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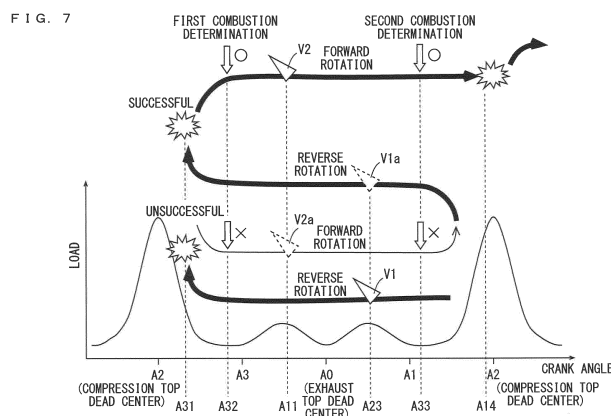
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(54) **ENGINE SYSTEM AND SADDLE-TYPE VEHICLE**

(57) During start-up of an engine, a reverse rotation start-up operation of rotating a crankshaft in a forward direction is performed after rotation of the crankshaft in a reverse direction. In the operation, a fuel injection device injects fuel such that a fuel-air mixture is introduced into a combustion chamber from an intake passage through an intake port, at at least one of a time when the crankshaft is rotated in the reverse direction and a crank angle is in a start-up intake range and a time when the crankshaft is rotated in the forward direction and the

crank angle is in the normal intake range, and an ignition device ignites the fuel-air mixture in the combustion chamber when the crank angle is in a start-up ignition range. An engine unit is controlled such that the operation is performed again, in a case in which a rotation state detected by a rotation state detector does not satisfy a predetermined start-up condition, when the crankshaft is rotated in the forward direction in the operation and before a piston reaches a first compression top dead center.



Description

[Technical Field]

[0001] The present invention relates to an engine system and a straddled vehicle that includes the engine system.

[Background Art]

[0002] In a straddled vehicle such as a motorcycle, a large torque is required in order for a crank angle to exceed an angle corresponding to a first compression top dead center when a start-up operation of an engine is performed. There is a technique for rotating a crankshaft in a reverse direction in order to increase startability of the engine.

[0003] In an engine system described in Patent Document 1, a fuel-air mixture is introduced into a combustion chamber while a crankshaft is rotated in a reverse direction during start-up of the engine. With the fuel-air mixture being compressed in the combustion chamber, an ignition operation by an ignition device is performed. Thus, the fuel-air mixture is combusted, so that rotation of the crankshaft is driven in a forward direction by energy generated by the combustion.

[0004] [Patent Document 1] JP 2014-77405 A

[Summary of Invention]

[Technical Problem]

[0005] The present inventors have discovered by performing various experiments and analysis that the fuel-air mixture sometimes cannot be appropriately combusted by the ignition operation during rotation of the crankshaft in the reverse direction. For example, at cold start-up, injected fuel is unlikely to be atomized (it is unlikely to become mist-like). Therefore, it was found that variations are likely to be generated in a fuel-air ratio of the fuel-air mixture, so that the fuel-air mixture is not easily combusted. In this case, the engine cannot be appropriately started.

[0006] An object of the present invention is to provide an engine system and a straddled vehicle in which an engine can be appropriately started.

[Solution to Problem]

[0007]

(1) An engine system according to one aspect of the present invention includes an engine unit that includes an engine and a rotation driver, and a controller that controls the engine unit, wherein the engine includes a fuel injection device arranged to inject fuel into an intake passage for leading air to a combustion chamber, an ignition device configured

to ignite a fuel-air mixture in the combustion chamber, a valve driver configured to drive each of an intake valve for opening and closing an intake port and an exhaust valve for opening and closing an exhaust port, and a rotation state detector that detects a rotation state of a crankshaft, the rotation driver is configured to drive rotation of the crankshaft in forward and reverse directions, the controller controls the engine unit such that a reverse rotation start-up operation of rotating the crankshaft in the forward direction is performed after rotation of the crankshaft in the reverse direction, during start-up of the engine, the rotation driver rotates the crankshaft in the reverse direction such that a crank angle exceeds a predetermined start-up intake range and reaches a predetermined start-up ignition range, in the reverse rotation start-up operation, the valve driver drives the intake valve such that the intake port is opened, when the crankshaft is rotated in the reverse direction and the crank angle is in the start-up intake range, and drives the intake valve such that the intake port is opened, when the crankshaft is rotated in the forward direction and the crank angle is in a predetermined normal intake range, in the reverse rotation start-up operation, the fuel injection device injects the fuel such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port, at at least one of a time when the crankshaft is rotated in the reverse direction and the crank angle is in the start-up intake range and a time when the crankshaft is rotated in the forward direction and the crank angle is in the normal intake range, in the reverse rotation start-up operation, the ignition device ignites the fuel-air mixture in the combustion chamber when the crank angle is in the start-up ignition range, in the reverse rotation start-up operation, and the controller controls the engine unit such that the reverse rotation start-up operation is performed again, in a case in which a rotation state detected by the rotation state detector does not satisfy a predetermined start-up condition when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and before a piston reaches a first compression top dead center.

[0008] In this engine system, the engine unit performs the reverse rotation start-up operation during the start-up of the engine. In the reverse rotation start-up operation, the crankshaft is rotated in the forward direction after being rotated in the reverse direction. At at least one of the time when the crankshaft is rotated in the reverse direction and the crank angle is in the start-up intake range and the time when the crankshaft is rotated in the forward direction and the crank angle is in the normal intake range, the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port. Further, when the crank angle is in the

start-up ignition range, the fuel-air mixture in the combustion chamber is ignited by the ignition device.

[0009] In this case, when concentration of the fuel in the fuel-air mixture is high, the fuel-air mixture is appropriately combusted, so that the rotation of the crankshaft is driven in the forward direction by the energy generated by the combustion. Therefore, the rotation state of the crankshaft satisfies the start-up condition. On the other hand, when the concentration of the fuel in the fuel-air mixture is low, the fuel-air mixture is not appropriately combusted, so that the rotation state of the crankshaft does not satisfy the start-up condition.

[0010] When the rotation state of the crankshaft does not satisfy the start-up state, the reverse rotation start-up operation is performed again. Thus, the fuel-air mixture is introduced into the combustion chamber again, and the concentration of the fuel in the fuel-air mixture is increased. The reverse rotation start-up operation is repeated until the rotation state of the crankshaft satisfies the start-up condition. Finally, the concentration of the fuel in the fuel-air mixture is sufficiently increased, and the fuel-air mixture is appropriately combusted. Thus, the crankshaft is rotated such that the crank angle exceeds an angle corresponding to the first compression top dead center. As a result, the engine is appropriately started.

(2) The controller may control the engine unit such that the crankshaft is continuously rotated in the forward direction by combustion of the fuel-air mixture, in a case in which the rotation state detected by the rotation state detector satisfies the start-up condition when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and before the piston reaches the first compression top dead center.

[0011] When the rotation state of the crankshaft satisfies the start-up condition, the combustion of the fuel-air mixture in the reverse rotation start-up operation is appropriately performed, so that the crank angle exceeds the angle corresponding to the first compression top dead center. In that case, without a repetition of the reverse rotation start-up operation, the crankshaft is continuously rotated in the forward direction by the combustion of the fuel-air mixture, whereby the engine unit can be shifted to the normal operation.

(3) The start-up condition may be that a rotation speed of the crankshaft is higher than a predetermined threshold value. In this case, it can be accurately determined whether the fuel-air mixture is appropriately combusted.

(4) The start-up condition may be that a rate of change of a rotation speed of the crankshaft is larger than a predetermined threshold value. In this case, it can be accurately determined whether the fuel-air mixture is appropriately combusted.

(5) The controller may control the engine unit such

that the reverse rotation start-up operation is performed again, at a first point of time when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and at which the crank angle has passed through the normal intake range, in a case in which the rotation state detected by the rotation state detector does not satisfy the start-up condition.

[0012] In this case, determination whether the start-up condition is satisfied is performed at the first point of time after the crankshaft is rotated to a position near the crank angle corresponding to the compression top dead center. Therefore, it can be accurately determined whether the crank angle exceeds the angle corresponding to the first compression top dead center.

(6) The fuel injection device may inject a first amount of fuel such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port when the crank angle is in the normal intake range, at a second point of time when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and before the crank angle reaches the normal intake range, in a case in which the rotation state detected by the rotation state detector does not satisfy a predetermined start-up preparation condition, and may inject a second amount of fuel different from the first amount such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port when the crank angle is in the normal intake range, in a case in which the rotation state detected by the rotation state detector satisfies the start-up preparation condition at the second point of time.

[0013] In this case, when the start-up preparation condition is satisfied at the second point of time, the first amount of fuel is injected in preparation for a normal combustion stroke after the crank angle exceeds the angle corresponding to the compression top dead center, and the fuel-air mixture is introduced into the combustion chamber in the normal intake range. On the other hand, when the start-up preparation condition is not satisfied at the second point of time, the second amount of fuel is injected in preparation for the next reverse rotation start-up operation, and the fuel-air mixture is introduced into the combustion chamber in the normal intake range. In this manner, respective suitable amounts of fuel are injected in preparation for the normal combustion stroke and the next reverse rotation start-up operation.

[0014] Further, even in a case in which the start-up preparation condition is satisfied at the second point of time, when the start-up condition is not satisfied at the first point of time, the reverse rotation start-up operation is performed again. In this manner, the determination based on the rotation state of the crankshaft is gradually

performed, whereby the start-up of the engine can be appropriately performed.

(7) The fuel injection device may inject a first amount of fuel such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port when the crank angle is in the normal intake range, at a second point of time when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and before the crank angle reaches the normal intake range, in a case in which the rotation state detected by the rotation state detector does not satisfy the start-up condition, and may injects a second amount of fuel different from the first amount such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port when the crank angle is in the normal intake range, in a case in which the rotation state detected by the rotation state detector satisfies the start-up condition at the second point of time.

[0015] In this case, when the start-up condition is satisfied at the second point of time, the first amount of fuel is injected in preparation for the normal combustion stroke after the crank angle exceeds the angle corresponding to the compression top dead center, and the fuel-air mixture is introduced into the combustion chamber in the normal intake range. On the other hand, when the start-up condition is not satisfied at the second point of time, the second amount of fuel is injected in preparation for the next reverse rotation start-up operation, and the fuel-air mixture is introduced into the combustion chamber in the normal intake range. In this manner, because the amount of fuel to be injected varies depending on whether the start-up condition is satisfied, the fuel-air mixture having the respective suitable concentration for the normal combustion stroke and the next reverse rotation start-up operation can be introduced into the combustion chamber.

(8) The fuel injection device may inject a third amount of fuel such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port, when the crankshaft is rotated in the reverse direction and the crank angle is in the start-up intake range, in the first reverse rotation start-up operation during the start-up of the engine, and may inject a fourth amount of fuel different from the third amount such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port, when the crankshaft is rotated in the reverse direction and the crank angle is in the start-up intake range, in the second reverse rotation start-up operation during the start-up of the engine.

[0016] In this case, the amount of fuel introduced into

the combustion chamber in the second reverse rotation start-up operation is different from the amount of fuel introduced into the combustion chamber in the first reverse rotation start-up operation. Thus, the concentration of the fuel in the fuel-air mixture can be gradually increased while the fuel is prevented from being wastefully consumed.

(9) The valve driver may drive the exhaust valve such that the exhaust port is opened when the crank angle is in a normal exhaust range, when the crankshaft is rotated in the forward and reverse directions, and the normal exhaust range may include the start-up intake range.

[0017] In this case, after the engine is started, the exhaust port is opened when the crank angle is in the normal exhaust range. Further, the exhaust port is opened when the crankshaft is rotated in the reverse direction in the reverse rotation start-up operation and the crank angle is in the normal exhaust range. In this manner, the exhaust port is opened in the same range of the crank angle during the rotation of the crankshaft in the forward and reverse directions, whereby the configuration of the valve driver can be inhibited from being complicated.

[0018] On the other hand, the start-up intake range is included in the normal exhaust range, so that the intake port and the exhaust port are simultaneously opened during the rotation of the crankshaft in the reverse direction in the reverse rotation start-up operation. In this case, a flow velocity of gas from the intake passage towards the combustion chamber is reduced, so that the fuel is unlikely to be atomized, and the concentration of the fuel in the fuel-air mixture is unlikely to increase. Even in this case, the reverse rotation start-up operation is repeated, so that the concentration of the fuel in the fuel-air mixture is sufficiently increased and the fuel-air mixture is appropriately combusted. Thus, the engine can be appropriately started.

(10) A straddled vehicle according to another aspect of the present invention includes a main body having a drive wheel, and the above-mentioned engine system that generates motive power for rotating the drive wheel.

[0019] In this saddle-type vehicle, the above-mentioned engine system is used, so that the engine is appropriately started.

[Advantageous Effects of Invention]

[0020] The present invention enables the engine to be appropriately started.

[Brief Description of Drawings]

[0021]

[FIG. 1] FIG. 1 is a schematic side view showing the schematic configuration of a motorcycle according to one embodiment of the present invention.

[FIG. 2] FIG. 2 is a schematic diagram for explaining the configuration of an engine system.

[FIG. 3] FIG. 3 is a diagram for explaining a normal operation of an engine unit.

[FIG. 4] FIG. 4 is a diagram for explaining a reverse rotation start-up operation of the engine unit.

[FIG. 5] FIG. 5 is a diagram for explaining the reverse rotation start-up operation of the engine unit.

[FIG. 6] FIG. 6 is a schematic diagram for explaining a repetition of first and second combustion determination and the reverse rotation start-up operation.

[FIG. 7] FIG. 7 is a schematic diagram for explaining the repetition of the first and second combustion determination and the reverse rotation start-up operation.

[FIG. 8] FIG. 8 is a diagram for explaining effects of the repetition of the reverse rotation start-up operation.

[FIG. 9] FIG. 9 is a diagram for explaining the effects of the repetition of the reverse rotation start-up operation.

