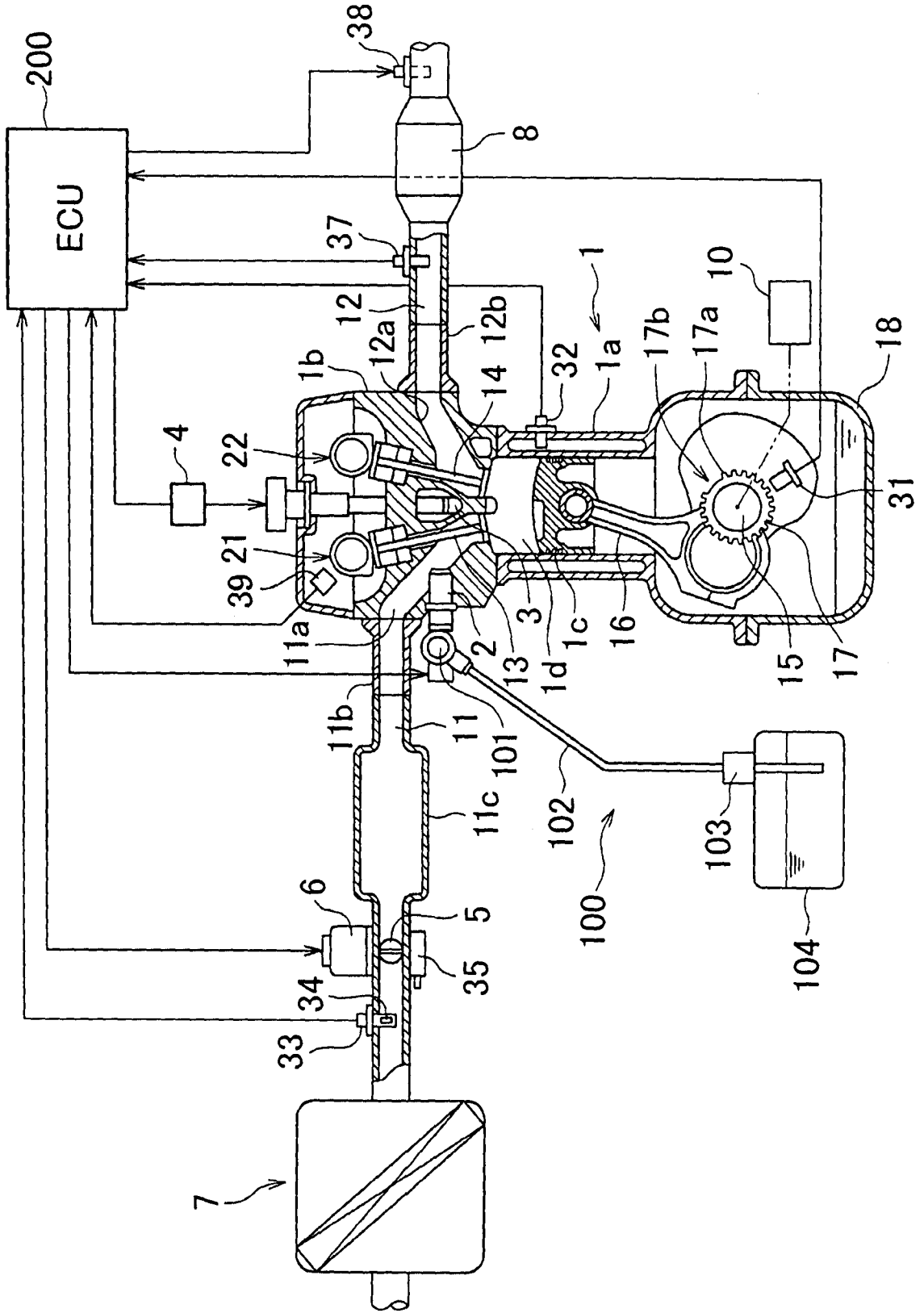


FIG. 2

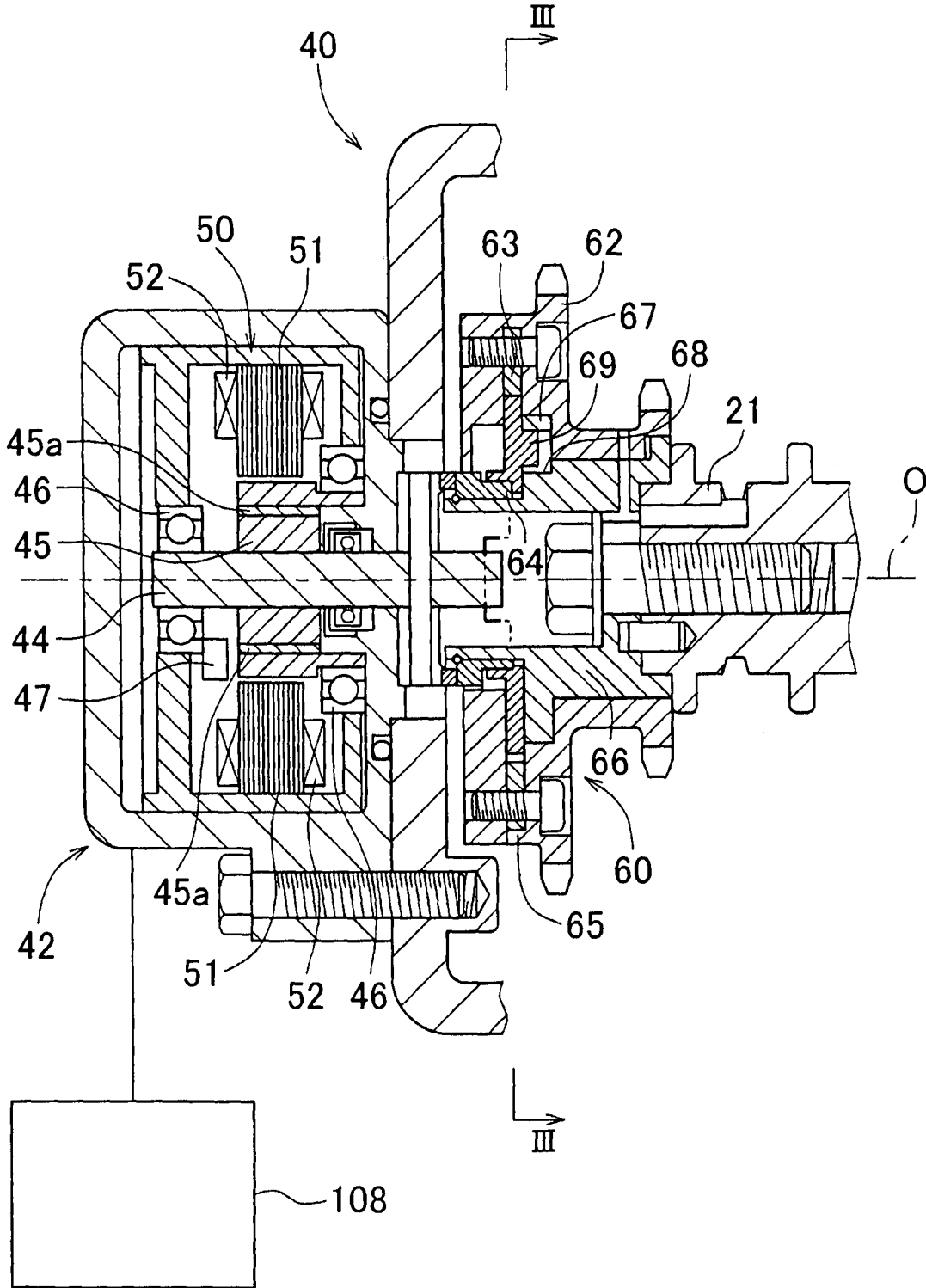


FIG. 3

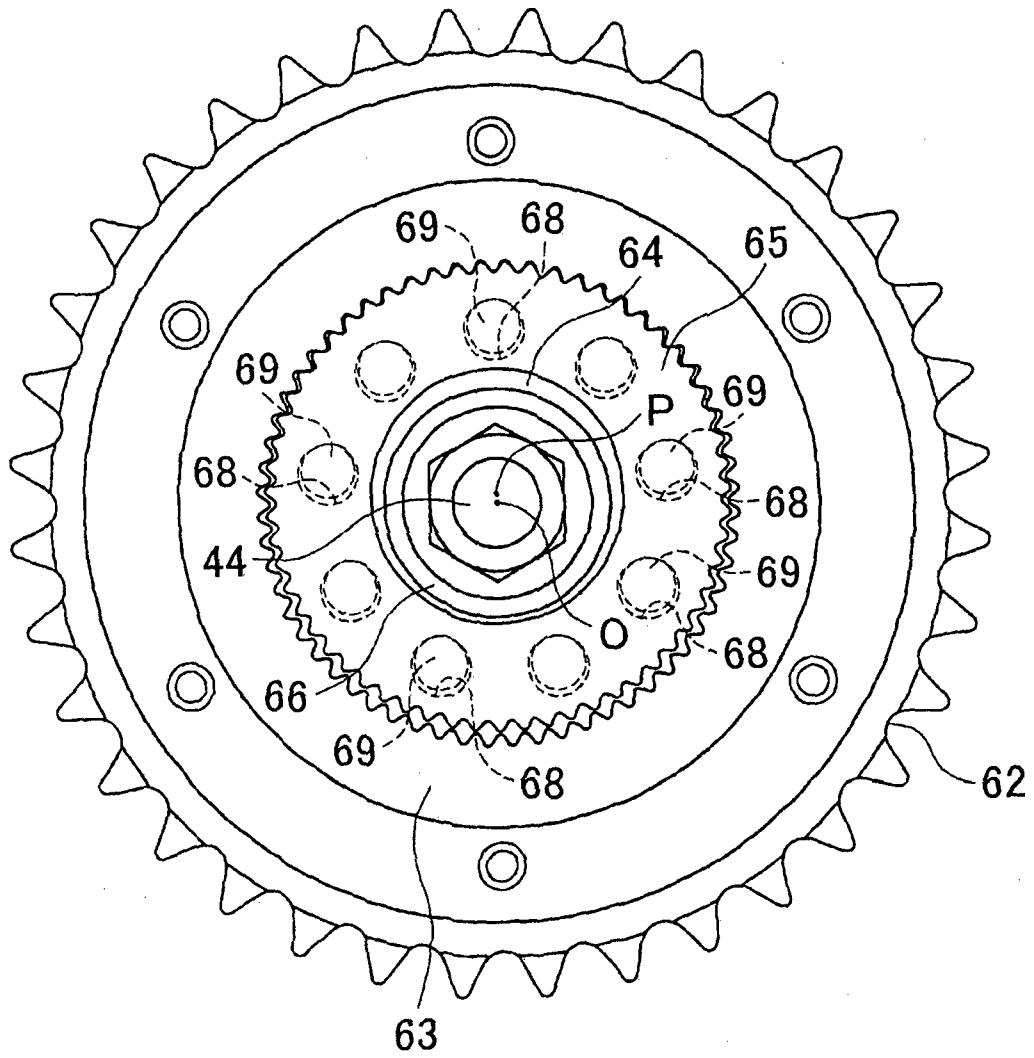


FIG. 4

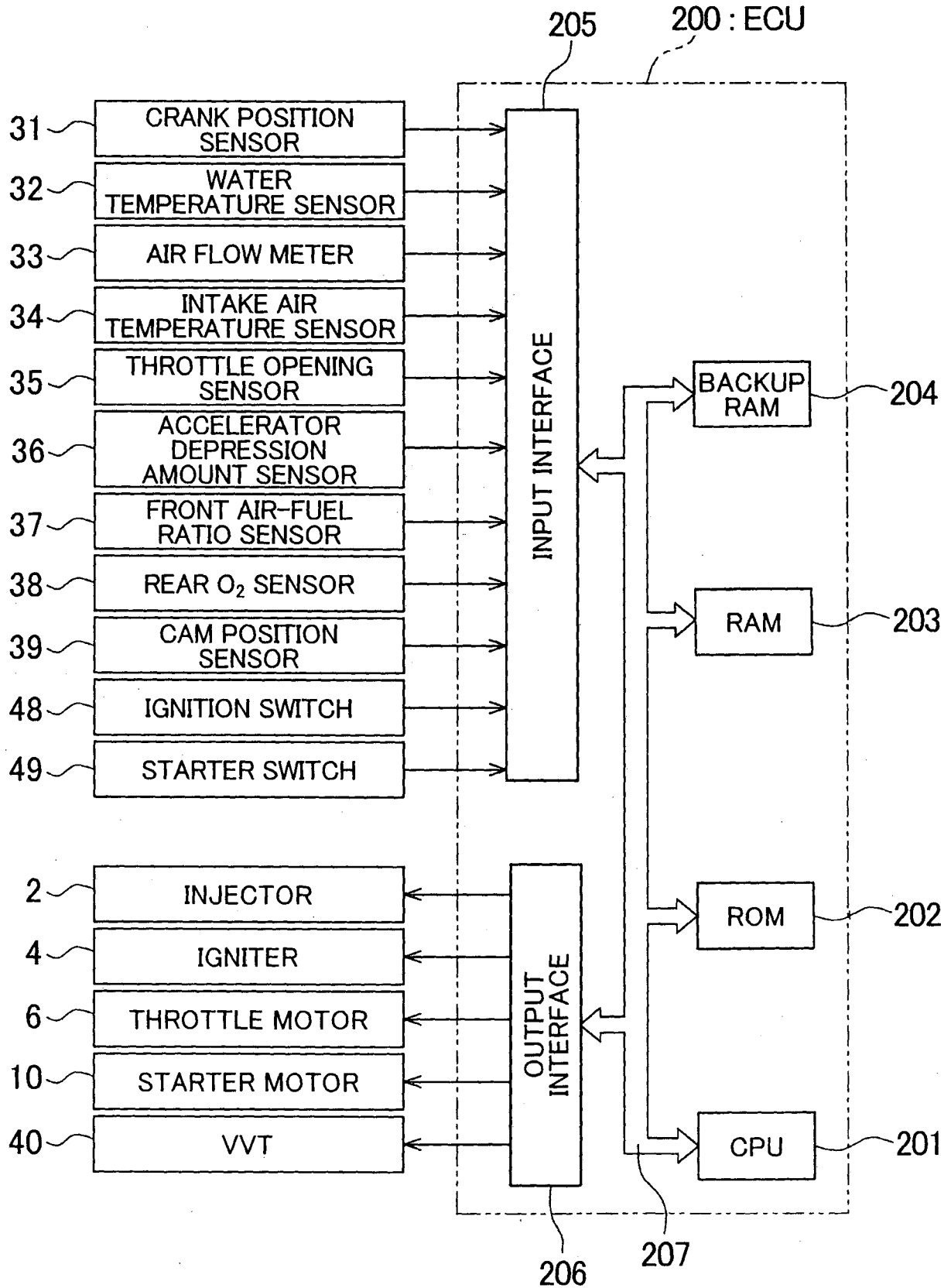