[FIG. 10] FIG. 10 is a flow chart of an engine start-up process.

[FIG. 11] FIG. 11 is a flow chart of the engine start-up process.

[FIG. 12] FIG. 12 is a flow chart of the engine start-up process.

[FIG. 13] FIG. 13 is a diagram for explaining other examples of an amount of injection of fuel.

[Description of Embodiments]

[0022] A motorcycle will be described below as one example of a straddled vehicle according to embodiments of the present invention with reference to drawings.

(1) Motorcycle

[0023] Fig. 1 is a schematic side view showing schematic configuration of the motorcycle according to one embodiment of the present invention. In the motorcycle 100 of Fig. 1, a front fork 2 is provided at the front of a vehicle body 1 to be swingable to the right and the left. A handle 4 is attached to the upper end of the front fork 2, and a front wheel 3 is attached to the lower end of the front fork 2 to be rotatable.

[0024] A seat 5 is provided at substantially the center of the upper portion of the vehicle body 1. An ECU (Engine Control Unit) 6 and an engine unit EU are provided below the seat 5. The engine unit EU includes a single-cylinder engine 10, for example. An engine system 200 is constituted by the ECU 6 and the engine unit EU. A rear wheel 7 is attached to the lower portion of the rear end of the vehicle body 1 to be rotatable. The rotation of

the rear wheel 7 is driven by the motive power generated by the engine 10.

(2) Engine System

[0025] Fig. 2 is a schematic diagram for explaining the configuration of the engine system 200. As shown in Fig. 2, the engine unit EU includes the engine 10 and an integrated starter generator 14. The engine 10 includes a piston 11, a connecting rod 12, a crankshaft 13, an intake valve 15, an exhaust valve 16, a valve driver 17, an ignition plug 18 and an injector 19.

[0026] The piston 11 is provided to be reciprocable in a cylinder 31 and connected to the crankshaft 13 via the connecting rod 12. The reciprocating motion of the piston 11 is transformed into the rotational motion of the crankshaft 13. The integrated starter generator 14 is provided at the crankshaft 13. The integrated starter generator 14 is a generator having the function of a starter motor, drives the rotation of the crankshaft 13 in forward and reverse directions and generates electric power by the rotation of the crankshaft 13. The forward direction is a rotation direction of the crankshaft 210 during a normal operation of the engine 10, and the reverse direction is the opposite direction to the forward direction. The integrated starter generator 14 directly transmits a torque to the crankshaft 13 without a reduction gear therebetween. The rotation of the crankshaft 13 in the forward direction (a forward rotation) is transmitted to the rear wheel 7, so that the rotation of the rear wheel 7 is driven.

[0027] A combustion chamber 31 a is formed on the piston 11. The combustion chamber 31 a communicates with an intake passage 22 through an intake port 21 and communicates with an exhaust passage 24 through an exhaust port 23. The intake valve 15 is provided to open and close the intake port 21, and the exhaust valve 16 is provided to open and close the exhaust port 23. The intake valve 15 and the exhaust valve 16 are driven by the valve driver 17. A throttle valve TV for adjusting a flow rate of air from the outside is provided in the intake passage 22. The ignition plug 18 is configured to ignite a fuel-air mixture in the combustion chamber 31 a. The injector 19 is configured to inject fuel into the intake passage 22.

[0028] The ECU 6 includes a CPU (Central Processing Unit) and a memory, for example. A microcomputer may be used instead of the CPU and the memory. A starter switch 41, an intake pressure sensor 42, a crank angle sensor 43 and a current sensor 44 are electrically connected to the ECU 6. The starter switch 41 is provided at the handle 4 of Fig. 1, for example, and is operated by a driver. The intake pressure sensor 42 detects pressure in the intake passage 22. The crank angle sensor 43 detects a rotation position of the crankshaft 13 (hereinafter referred to as a crank angle). The current sensor 44 detects a current that flows in the integrated starter generator 14 (hereinafter referred to as a motor current).

[0029] An operation of the starter switch 41 is supplied

to the ECU 6 as an operation signal, and the results of detection by the intake pressure sensor 42, the crank angle sensor 43 and the current sensor 44 are supplied to the ECU 6 as detection signals. The ECU 6 controls the integrated starter generator 14, the ignition plug 18 and the injector 19 based on the supplied operation signal and the detection signals.

(3) Operation of Engine

[0030] For example, the engine 10 is started when the starter switch 41 of Fig. 2 is turned on, and the engine 10 is stopped when a main switch (not shown) is turned off. Further, the engine 10 may be automatically stopped when a predetermined idle stop condition is satisfied, and the engine 10 may be automatically restarted when a predetermined idle stop release condition is satisfied. The idle stop condition includes a condition that relates to at least one of a throttle opening (a degree of opening of the throttle valve TV), a vehicle speed and a rotation speed of the engine 10, for example. The idle stop release condition is that the throttle opening is larger than 0 when an accelerator grip is operated, for example. Hereinafter, a state in which the engine 10 is automatically stopped when the idle stop condition is satisfied is referred to as an idle stop state.

[0031] The engine unit EU performs a reverse rotation start-up operation during start-up of the engine 10. Thereafter, when the crank angle exceeds an angle corresponding to a first compression top dead center, the engine unit EU performs the normal operation. Fig. 3 is a diagram for explaining the normal operation of the engine unit EU. Figs. 4 and 5 are diagrams for explaining the reverse rotation start-up operation of the engine unit EU.

[0032] In the following description, a top dead center through which the piston 11 passes at a time of shifting from a compression stroke to an expansion stroke is referred to as a compression top dead center, and a top dead center through which the piston 11 passes at a time of shifting from an exhaust stroke to an intake stroke is referred to as an exhaust top dead center. A bottom dead center through which the piston 11 passes at a time of shifting from the intake stroke to the compression stroke is referred to as an intake bottom dead center, and a bottom dead center through which the piston 11 passes at a time of shifting from the expansion stroke to the exhaust stroke is referred to as an expansion bottom dead center.

[0033] In Figs. 3 to 5, a rotation angle in a range of two rotations (720 degrees) of the crankshaft 13 is indicated by one circle. The two rotations of the crankshaft 13 is equivalent to one cycle of the engine 10. The crank angle sensor 43 of Fig. 2 detects the rotation position in a range of one rotation (360 degrees) of the crankshaft 13. The ECU 6 determines based on the pressure in the intake passage 22 detected by the intake pressure sensor 42 which one of the two rotations of the crankshaft 13 equivalent to the one cycle of the engine 10 the crank position

detected by the crank angle sensor 43 corresponds to. Thus, the ECU 6 can acquire the rotation position in the range of the two rotations (720 degrees) of the crankshaft 13.

[0034] In Figs. 3 to 5, an angle A0 is a crank angle when the piston 11 (Fig. 2) is positioned at the exhaust top dead center, an angle A2 is a crank angle when the piston 11 is positioned at the compression top dead center, an angle A1 is a crank angle when the piston 11 is positioned at the intake bottom dead center and an angle A3 is a crank angle when the piston 11 is positioned at the expansion bottom dead center. An arrow R1 indicates a direction in which the crank angle changes during the forward rotation of the crankshaft 13, and an arrow R2 indicates a direction in which the crank angle changes during the reverse rotation of the crankshaft 13. Arrows P1 to P4 indicate moving directions of the piston 11 during the forward rotation of the crankshaft 13, and arrows P5 to P8 indicate the moving directions of the piston 11 during the reverse rotation of the crankshaft 13.

(3-1) Normal Operation

[0035] The normal operation of the engine unit EU will be described with reference to Fig. 3. In the normal operation, the crankshaft 13 (Fig. 2) is rotated in the forward direction. Thus, the crank angle changes in the direction of the arrow R1. In this case, as indicated by the arrows P1 to P4, the piston 11 (Fig. 2) falls in a range from the angle A0 to the angle A1, the piston 11 rises in a range from the angle A1 to the angle A2, the piston 11 falls in a range from the angle A2 to the angle A3 and the piston 11 rises in a range from the angle A3 to the angle A0.

[0036] At an angle A11, the fuel is injected into the intake passage 22 (Fig. 2) by the injector 19 (Fig. 2). In the forward direction, the angle A11 is positioned at a further advanced angle than the angle A0. Then, in a range from an angle A12 to an angle A13, the intake port 21 (Fig. 2) is opened by the intake valve 15 (Fig. 2). In the forward direction, the angle A12 is positioned at a further retarded angle than the angle A11 and a further advanced angle than the angle A0, and the angle A13 is positioned at a further retarded angle than the angle A1. The range from the angle A12 to the angle A13 is an example of a normal intake range. Thus, the fuel-air mixture including air and the fuel is introduced into the combustion chamber 31 a (Fig. 2) through the intake port 21.

[0037] Next, at an angle A14, the fuel-air mixture in the combustion chamber 31 a (Fig. 2) is ignited by the ignition plug 18 (Fig. 2). In the forward direction, the angle A14 is positioned at a further advanced angle than the angle A2. The fuel-air mixture is ignited, so that an explosion (combustion of the fuel-air mixture) occurs in the combustion chamber 31 a. Energy generated by the combustion of the fuel-air mixture is turned into the driving force for the piston 11. Thereafter, in a range from an angle A15 to an angle A16, the exhaust port 23 (Fig. 2) is opened by the exhaust valve 16 (Fig. 2). In the forward

direction, the angle A15 is positioned at a further advanced angle than the angle A3, and the angle A16 is positioned at a further retarded angle than the angle A0. The range from the angle A15 to the angle A16 is an example of a normal exhaust range. Thus, a combusted gas is exhausted from the combustion chamber 31 a through the exhaust port 23.

(3-2) Reverse Rotation Start-up Operation

[0038] The reverse rotation start-up operation of the engine unit EU will be described with reference to Figs. 4 and 5. In the reverse rotation start-up operation, the crankshaft 13 is rotated in the forward direction after being rotated in the reverse direction. In this case, the fuel-air mixture is compressed in the combustion chamber 31 a by the reverse rotation of the crankshaft 13, the compressed fuel-air mixture is ignited and the crankshaft 13 is rotated in the forward direction. When the fuel-air mixture is appropriately combusted, a torque of the crankshaft 13 in the forward direction is sufficiently increased by the energy generated by the combustion. Thus, the crank angle exceeds the angle A2 corresponding to the first compression top dead center. On the other hand, when the fuel-air mixture is not appropriately combusted, the torque of the crankshaft 13 in the forward direction is not sufficiently increased. Therefore, the crank angle does not exceed the angle A2 corresponding to the first compression top dead center. In the present embodiment, the reverse rotation start-up operation is repeated until the fuel-air mixture is successfully combusted. Successful combustion of the fuel-air mixture means that the fuel-air mixture is appropriately combusted by ignition. The reverse rotation start-up operation will be specifically explained below.

[0039] In the present example, the crank angle is adjusted in a predetermined reverse rotation starting range before the first reverse rotation start-up operation is performed. The reverse rotation starting range is in a range from the angle A0 to the angle A2, for example, and is preferably in a range from the angle A13 to the angle A2, in the forward direction. In Fig. 4, the reverse rotation starting range is in a range from an angle A30a to an angle A30b. Angular ranges A30a, A30b are in a range from the angular range A13 to the angle A2.

[0040] As shown in Fig. 4, the crankshaft 13 is rotated in the reverse direction from a state in which the crank angle is in the reverse rotation starting range. Thus, the crank angle changes in a direction of the arrow R2. In this case, as indicated by the arrows P5 to P8, the piston 11 falls in a range from the angle A2 to the angle A1, the piston 11 rises in a range from the angle A1 to the angle A0, the piston 11 falls in a range from the angle A0 to the angle A3, and the piston 11 rises in a range from the angle A3 to the angle A2. A moving direction of the piston 11 during the reverse rotation of the crankshaft 13 is opposite to the moving direction of the piston 11 during the forward rotation of the crankshaft 13.

[0041] At an angle A23, the fuel is injected into the intake passage 22 (Fig. 2) by the injector 19 (Fig. 2). In the reverse direction, the angle A23 is positioned at a further advanced angle than the angle A0. As described below, in the present example, an amount of injection of the fuel at the angle A23 in the first reverse rotation start-up operation is different from an amount of injection of the fuel at the angle A23 in the second reverse rotation start-up operation and the subsequent reverse rotation start-up operations.

[0042] In a range from the angle A13 to the angle A12, and a range from an angle A21 to an angle A22, the intake port 21 (Fig. 2) is opened by the intake valve 15 (Fig. 2). The range from the angle A21 to the angle A22 is an example of a start-up intake range. In the reverse direction, the angles A21, A22 are in the range from the angle A0 to the angle A3. In this case, because the piston 11 rises in the range from the angle A1 to the angle A0, air and the fuel are hardly introduced into the combustion chamber 31a in the range from the angle A13 to the angle A12. Thereafter, because the piston 11 falls in the range from the angle A0 to the A3, the fuel-air mixture including air and the fuel is introduced into the combustion chamber 31 a from the intake passage 22 through the intake port 21 in the range from the angle A21 to the angle A22.

[0043] Further, in a range from the angle A16 to the angle A15, the exhaust port 23 (Fig. 2) is opened by the exhaust valve 16 (Fig. 2). In this case, because the piston 11 falls in the range from the angle A0 to the angle A3, gas is led to the combustion chamber 31a from the exhaust passage 24. As described below, in the second reverse rotation start-up operation and the subsequent reverse rotation start-up operations, an uncombusted fuel-air mixture, which remains in the exhaust passage 24, is led to the combustion chamber 31 a.

[0044] Energization to an ignition coil connected to the ignition plug 18 (Fig. 2) is started at an angle 31a, and the fuel-air mixture in the combustion chamber 31a is ignited by the ignition plug 18 (Fig. 2) at an angle A31. In the reverse direction, the angle A31a is positioned at a further advanced angle than the angle A31, and the angle A31 is positioned at a further advanced angle than the angle A2. The angle A31 is an example of a start-up ignition range.

[0045] The fuel-air mixture is ignited at the angle A31, and the crankshaft 13 is rotated in the forward direction. Thus, as shown in Fig. 5, the crank angle changes in the direction of the arrow R1. Similarly to the normal operation of Fig. 3, the exhaust port 23 (Fig. 2) is opened by the exhaust valve 16 (Fig. 2) in the range from the angle A15 to the angle A16. In a case in which the fuel-air mixture is successfully combusted right before, the combusted gas is led to the exhaust passage 24 from the combustion chamber 31 a. On the other hand, in a case in which the fuel-air mixture is not successfully combusted, the uncombusted fuel-air mixture is led to the exhaust passage 24 from the combustion chamber 31 a.

[0046] The fuel is injected into the intake passage 22

(Fig. 2) by the injector 19 (Fig. 2) at the angle A11, and the intake port 21 (Fig. 2) is opened by the intake valve 15 (Fig. 2) in the range from the angle A12 to the angle A13. Therefore, the fuel-air mixture is introduced into the combustion chamber 31a from the intake passage 22. As described below, in the present example, an amount of injection of the fuel at the angle A11 in the reverse rotation start-up operation varies depending on a result of determination whether the fuel-air mixture is successfully combusted.

[0047] In the reverse rotation start-up operation, the combustion determination whether the fuel-air mixture is successfully combusted is performed after the ignition at the angle A31 and before the crank angle reaches the angle A2 corresponding to the first compression top dead center. In the present example, first combustion determination is performed at an angle A32, and second combustion determination is performed at an angle A33. A point of time at which the crank angle is at the angle A33 is an example of a first point of time, and a point of time at which the crank angle is at the angle A32 is an example of a second point of time. In the forward direction, the angle A32 is positioned at a further advanced angle than the angle A15, and the angle A33 is positioned at a further retarded angle than the angle A13.

[0048] In the first combustion determination, it is determined based on a result of detection of the crank angle sensor 43 (Fig. 2) whether a rotation state of the crankshaft 13 satisfies a predetermined first condition. Similarly, in the second combustion determination, it is determined based on a result of detection of the crank angle sensor 43 (Fig. 2) whether the rotation state of the crankshaft 13 satisfies a predetermined second condition.

[0049] The rotation state of the crankshaft 13 is a rotation speed of the crankshaft 13, or a rate of change of the rotation speed (rotation acceleration) of the crankshaft 13, for example. The first and second conditions are that the rotation speed or the rotation acceleration of the crankshaft 13 is higher than each of predetermined threshold values, for example. In this case, the threshold value of the first condition and the threshold value of the second condition are different from each other. Thus, it is possible to accurately determine whether the fuel-air mixture is appropriately combusted.

[0050] It is determined based on results of the first and second combustion determination whether the fuel-air mixture is successfully combusted. In the present example, in a case in which the first condition is satisfied in the first combustion determination and the second condition is satisfied in the second combustion determination, it is determined that the fuel-air mixture is successfully combusted. It is determined that the fuel-air mixture is not successfully combusted in other cases.

[0051] Determination whether the fuel-air mixture is successfully combusted is not limited to the above-mentioned example. When at least one of the first condition in the first combustion determination and the second condition in the second combustion determination is satis-

fied, it may be determined that the fuel-air mixture is successfully combusted. For example, the second combustion determination is performed at a point of time at which the crank angle is close to the angle A2 corresponding to the compression top dead center. Therefore, when the second condition is satisfied in the second combustion determination, it is likely that the fuel-air mixture is successfully combusted. Therefore, even when the first condition is not satisfied in the first combustion determination, in a case in which the second condition is satisfied in the second combustion determination, it may be determined that the fuel-air mixture is successfully combusted. Further, even when the first condition is satisfied in the first combustion determination, in a case in which the second condition is not satisfied in the second combustion determination, it may be determined that the fuel-air mixture is not successfully combusted.

[0052] Alternatively, the determination whether the fuel-air mixture is successfully combusted may be performed in consideration of both of the rotation speeds of the crankshaft 13 at a time of the first combustion determination and the rotation speed of the crankshaft 13 at a time of the second combustion determination. For example, when an average value of the rotation speed of the crankshaft 13 at the time of the first combustion determination and the rotation speed of the crankshaft 13 at the time of the second combustion determination is higher than a predetermined value, it may be determined that the fuel-air mixture is successfully combusted. Similarly, the determination whether the fuel-air mixture is successfully combusted may be performed in consideration of both of the rotation acceleration of the crankshaft 13 at the time of the first combustion determination and the rotation acceleration of the crankshaft 13 at the time of the second combustion determination.

[0053] When the fuel-air mixture is successfully combusted, the engine unit EU is shifted to the normal operation of Fig. 3. On the other hand, when the fuel-air mixture is not successfully combusted, the reverse rotation start-up operation is repeated until the fuel-air mixture is successfully combusted.

[0054] Figs. 6 and 7 are schematic diagrams for explaining the first and second combustion determination and the repetition of a reverse rotation start-up operation. In Figs. 6 and 7, a relationship between the crank angle and a rotational load of the crankshaft 13 is shown as a reference. The crank angle is indicated by an abscissa, and the rotational load of the crankshaft 13 is indicated by an ordinate.

[0055] As shown in Figs. 6 and 7, the rotational load of the crankshaft 13 is the largest at the angle A2 corresponding to the compression top dead center. Further, in the examples of Figs. 6 and 7, a load for driving the intake valve 15 is applied to the crankshaft 13 at an intermediate position between the angle A1 and the angle A0, so that the rotational load of the crankshaft 13 is increased. Further, a load for driving the exhaust valve 16 is applied to the crankshaft 13 at an intermediate po-

sition between the angle A0 and the angle A3, so that the rotational load of the crankshaft 13 is increased.

[0056] In the example of Fig. 6, the fuel is injected at the angle A23 while the crankshaft 13 is rotated in the reverse direction. In the first reverse rotation start-up operation, the amount of injection of the fuel at the angle A23 is set to a V1. The amount V1 is an example of a third amount.

[0057] At the angle A31, the fuel-air mixture is successfully combusted. Thus, the fuel-air mixture is appropriately combusted, so that the crankshaft 13 is driven in the forward direction. Therefore, the first condition is satisfied in the first combustion determination at the angle A32. When the first condition is satisfied in the first combustion determination, the amount of injection of the fuel at the angle A11 is set to a V2. The amount V2 is an amount prepared for the ignition at the angle A14 in the normal operation. The amount V2 is an example of a second amount.

[0058] Thereafter, the second condition is satisfied in the second combustion determination at the angle A33. In this manner, when the first and second conditions are respectively satisfied in the first and second combustion determination, the engine unit EU is shifted to the normal operation without the repetition of the reverse rotation start-up operation. Specifically, the crank angle exceeds the angle A2 corresponding to the compression top dead center, and the fuel-air mixture is ignited at the angle A14.

[0059] As for the example of Fig. 7, differences from the example of Fig. 6 will be described. In the example of Fig. 7, the fuel-air mixture is not successfully combusted by the ignition at the angle A31 in the first reverse rotation start-up operation. Therefore, the first condition is not satisfied in the first combustion determination at the angle A32. When the first condition is not satisfied in the first combustion determination, the amount of injection of the fuel is set to a V2a at the angle A11. The amount V2a is an amount prepared for the ignition in the next reverse rotation start-up operation and is smaller than the amount V2 of the example of Fig. 6. The amount V2a is an example of a first amount. In this case, the fuel is prevented from being wastefully consumed.

[0060] Thereafter, the second condition is not satisfied in the second combustion determination at the angle A33 either. In this manner, when the first and second conditions are not respectively satisfied in the first and second combustion determination, the rotation direction of the crankshaft 13 is switched to the reverse direction again, and the reverse rotation start-up operation is repeated.

[0061] In the second and the subsequent reverse rotation start-up operations, an amount of injection of the fuel at the angle A23 during the reverse rotation is set to a V1a. The amount V1a is an example of a fourth amount, and smaller than the amount V1 in the first reverse rotation start-up operation. In this case, the fuel is prevented from being wastefully consumed.

[0062] The fuel-air mixture is successfully combusted by the ignition at the angle A31 in the second reverse

rotation start-up operation. Thus, the fuel-air mixture is appropriately combusted, and the crankshaft 13 is driven in the forward direction. Therefore, the first condition is satisfied in the first combustion determination at the angle A32. In this case, an amount of injection of the fuel at the angle A11 is set to the V2. Thereafter, the second condition is satisfied in the second combustion determination at the angle A33. Thus, the engine unit EU is shifted to the normal operation without the repetition of the reverse rotation start-up operation.

[0063] As described in the example of Fig. 7, when the reverse rotation start-up operation is repeated, it is more likely that the fuel-air mixture is successfully combusted. Reasons will be described below. Figs. 8 and 9 are diagrams for explaining effects of the repetition of the reverse rotation start-up operation.

[0064] First, the operation in the first reverse rotation start-up operation will be described. As shown in Fig. 8(a), the fuel is injected into the intake passage 22 at the angle A23 while the crankshaft 13 is rotated in the reverse direction. As described above, the piston 11 is raised at the angle A23, so that the fuel is not introduced into the combustion chamber 31 a.

[0065] The injected fuel vaporizes in the intake passage 22, so that the fuel-air mixture is produced. In this case, when the temperature of the engine 10 is high, the fuel is likely to vaporize, so that the fuel-air mixture is likely to be produced. On the other hand, when the temperature of the engine 10 is low, the fuel is unlikely to vaporize, so that the fuel-air mixture is unlikely to be produced. Normally, the temperature of the engine 10 is high right after the engine 10 is stopped, and in a case in which a long period of time has elapsed after the engine 10 is stopped, the temperature of the engine 10 is decreased. Therefore, during re-start from the idle stop state, for example, the fuel is likely to vaporize, so that the fuel-air mixture is likely to be produced. On the other hand, during cold start-up, the fuel is unlikely to vaporize, so that the fuel-air mixture is unlikely to be produced.

[0066] Subsequently, as shown in Fig. 8(b), the fuel-air mixture is introduced into the combustion chamber 31 a from the intake passage 22 through the intake port 21 in the range from the angle A21 to the angle A22. In this period, the exhaust port 23 is opened, so that gas is introduced into the combustion chamber 31 a from the exhaust port 23. In this manner, when the intake port 21 and the exhaust port 23 are both opened, a flow velocity of gas from the intake passage 22 to the combustion chamber 31 a is low as compared to a case in which only the intake port 21 is opened. Thus, part of the fuel-air mixture in the intake passage 22 may remain in the intake passage 22 without being introduced into the combustion chamber 31 a.

[0067] Further, part of the fuel that has not vaporized in the intake passage 22 is moved to the combustion chamber 31 a by a flow of gas passing through the intake passage 22. In this case, when a flow velocity of the gas passing through the intake passage 22 is high, the fuel

is atomized (a reduction in a particle diameter), so that fuel-air mixture concentration is increased. The fuel-air mixture concentration means concentration of the fuel in the fuel-air mixture. However, as described above, the flow velocity of the gas passing through the intake passage 22 is low in the range from the angle A21 to the angle A22, so that the fuel is unlikely to be atomized.

[0068] In this manner, in the reverse rotation start-up operation, the fuel-air mixture is unlikely to be sufficiently introduced into the combustion chamber 31 a from the intake passage 22, and unvaporized fuel is unlikely to be atomized. Further, during the cold start-up, the fuel-air mixture is unlikely to be produced in the intake passage 22. Therefore, at the first reverse rotation start-up operation, the fuel-air mixture concentration in the combustion chamber 31 a is likely to be lower than an appropriate value. As a result, as shown in Fig. 8(c), it is likely that the fuel-air mixture is not successfully combusted by the ignition at the angle A31.

[0069] When the fuel-air mixture is not successfully combusted, as shown in Fig. 8(d), an uncombusted fuel-air mixture in the combustion chamber 31 a is led to the exhaust passage 24 through the exhaust port 23 in the range from the angle A15 to the angle A16 while the crankshaft 13 is rotated in the forward direction. In a period in which the reverse rotation start-up operation is performed, a flow velocity of the gas passing through the exhaust passage 24 is low. Therefore, a large part of the fuel-air mixture led to the exhaust passage 24 remains in the exhaust passage 24 without being exhausted to the outside. Further, the unvaporized fuel is moved to the exhaust passage 24 from the combustion chamber 31 a with the fuel-air mixture. Further, at the angle A11 in the range from the angle A15 to the angle A16, the fuel is injected into the intake passage 22.

[0070] Subsequently, as shown in Fig. 9(a), the fuel-air mixture is introduced into the combustion chamber 31 a through the intake port 21 in the range from the angle A12 to the angle A13. In this case, only the intake port 21 is opened except for a range from the angle A12 to the angle A16 (Fig. 5) (overlap). Therefore, a flow velocity of the gas from the intake passage 22 to the combustion chamber 31 a is relatively fast. Thus, the fuel-air mixture in the intake passage 22 is efficiently introduced into the combustion chamber 31a, and the fuel is likely to be atomized by the flow of gas passing through the intake passage 22. Thereafter, the rotation direction of the crankshaft 13 is switched to the reverse direction.

[0071] The second reverse rotation start-up operation will be described. As shown in Fig. 9(b), the fuel is injected into the intake passage 22 at the angle A23 while the crankshaft 13 is rotated in the reverse direction. Then, as shown in Fig. 9(c), the fuel-air mixture is introduced into the combustion chamber 31 a from the intake passage 22 through the intake port 21 in the range from the angle A21 to the angle A22. In this case, the fuel-air mixture, which remains in the exhaust passage 24, is introduced into the combustion chamber 31 a through the

exhaust port 23.

[0072] Thus, the fuel-air mixture in the combustion chamber 31 a includes each of the fuel injected at the angle A23 in the first reverse rotation start-up operation (Fig. 8(a)), the fuel injected at the angle A11 in the first reverse rotation start-up operation (Fig. 8(d)), and the fuel injected at the angle A23 in the second reverse rotation start-up operation (Fig. 9(b)). In this manner, the reverse rotation start-up operation is repeated, so that the fuel in the combustion chamber 31 a is accumulated.