FIG. 5

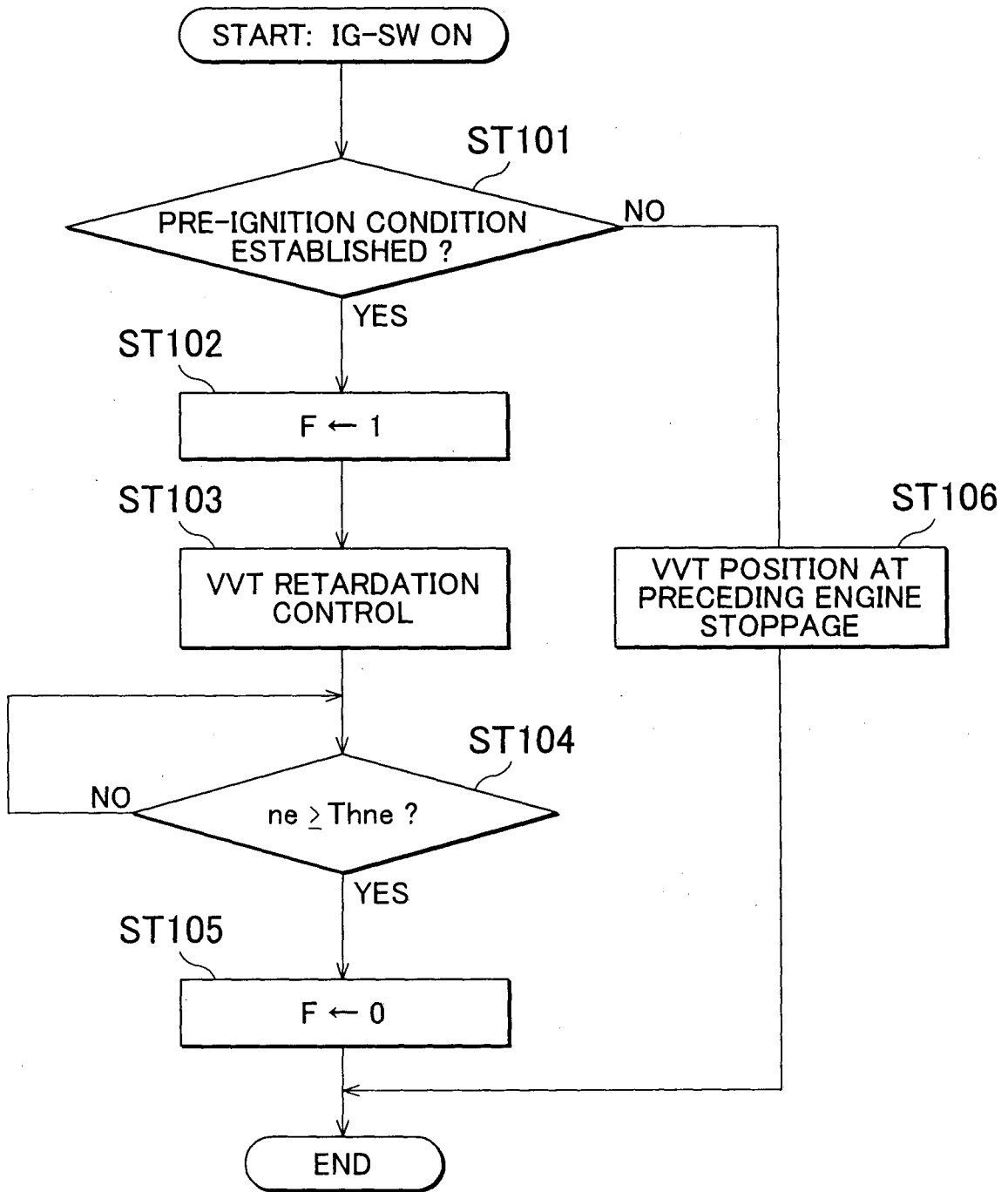


FIG. 6

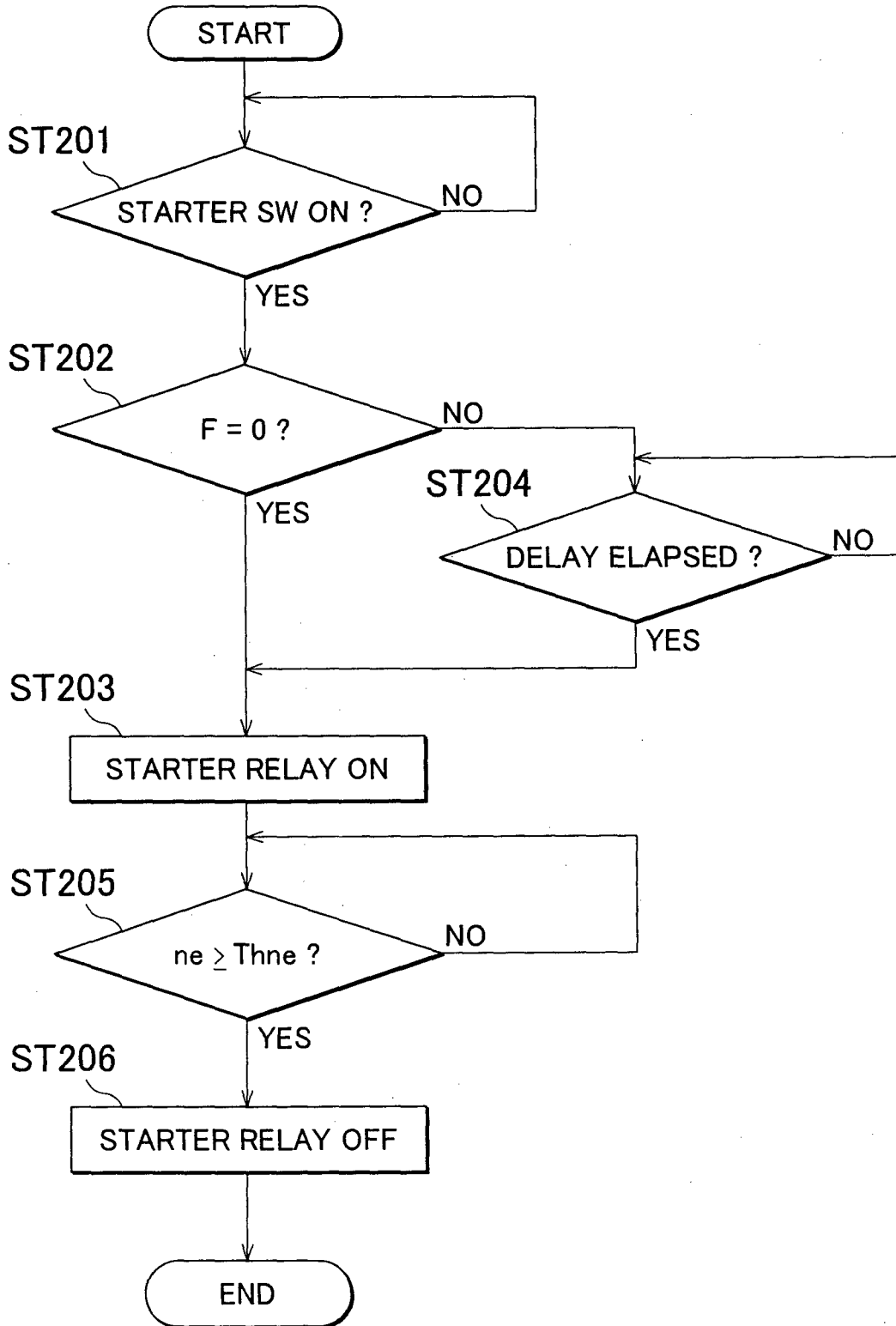


FIG. 7A

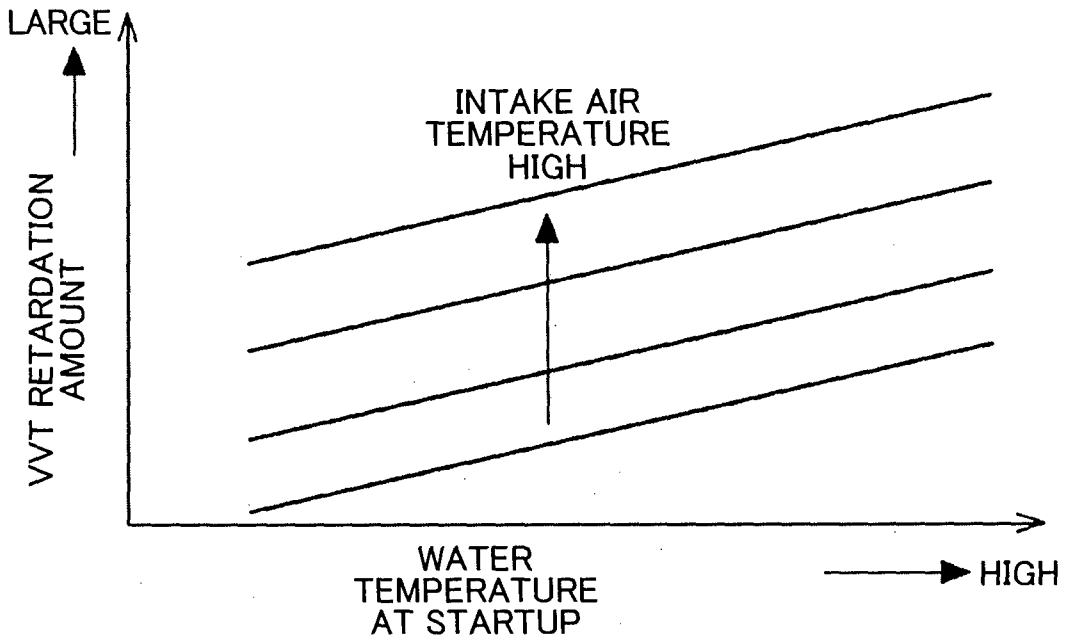


FIG. 7B