[0073] Further, the unvaporized fuel is introduced into the combustion chamber 31 a from the intake passage 22 and the exhaust passage 24. The unvaporized fuel flows in the intake passage 22, the combustion chamber 31 a and the exhaust passage 24, thereby being gradually atomized. Therefore, the reverse rotation start-up operation is repeated, so that atomization of the fuel is progressed. Further, the temperature of the engine 10 is increased by the repetition of the reverse rotation start-up operation, so that the fuel is likely to vaporize.

[0074] Accordingly, the reverse rotation start-up operation is repeated, so that the fuel-air mixture concentration in the combustion chamber 31 a is increased. As a result, as shown in Fig. 9(d), the fuel-air mixture is successfully combusted by the ignition at the angle A31.

(4) Engine Start-up Process

[0075] The ECU 6 performs the engine start-up process based on a control program stored in advance in the memory. Figs. 10 to 12 are flow charts of the engine start-up process. The engine start-up process is performed when a main switch (not shown) is turned on, or when the engine 10 is shifted to the idle stop state, for example.

[0076] As shown in Fig. 10, the ECU 6 determines whether a predetermined starting condition is satisfied (step S1). When the engine unit EU is not in the idle stop state, the starting condition is that the starter switch 41 (Fig. 2) is turned on, for example. When the engine unit EU is in the idle stop state, the starting condition is that an idle stop release condition is satisfied.

[0077] When the starting condition is not satisfied, the ECU 6 repeats the process of step S1 until the starting condition is satisfied. When the starting condition is satisfied, the ECU 6 controls the integrated starter generator 14 such that the crankshaft 13 is rotated in the reverse direction (step S2).

[0078] At the start of the engine start-up process, when the crank angle is not in the reverse rotation starting range (the range from the angle A30a to A30b), the crank angle may be adjusted in the reverse rotation starting range before the crankshaft 13 is rotated in the reverse direction as described above.

[0079] Next, the ECU 6 determines whether a reverse rotation fuel injection condition is satisfied (step S3). In the present example, the reverse rotation fuel injection condition is that the crank angle acquired from results of detection of the intake pressure sensor 42 (Fig. 2) and

the crank angle sensor 43 (Fig. 2) reaches the angle A23 of Fig. 4. When the reverse rotation fuel injection condition is not satisfied, the ECU 6 repeats the process of step S3. When the reverse rotation fuel injection condition is satisfied, the ECU 6 controls the injector 19 (Fig. 2) such that the fuel is injected into the intake passage 22 (Fig. 2) (step S4). In this case, the amount of injection of the fuel is set to the V1.

[0080] Next, the ECU 6 determines whether a reverse rotation energization starting condition is satisfied (step S5). In the present example, the reverse rotation energization starting condition is that the crank angle acquired from the results of detection of the intake pressure sensor 42 (Fig. 2) and the crank angle sensor 43 (Fig. 2) reaches the angle A31a of Fig. 4. When the reverse rotation energization starting condition is not satisfied, the ECU 6 repeats the process of step S5. When the reverse rotation energization starting condition is satisfied, the ECU 6 starts the energization to the ignition coil (step S6).

[0081] Next, as shown in Fig. 11, the ECU 6 determines whether a reverse rotation ignition condition is satisfied (step S7). In the present example, the reverse rotation ignition condition is that a motor current acquired from a result of detection of the current sensor 44 (Fig. 2) reaches a predetermined threshold value. The motor current is increased as the crank angle becomes closer to the angle A2 of Fig. 4. In the present example, when the crank angle reaches the angle A31 of Fig. 4, the motor current reaches the threshold value.

[0082] When the reverse rotation ignition condition is not satisfied, the ECU 6 repeats the process of step S7. When the reverse rotation ignition condition is satisfied, the ECU 6 controls the integrated starter generator 14 such that the crankshaft 13 is rotated in the forward direction (step S8), and controls the ignition plug 18 such that the fuel-air mixture in the combustion chamber 31 a is ignited (step S9).

[0083] Next, the ECU 6 determines whether a first combustion determination condition is satisfied (step S10). In the present example, the first combustion determination condition is that the crank angle acquired from the results of detection of the intake pressure sensor 42 (Fig. 2) and the crank angle sensor 43 (Fig. 2) reaches the angle A32 of Fig. 5. When the first combustion determination condition is not satisfied, the ECU 6 repeats the process of step S10. When the first combustion determination condition is satisfied, the ECU 6 performs the first combustion determination (step S11).

[0084] Next, the ECU 6 determines whether a forward rotation fuel injection condition is satisfied (step S12). In the present example, the forward rotation fuel injection condition is that the crank angle acquired from the results of detection of the intake pressure sensor 42 (Fig. 2) and the crank angle sensor 43 (Fig. 2) reach the angle A11 of Fig. 5. When the forward rotation fuel injection condition is not satisfied, the ECU 6 repeats the process of step S12. When the forward rotation fuel injection condition is satisfied, the ECU 6 controls the injector 19 (Fig.

2) such that the fuel is injected into the intake passage 22 (Fig. 2) (step S13).

[0085] In this case, an amount of injection of the fuel is set based on the result of the first combustion determination in step S11. As described above, when the first condition is satisfied in the first combustion determination, an amount of injection of the fuel is set to the V2. On the other hand, when the first condition is not satisfied in the first combustion determination, the amount of injection of the fuel is set to the V2a smaller than the V2.

[0086] Next, as shown in Fig. 12, the ECU 6 determines whether a second combustion determination condition is satisfied (step S14). In the present example, the second combustion determination condition is that the crank angle acquired from the results of detection of the intake pressure sensor 42 (Fig. 2) and the crank angle sensor 43 (Fig. 2) reaches the angle A33 of Fig. 5. When the second combustion determination condition is not satisfied, the ECU 6 repeats the process of step S14. When the second combustion determination condition is satisfied, the ECU 6 performs the second combustion determination (step S15).

[0087] Next, the ECU 6 determines based on results of the first combustion determination in step S11 of Fig. 11 and the second combustion determination in step S14 of Fig. 12 whether the fuel-air mixture is successfully combusted by the ignition in step S9 of Fig. 11 (step S16).

[0088] When the fuel-air mixture is successfully combusted, the ECU 6 finishes the engine start-up process. In this case, the crank angle exceeds the angle corresponding to the first compression top dead center by the energy generated by the combustion of the fuel-air mixture, and the engine unit EU is shifted to the normal operation of Fig. 3.

[0089] On the other hand, when the fuel-air mixture is not successfully combusted, the ECU 6 controls the integrated starter generator 14 such that the crankshaft 13 is rotated in the reverse direction again (step S17). Next, the ECU 6 determines whether the reverse rotation fuel injection condition is satisfied (step S18). The reverse rotation fuel injection condition is the same as step S3 of Fig. 10. When the reverse rotation fuel injection condition is not satisfied, the ECU 6 repeats the process of step S18. When the reverse rotation fuel injection condition is satisfied, the ECU 6 controls the injector 19 (Fig. 2) such that the fuel is injected into the intake passage 22 (Fig. 2) (step S19). In this case, an amount of injection of the fuel is set to the V1a smaller than the amount of injection V1 in step S4. Thereafter, the ECU 6 returns to the process of step S5. Thus, the reverse rotation start-up operation is repeated.

(5) Effects

[0090] In the engine system 200 according to the present embodiment, the first and second combustion determination is performed after the ignition of the fuel-air mixture in the reverse rotation start-up operation, and

the reverse rotation start-up operation is repeated when it is determined that the fuel-air mixture is not successfully combusted. The reverse rotation start-up operation is repeated, so that the fuel-air mixture concentration in the combustion chamber 31 a is gradually increased. Thus, the fuel-air mixture can be finally appropriately combusted. Therefore, the crankshaft 13 can be rotated such that the crank angle exceeds the angle A2 corresponding to the first compression top dead center. As a result, the engine 10 can be appropriately started.

[0091] Further, in the present embodiment, after the fuel-air mixture is ignited in the reverse rotation start-up operation, the first combustion determination is performed at the angle A32 before the crank angle reaches the normal exhaust range, and the second combustion determination is performed at the angle A33 after the crank angle has passed the normal intake range. In this manner, the combustion determination is gradually performed, so that it can be appropriately determined whether the fuel-air mixture is successfully combusted. Thus, the engine 10 can be appropriately started.

[0092] Further, in the present embodiment, an amount of injection at the combustion at the angle A11 is adjusted based on the result of the first combustion determination. Thus, respective suitable amounts of the fuel for the ignition in the normal operation and the ignition in the next reverse rotation start-up operation can be injected. Therefore, the fuel-air mixture having respective suitable concentration can be introduced into the combustion chamber 31a.

[0093] Further, in the present embodiment, the amount of injection of the fuel at the angle A23 in the first reverse rotation start-up operation is different from the amount of injection of the fuel at the angle A23 in the second reverse rotation start-up operation and the subsequent reverse rotation start-up operations. Thus, the fuel-air mixture concentration in the combustion chamber 31 a can be gradually increased while the fuel is prevented from being wastefully consumed.

(6) Other Examples of Amount of Injection of Fuel

[0094] In the above-mentioned embodiment, the amount of injection of the fuel at the angle A23 in the first reverse rotation start-up operation is set to the V1, and the amount of injection of the fuel at the angle A23 in the second reverse rotation start-up operation and subsequent reverse rotation start-up operations is set to the V1a. However, the present invention is not limited to this.

[0095] Fig. 13 is a diagram for explaining other examples of the amount of injection of the fuel. In Fig. 13, the abscissa indicates the number of times of the reverse rotation start-up operation, and the ordinate indicates the amount of injection of the fuel at the angle A23. As described above, the reverse rotation start-up operation is repeated, so that the fuel-air mixture concentration in the combustion chamber 31 a is gradually increased. In the example of Fig. 13, the amount of injection of the fuel is

adjusted to gradually be reduced as the number of times of the reverse rotation start-up operation is increased. Thus, the fuel is prevented from being wastefully consumed, and the fuel-air mixture concentration in the combustion chamber 31a is prevented from being excessively high.

[0096] Further, the amount of injection of the fuel at the angle A11 when the fuel-air mixture is not successfully combusted in the reverse rotation start-up operation may also be adjusted to be gradually reduced as the number of times of the reverse rotation start-up operation is increased similarly to the example of Fig. 13.

(7) Other Embodiments

(7-1)

[0097] While the combustion determination is performed two times including the first and second combustion determination after the fuel-air mixture is ignited in the reverse rotation start-up operation in the above-mentioned embodiment, the present invention is not limited to this. Only one of the first and second combustion determination may be performed. Further, the number of times of the combustion determination to be performed, and the crank angle at which the combustion determination is performed, are not limited to the above-mentioned example, but can be suitably changed. For example, the combustion determination based on the rotation state of the crankshaft may be continuously performed in the range from the angle A32 to the angle A33, and it may be determined whether the fuel-air mixture is successfully combusted.

(7-2)

[0098] While the amount of injection of the fuel at the angle A11 is adjusted based on the results of the first and second combustion determination in the above-mentioned embodiment, the amount of injection of the fuel at the angle A11 may be constant regardless of the results of the first and second combustion determination. Further, while the amount of injection of the fuel at the angle A23 is adjusted based on the number of times of the repetition of the reverse rotation start-up operation in the above-mentioned embodiment, the amount of injection of the fuel at the angle A23 may be constant regardless of the number of times of the repetition of the reverse rotation start-up operation.

(7-3)

[0099] While the exhaust port 23 is opened in a range from the angle A16 to the angle A15 during the reverse rotation of the crankshaft 13 in the above-mentioned embodiment, the present invention is not limited to this. As described above, in the second reverse rotation start-up operation and subsequent reverse rotation start-up op-

erations, the fuel-air mixture that remains in the exhaust passage 24 is introduced into the combustion chamber 31 a through the exhaust port 23 in the range from the angle A16 to the angle A15. If the exhaust port 23 is not opened in the range from the angle A16 to the angle A15, the fuel-air mixture is not introduced into the combustion chamber 31a from the exhaust passage 24 in this manner. However, because the fuel-air mixture is repeatedly introduced into the combustion chamber 31 a from the intake passage 22 by the repetition of the reverse rotation start-up operation, even when the exhaust port 23 is not opened in the above-mentioned range, the fuel-air mixture concentration in the combustion chamber 31a is gradually increased. Therefore, the exhaust port 23 does not have to be opened in the above-mentioned range during the reverse rotation of the crankshaft 13.

[0100] Further, while the intake port 21 is opened in the range from the angle A13 to the angle A12 during the reverse rotation of the crankshaft 13 in the above-mentioned embodiment, the intake port 21 does not have to be opened in this range.

(7-4)

[0101] While the above-mentioned embodiment is an example in which the present invention is applied to the motorcycle, the invention is not limited to this. The present invention may be applied to another straddled vehicle such as a motor tricycle, an All-Terrain Vehicle (ATV) or the like.

(8) Correspondences between Constituent Elements in Claims and Parts in Preferred Embodiments

[0102] In the following paragraphs, non-limiting examples of correspondences between various elements recited in the claims below and those described above with respect to various preferred embodiments of the present invention are explained.

[0103] In the above-mentioned embodiment, the engine unit EU is an example of an engine unit, the engine 10 is an example of an engine, the integrated starter generator 14 is an example of a rotation driver, the ECU 6 is an example of a controller, the injector 19 is an example of a fuel injection device, the ignition plug 18 is an example of an ignition device, the valve driver 17 is an example of a valve driver, the intake valve 15 is an example of an intake valve, the exhaust valve 16 is an example of an exhaust valve, the crank angle sensor 43 is an example of a rotation state detector and the crankshaft 13 is an example of a crankshaft. Further, the first and second conditions are examples of a start-up condition, the first condition is an example of a start-up preparation condition. Further, the motorcycle 100 is an example of a straddled vehicle, the rear wheel 7 is an example of a drive wheel and the vehicle body 1 is an example of a main body.

[0104] As each of constituent elements recited in the

claims, various other elements having configurations or functions described in the claims can be also used.

[Industrial Applicability]

[0105] The present invention is applicable to various types of engine systems and straddled vehicles.

Claims

1. An engine system comprising:

an engine unit that includes an engine and a rotation driver; and
a controller that controls the engine unit, wherein the engine includes
a fuel injection device arranged to inject fuel into an intake passage for leading air to a combustion chamber,
an ignition device configured to ignite a fuel-air mixture in the combustion chamber,
a valve driver configured to drive each of an intake valve for opening and closing an intake port and an exhaust valve for opening and closing an exhaust port, and
a rotation state detector that detects a rotation state of a crankshaft,
the rotation driver is configured to drive rotation of the crankshaft in forward and reverse directions,
the controller controls the engine unit such that a reverse rotation start-up operation of rotating the crankshaft in the forward direction is performed after rotation of the crankshaft in the reverse direction, during start-up of the engine,
the rotation driver rotates the crankshaft in the reverse direction such that a crank angle exceeds a predetermined start-up intake range and reaches a predetermined start-up ignition range, in the reverse rotation start-up operation, the valve driver drives the intake valve such that the intake port is opened, when the crankshaft is rotated in the reverse direction and the crank angle is in the start-up intake range, and drives the intake valve such that the intake port is opened, when the crankshaft is rotated in the forward direction and the crank angle is in a predetermined normal intake range, in the reverse rotation start-up operation,
the fuel injection device injects the fuel such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port, at at least one of a time when the crankshaft is rotated in the reverse direction and the crank angle is in the start-up intake range and a time when the crankshaft is rotated in the forward direction and the crank

- angle is in the normal intake range, in the reverse rotation start-up operation,
the ignition device ignites the fuel-air mixture in the combustion chamber when the crank angle is in the start-up ignition range, in the reverse rotation start-up operation, and
the controller controls the engine unit such that the reverse rotation start-up operation is performed again, in a case in which a rotation state detected by the rotation state detector does not satisfy a predetermined start-up condition when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and before a piston reaches a first compression top dead center.
2. The engine system according to claim 1, wherein the controller controls the engine unit such that the crankshaft is continuously rotated in the forward direction by combustion of the fuel-air mixture, in a case in which the rotation state detected by the rotation state detector satisfies the start-up condition when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and before the piston reaches the first compression top dead center.
 3. The engine unit according to claim 1 or 2, wherein the start-up condition is that a rotation speed of the crankshaft is higher than a predetermined threshold value.
 4. The engine unit according to claim 1 or 2, wherein the start-up condition is that a rate of change of a rotation speed of the crankshaft is larger than a predetermined threshold value.
 5. The engine system according to any one of claims 1 to 4, wherein
the controller controls the engine unit such that the reverse rotation start-up operation is performed again, at a first point of time when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and at which the crank angle has passed through the normal intake range, in a case in which the rotation state detected by the rotation state detector does not satisfy the start-up condition.
 6. The engine system according to claim 5, wherein
the fuel injection device injects a first amount of fuel such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port when the crank angle is in the normal intake range, at a second point of time when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and before the crank angle reaches the normal intake range, in a case in which the rotation state detected by the rotation state detector does not satisfy a predetermined start-up preparation condition, and
the fuel injection device injects a second amount of fuel different from the first amount such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port when the crank angle is in the normal intake range, in a case in which the rotation state detected by the rotation state detector satisfies the start-up preparation condition at the second point of time.
 7. The engine system according to any one of claims 1 to 4, wherein
the fuel injection device injects a first amount of fuel such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port when the crank angle is in the normal intake range, at a second point of time when the crankshaft is rotated in the forward direction in the reverse rotation start-up operation and before the crank angle reaches the normal intake range, in a case in which the rotation state detected by the rotation state detector does not satisfy the start-up condition, and
the fuel injection device injects a second amount of fuel different from the first amount such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port when the crank angle is in the normal intake range, in a case in which the rotation state detected by the rotation state detector satisfies the start-up condition at the second point of time.
 8. The engine system according to any one of claims 1 to 7, wherein
the fuel injection device injects a third amount of fuel such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port, when the crankshaft is rotated in the reverse direction and the crank angle is in the start-up intake range, in the first reverse rotation start-up operation during the start-up of the engine, and
the fuel injection device injects a fourth amount of fuel different from the third amount such that the fuel-air mixture is introduced into the combustion chamber from the intake passage through the intake port, when the crankshaft is rotated in the reverse direction and the crank angle is in the start-up intake range, in the second reverse rotation start-up operation during the start-up of the engine.
 9. The engine system according to any one of claims 1 to 8, wherein
the valve driver drives the exhaust valve such that the exhaust port is opened when the crank angle is in a normal exhaust range, when the crankshaft is rotated in the forward and reverse directions, and

the normal exhaust range includes the start-up intake range.

10. A straddled vehicle comprising:

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a main body having a drive wheel, and
an engine system according to any one of claims
1 to 9 that generates motive power for rotating
the drive wheel.