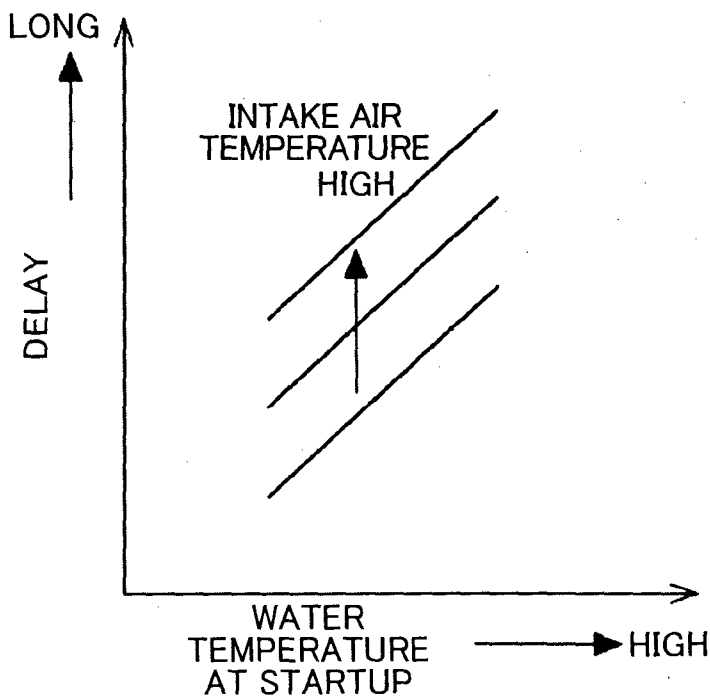
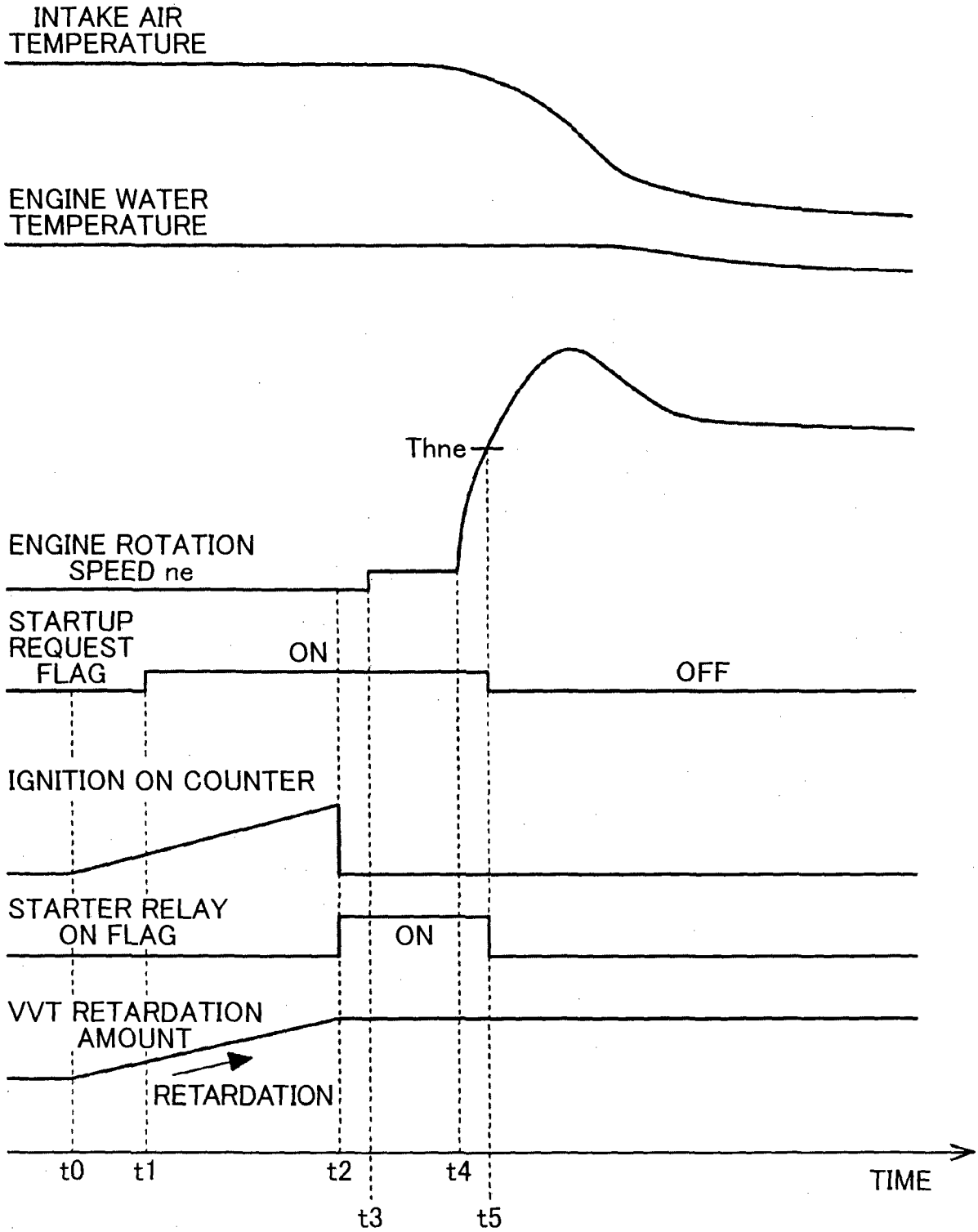


FIG. 8



INTERNATIONAL SEARCH REPORT

International application No PCT/IB2013/001649

A. CLASSIFICATION OF SUBJECT MATTER
 INV. F02D41/06
 ADD. F02D41/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 F02D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	WO 2007/015150 A1 (TOYOTA MOTOR CO LTD [JP]; MURASE NAO [JP]; ICHINOSE HIROKI [JP]; KATOU) 8 February 2007 (2007-02-08) paragraphs [0008], [0011]; figure 2 -----	1-8
A	US 2007/101961 A1 (TERAYA RYUTA [JP]) 10 May 2007 (2007-05-10) paragraphs [0013], [0015], [0018] -----	1-8
A	JP 2010 127178 A (NISSAN MOTOR) 10 June 2010 (2010-06-10) abstract -----	1-8

Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search

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European Patent Office, P.B. 5818 Patentlaan 2
 NL - 2280 HV Rijswijk
 Tel. (+31-70) 340-2040,
 Fax: (+31-70) 340-3016

Authorized officer

Jackson, Stephen

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/IB2013/001649

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