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FIG. 1

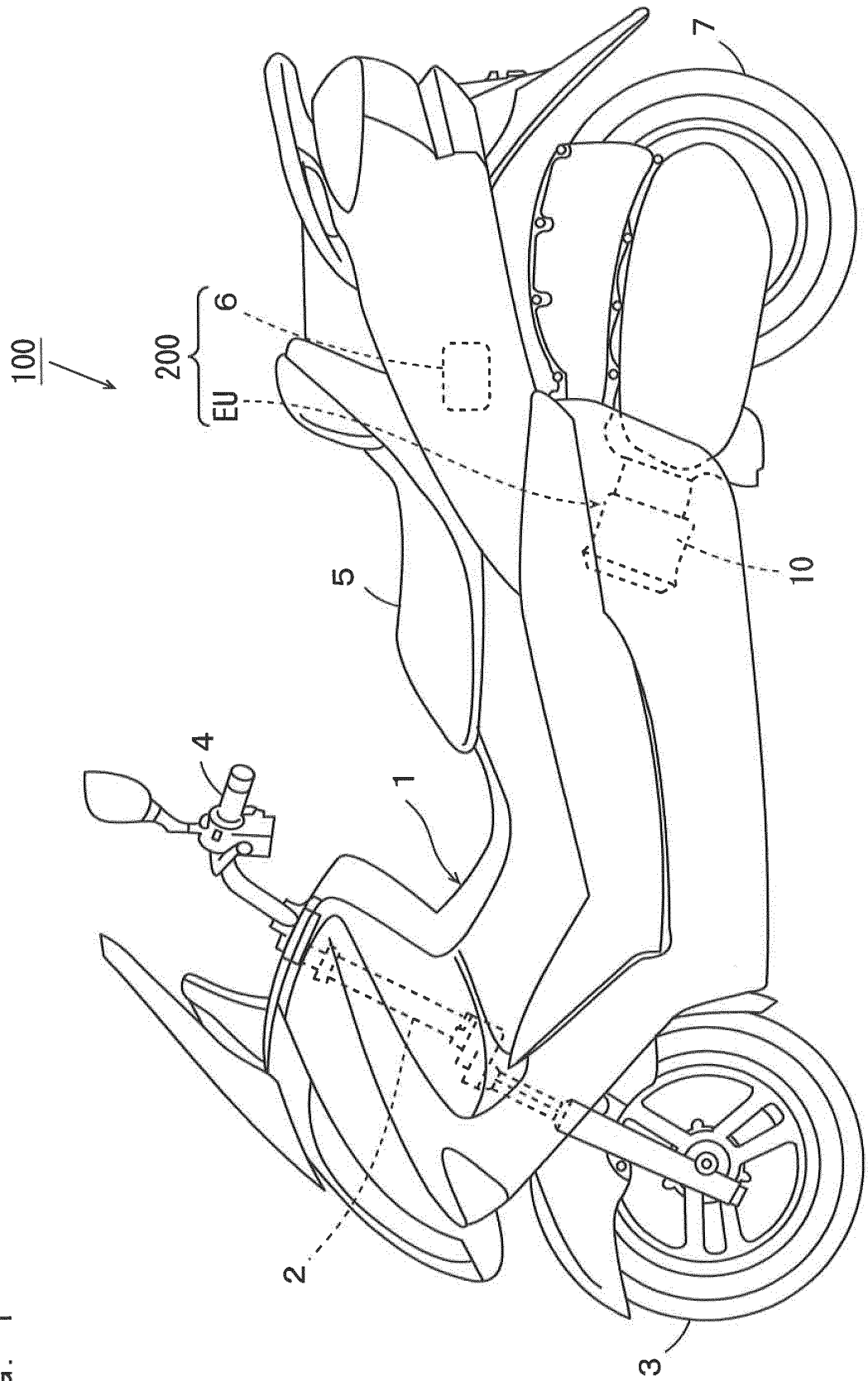


FIG. 2

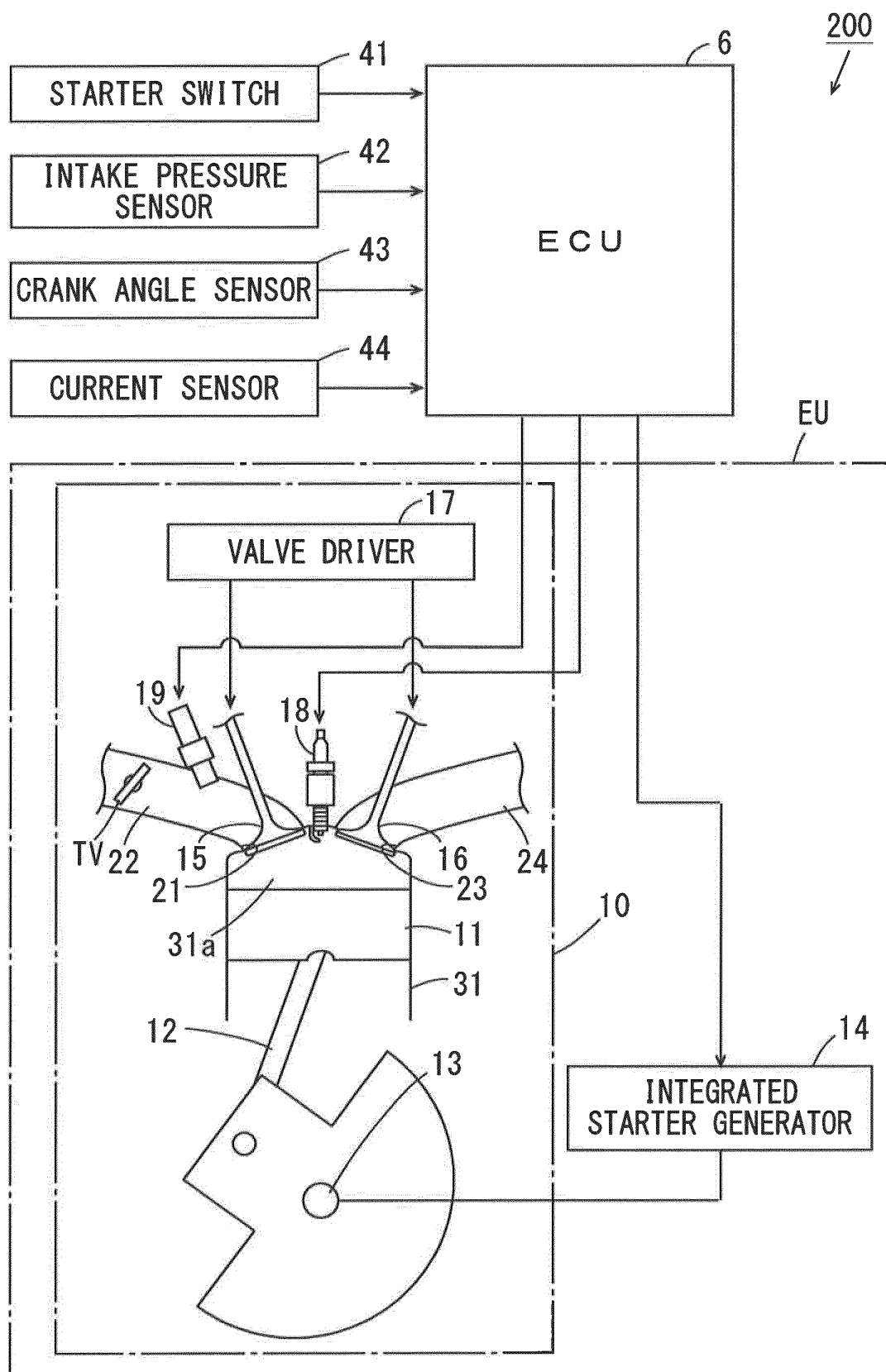


FIG. 3

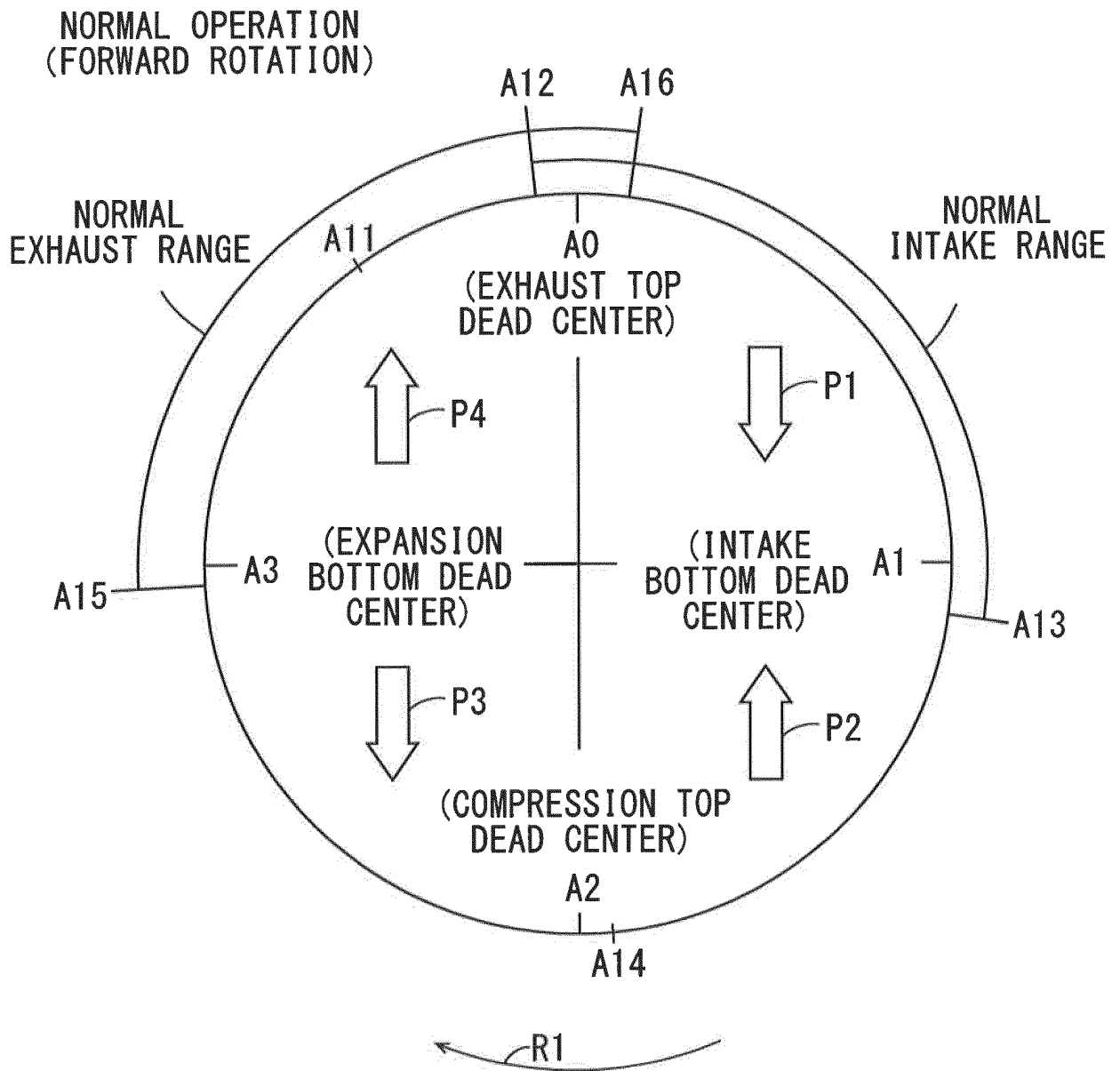


FIG. 4

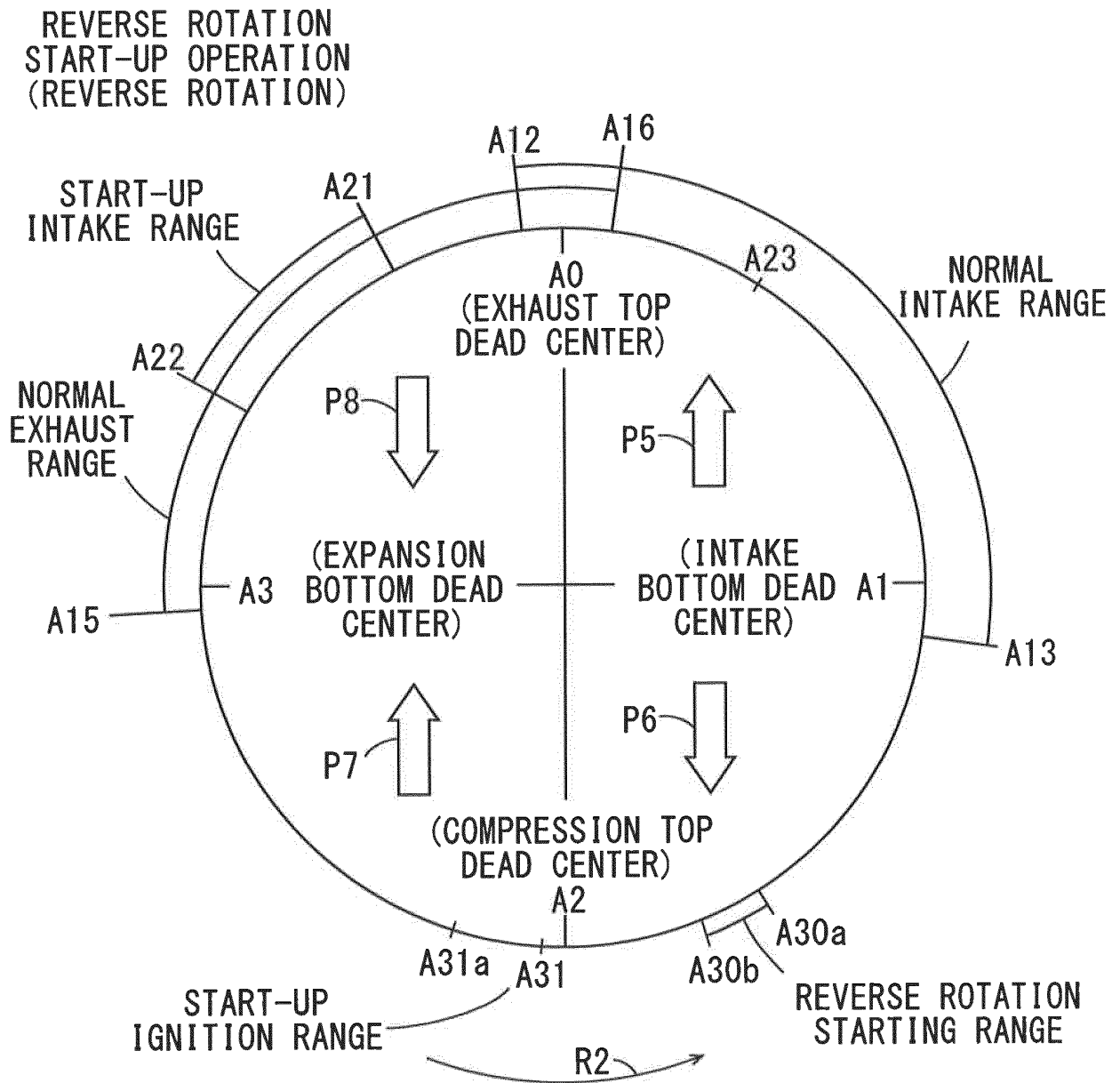


FIG. 5

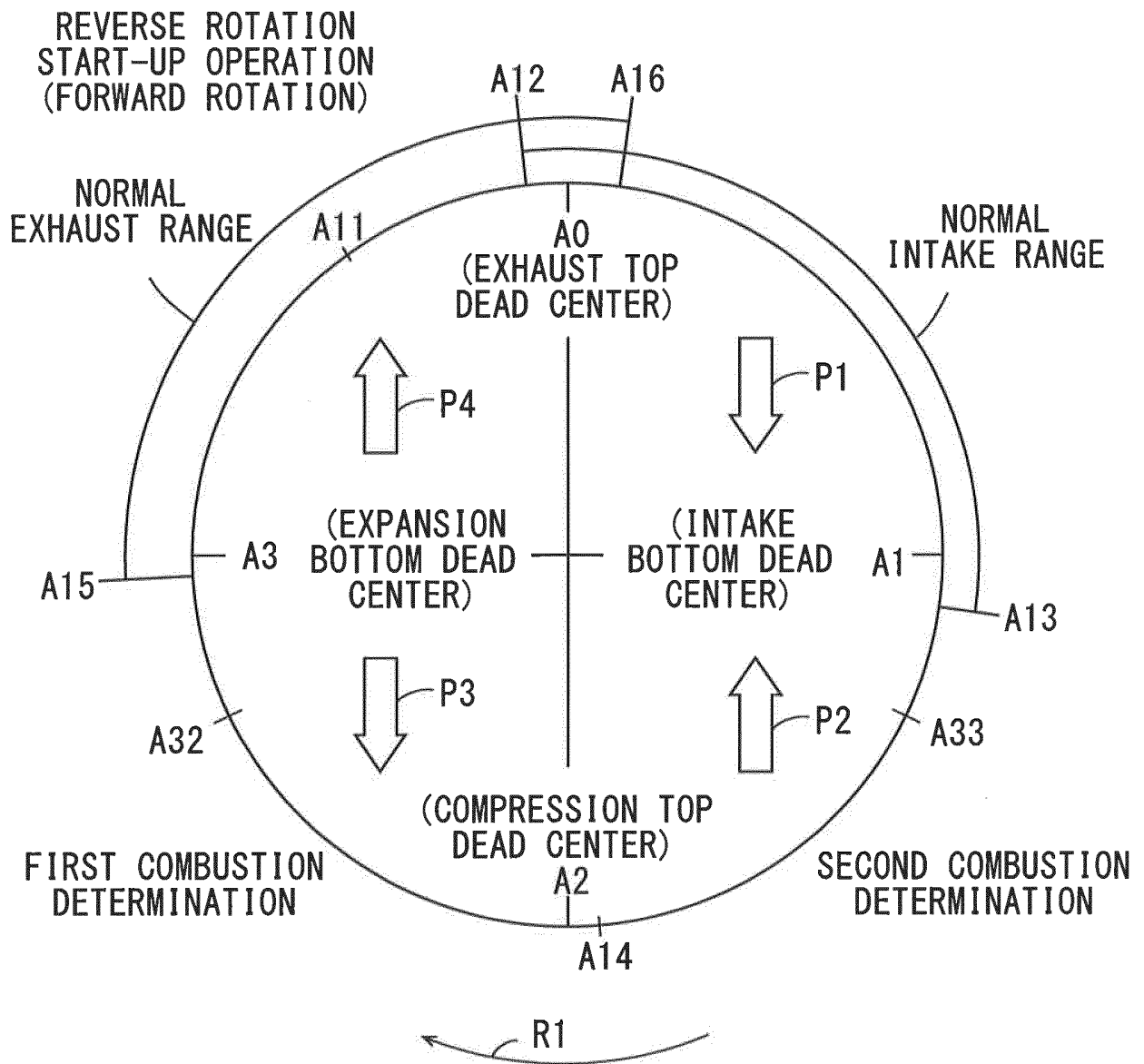


FIG. 6

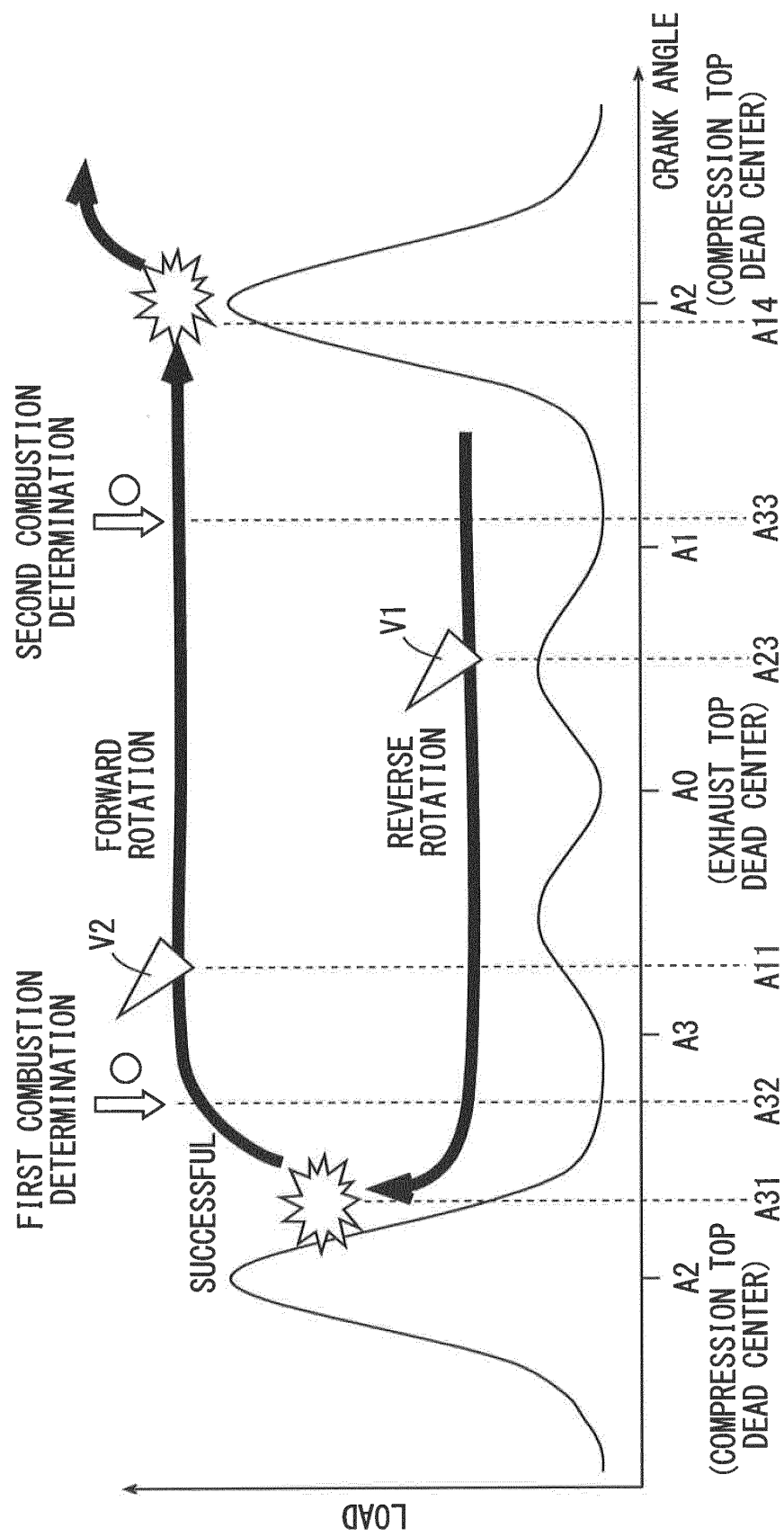


FIG. 7

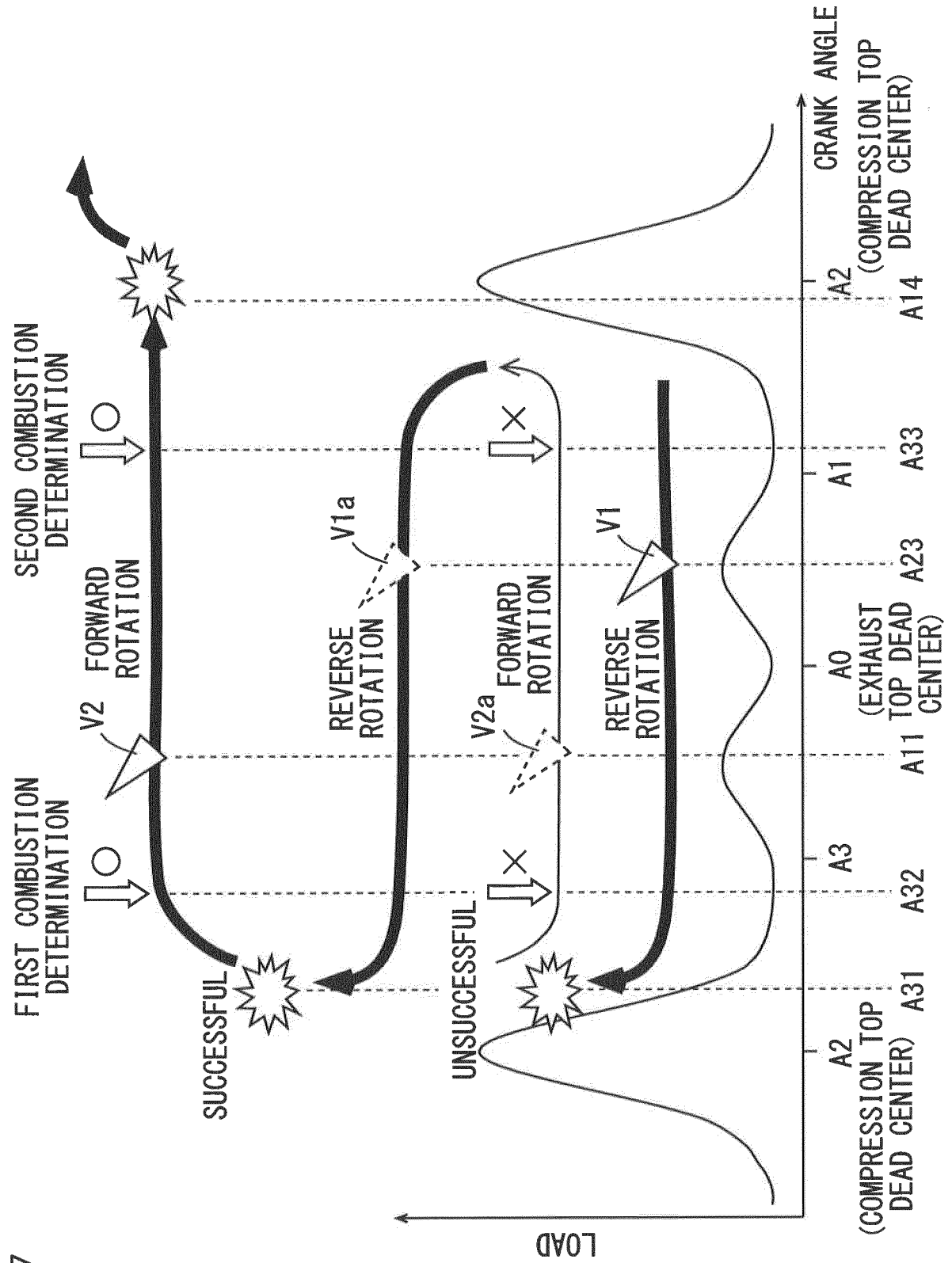
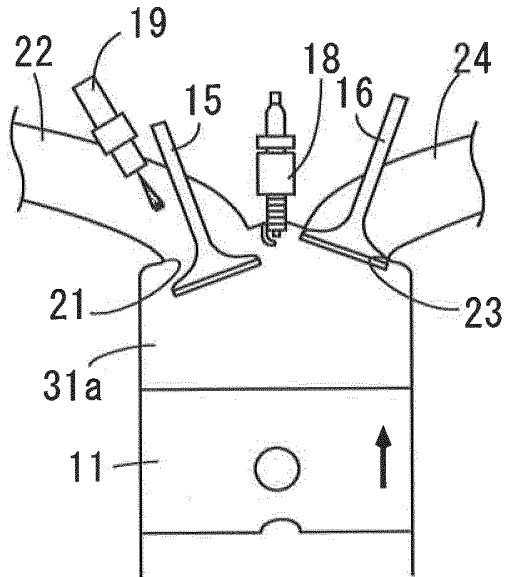
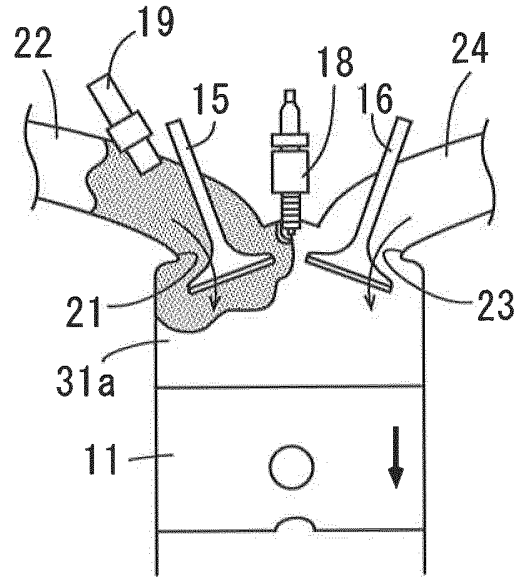


FIG. 8

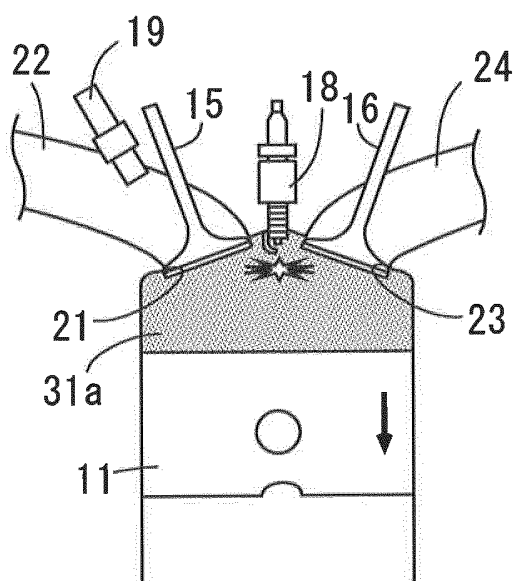
(a) ANGLE A23
(REVERSE ROTATION)



(b) ANGLES A21-A22
(REVERSE ROTATION)



(c) ANGLES A31-A15
(FORWARD ROTATION)



(d) ANGLES A15-A16
(FORWARD ROTATION)

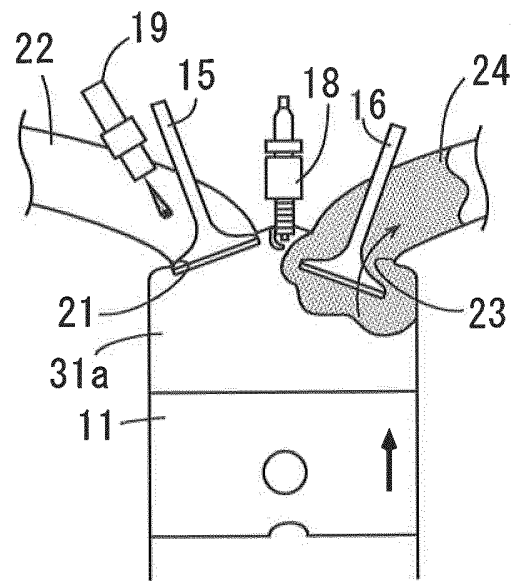
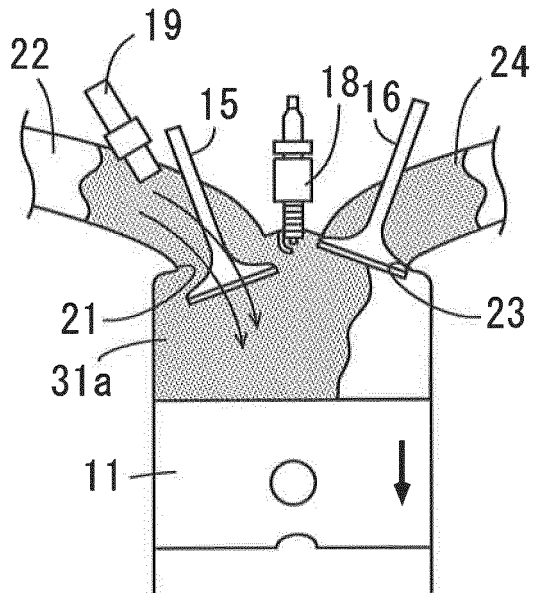
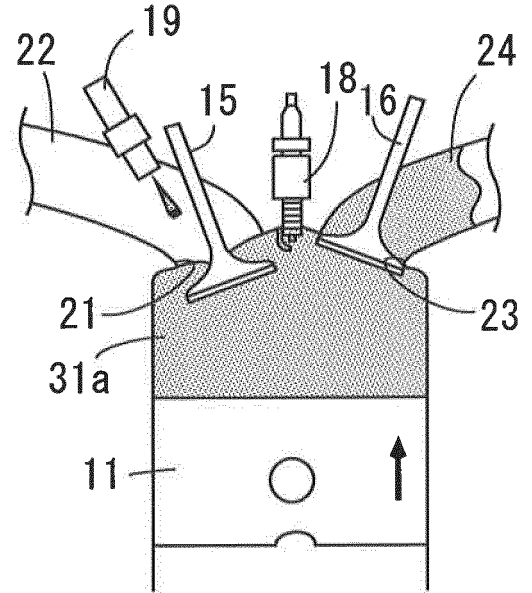


FIG. 9

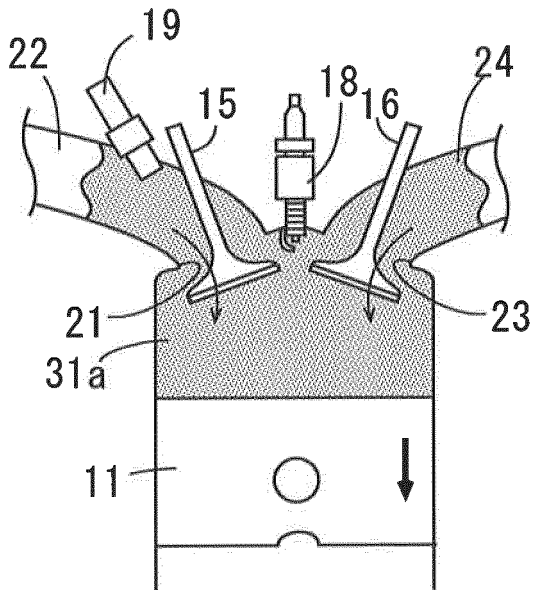
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(FORWARD ROTATION)



(b) ANGLE A23
(REVERSE ROTATION)



(c) ANGLES A21-A22
(REVERSE ROTATION)



(d) ANGLE A31
(FORWARD ROTATION)

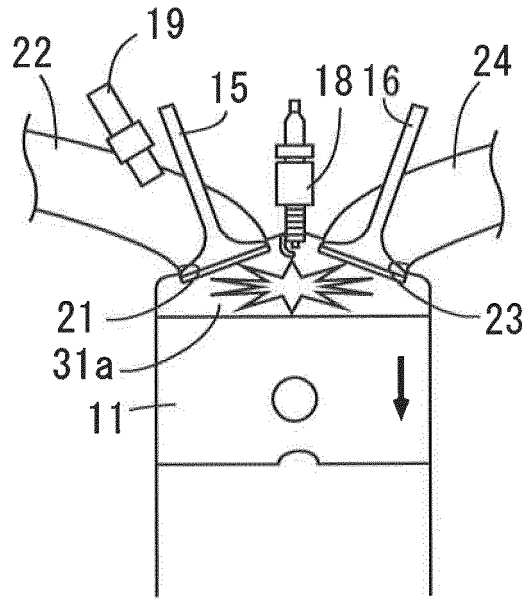


FIG. 10

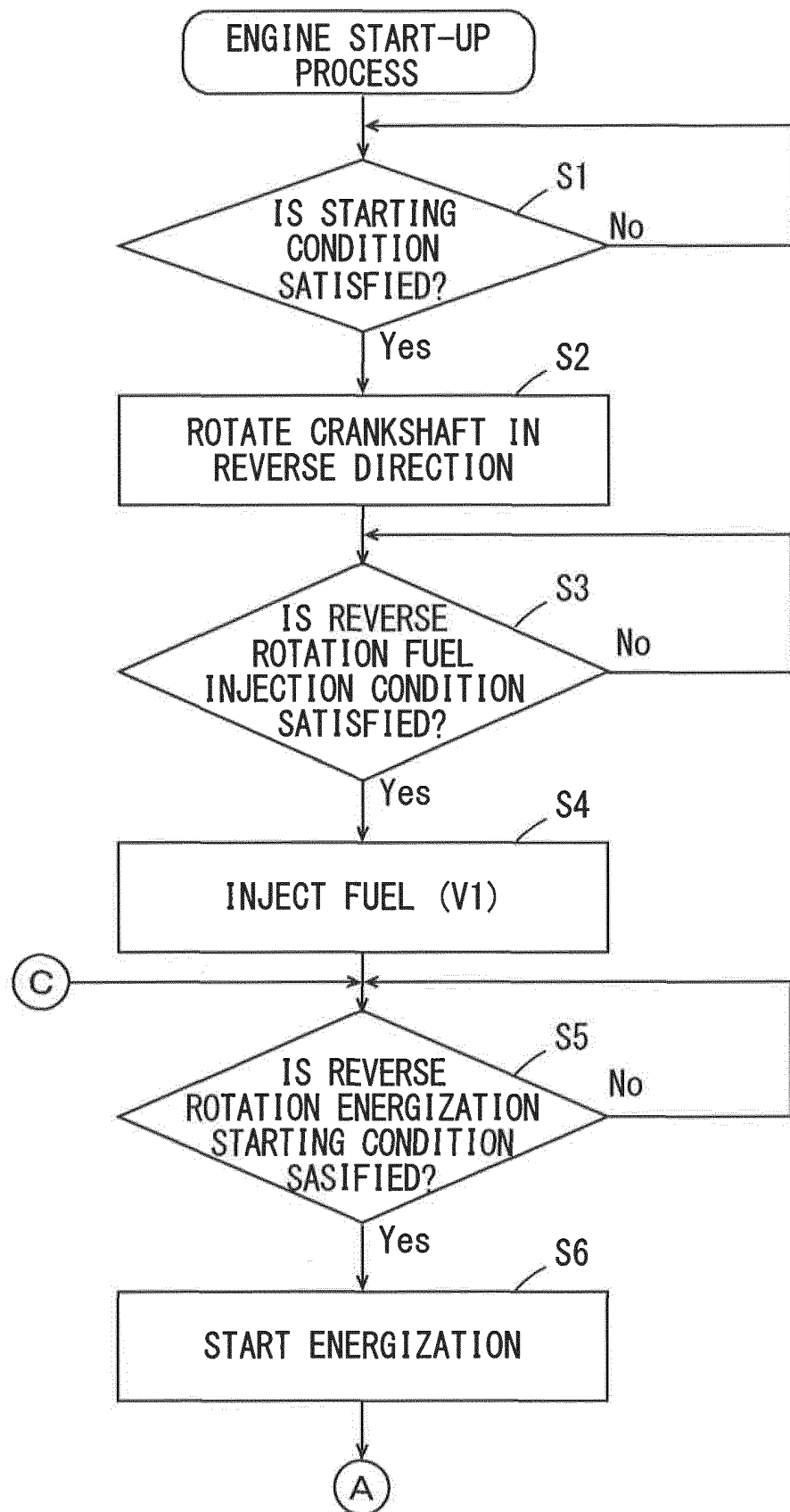


FIG. 11

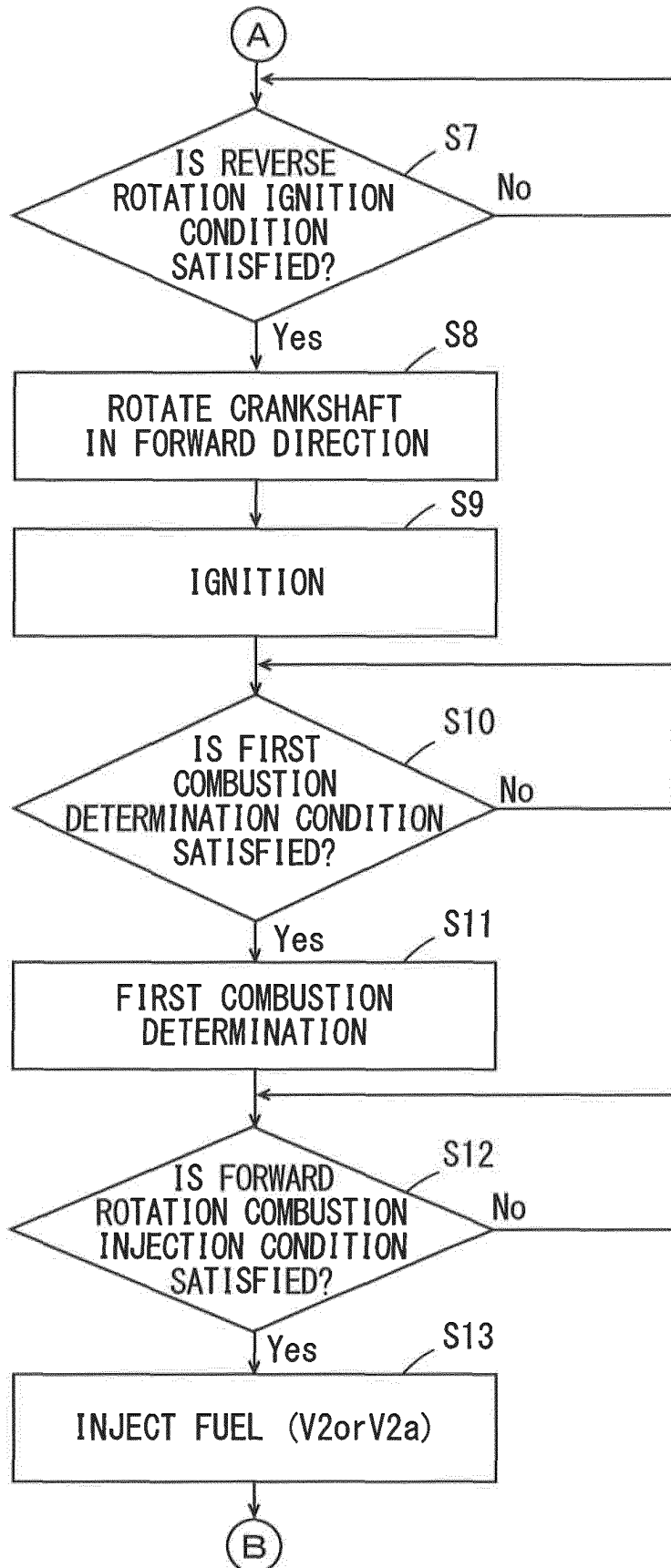


FIG. 12

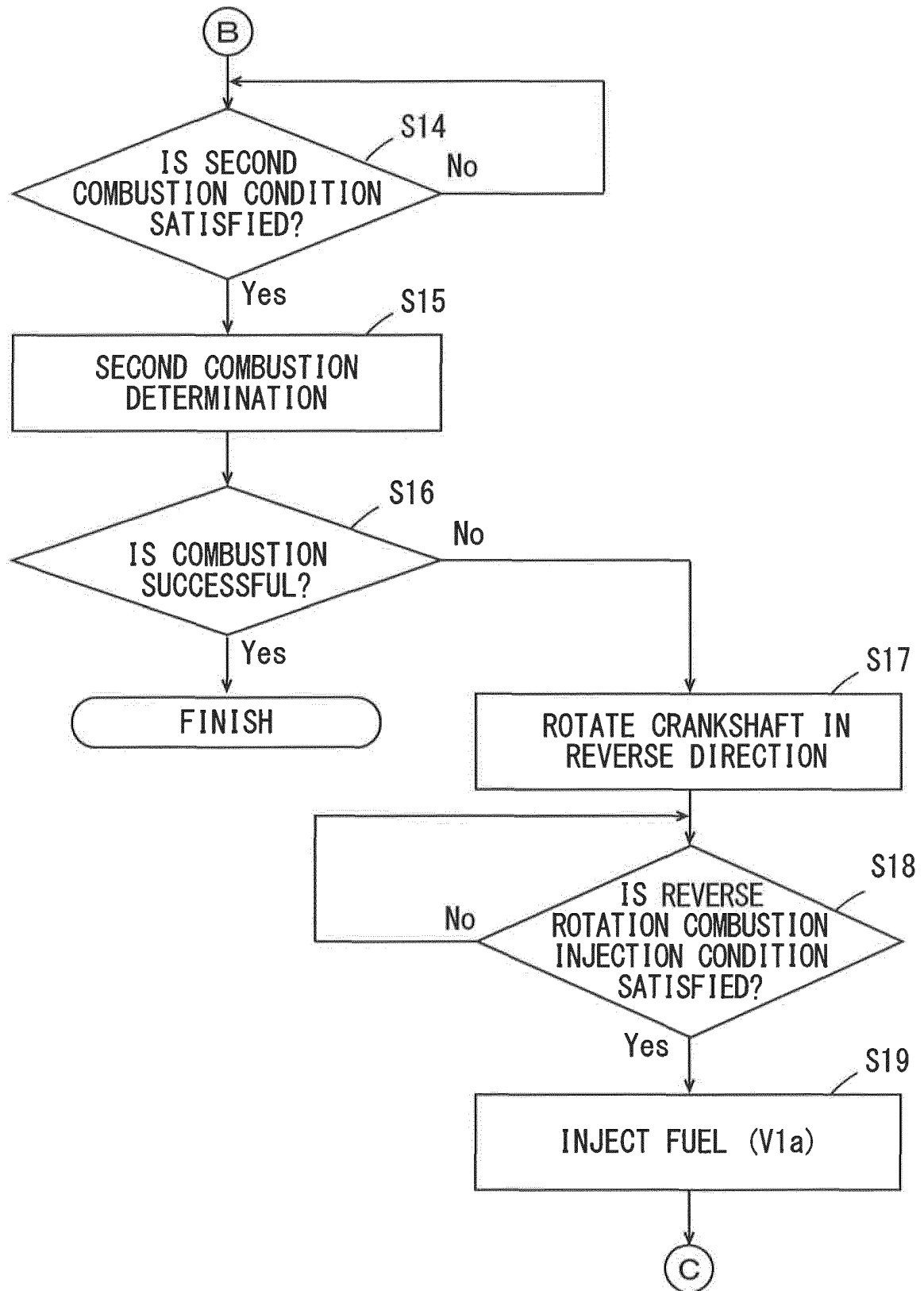
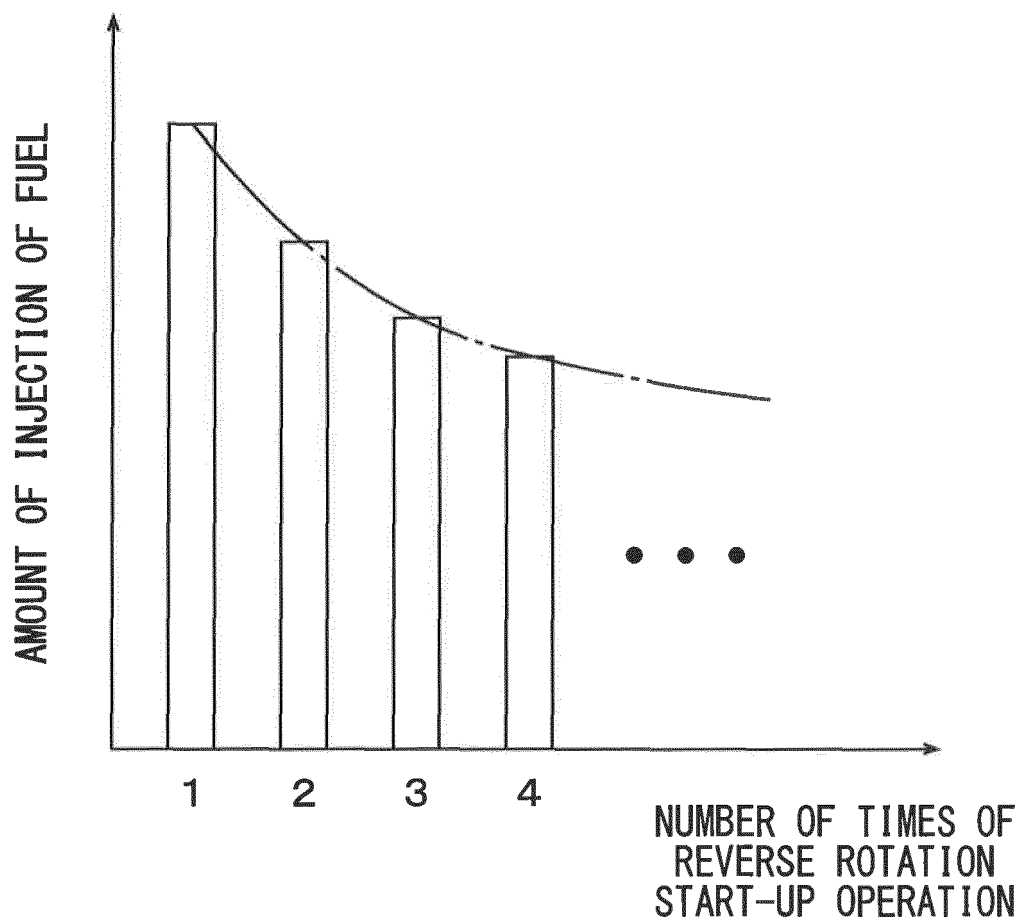


FIG. 13



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/003879

A. CLASSIFICATION OF SUBJECT MATTER

F02D29/02(2006.01)i, F02D13/02(2006.01)i, F02D41/06(2006.01)i, F02P5/15(2006.01)i, F02D43/00(2006.01)i, F02D45/00(2006.01)i, F02N11/08(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F02D29/00-29/02, F02D13/02, F02D41/00-41/40, F02P5/145-5/155, F02D43/00-45/00, F02N11/08

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2014
Kokai Jitsuyo Shinan Koho 1971-2014 Toroku Jitsuyo Shinan Koho 1994-2014

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2014-77405 A (Yamaha Motor Co., Ltd.), 01 May 2014 (01.05.2014), entire text & EP 2719883 A1	1-10
A	JP 2004-176709 A (Toyota Motor Corp.), 24 June 2004 (24.06.2004), entire text & US 2004/0060530 A1 & DE 10345153 A1 & FR 2846055 A1	1-10
A	JP 2005-315231 A (Mazda Motor Corp.), 10 November 2005 (10.11.2005), entire text (Family: none)	1-10

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

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search
20 October, 2014 (20.10.14)

Date of mailing of the international search report
28 October, 2014 (28.10.14)

Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/003879

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-339952 A (Toyota Motor Corp.), 02 December 2004 (02.12.2004), entire text & US 2004/0226530 A1 & EP 1486667 A2	1-10

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2014077405 A [0004]