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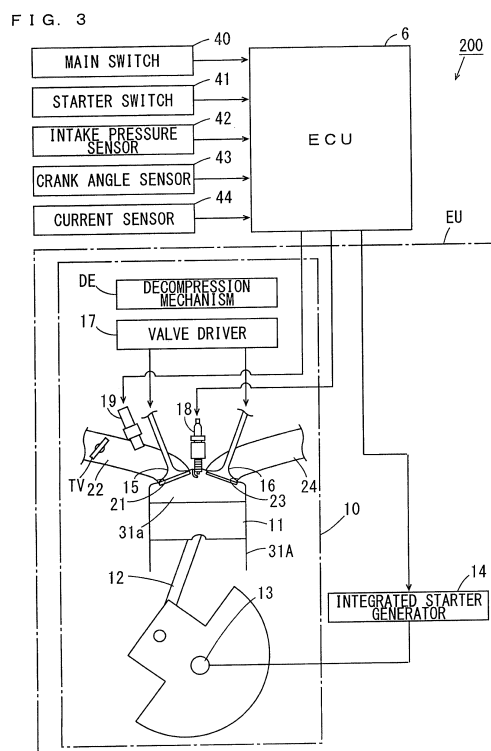
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Description

[Technical Field]

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

[Background Art]

[0002] In order to increase startability of an engine, there is a technology for rotating a crankshaft in a reverse direction and combusting a fuel-air mixture in a cylinder during start-up of the engine. In an engine start-up control device described in Patent Document 1, when the engine is stopped during idle stop control, a fuel-air mixture is introduced into a specific cylinder, and a crankshaft is stopped with the cylinder in an expansion stroke. Thereafter, during a re-start of the engine, the crankshaft is rotated in reverse such that a piston in the above-mentioned specific cylinder returns to an initial position of the expansion stroke or a position in the vicinity of the initial position of the expansion stroke, and the fuel-air mixture in the cylinder is ignited.

[0003] [Patent Document 1] JP 2005-180380 A

[Summary of Invention]

[Technical Problem]

[0004] In the idle stop control, the stop and the re-start of the engine are automatically performed. In this case, because a period during which the engine is stopped is relatively short, the fuel-air mixture introduced into the cylinder during the stop of the engine is likely to remain in the cylinder also during the re-start of the engine. On the other hand, if the period during which the engine is stopped is lengthened, the fuel-air mixture in the cylinder naturally dissipates. Therefore, the above-mentioned operation cannot be realized during cold start-up and the like.

[0005] Further, even in the case where the period during which the engine is stopped is short, the fuel-air mixture in the cylinder is diluted during the period. Therefore, it is difficult to appropriately adjust a fuel-air ratio in the cylinder at a time of ignition.

[0006] From the above, the start-up of the engine sometimes cannot be appropriately performed by the technology described in the above-mentioned document.

[0007] An object of the present invention is to provide an engine system and a vehicle capable of appropriately performing start-up of an engine.

[Solution to Problem]

[0008]

(1) According to one aspect of the present invention, an engine system includes an engine having a plu-

rality of cylinders, a rotation driver that rotates a crankshaft of the engine in forward and reverse directions, and a controller that controls the engine and the rotation driver such that an engine start-up operation including at least a reverse rotation start-up operation is performed, wherein the plurality of cylinders include first and second cylinders, a fuel-air mixture is introduced into the first cylinder while the crankshaft is rotated in the reverse direction, and the crankshaft is driven in the forward direction by combustion of the fuel-air mixture in the first cylinder, in the reverse rotation start-up operation, the engine includes a pressure reduction mechanism that reduces pressure in at least one cylinder of the first and second cylinders, and the pressure reduction mechanism, in the engine start-up operation, reduces the pressure in the at least one cylinder such that there is an increase in rotational resistance of the crankshaft caused by an increase in pressure in the at least one cylinder.

[0009] In this engine system, the engine is started by the engine start-up operation including at least the reverse rotation start-up operation. In the reverse rotation start-up operation, the fuel-air mixture is introduced into the first cylinder among the plurality of cylinders while the crankshaft is rotated in reverse, and the crankshaft is driven in the forward direction by the combustion of the fuel-air mixture in the first cylinder. In this case, because a time period from the time when the fuel-air mixture is introduced into the first cylinder until the time when the fuel-air mixture is ignited is short, the fuel-air mixture in the first cylinder is prevented from dissipating or being diluted, and a fuel-air ratio of the fuel-air mixture at the time of ignition can be appropriately adjusted.

[0010] In the engine start-up operation, the pressure in at least one cylinder of the first and second cylinders is reduced by the pressure reduction mechanism, whereby an increase in rotational resistance of the crankshaft caused by an increase in pressure in the at least one cylinder is inhibited. Thus, the rotation of the crankshaft is not prevented, and the engine start-up operation is smoothly performed. Therefore, a forward torque of the crankshaft can be sufficiently increased by the reverse rotation start-up operation. As a result, the engine can be appropriately started.

(2) The pressure reduction mechanism, in the reverse rotation start-up operation, may reduce the pressure in the at least one cylinder.

In this case, in the reverse rotation start-up operation, because an increase in rotational resistance of the crankshaft caused by an increase in pressure in the above-mentioned at least one cylinder is inhibited, the reverse rotation of the crankshaft is not prevented. Thus, the reverse rotation start-up operation can be appropriately performed.

(3) The engine may further include an opening clos-

ing mechanism that opens and closes an intake port and an exhaust port of each of the first and second cylinders, ranges of a crank angle respectively corresponding to an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke of the first cylinder during normal running may be defined as a first intake range, a first compression range, a first expansion range and a first exhaust range, and ranges of the crank angle respectively corresponding to an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke of the second cylinder during the normal running may be defined as a second intake range, a second compression range, a second expansion range and a second exhaust range, the first exhaust range may include a start-up intake range, and the first expansion range may include a start-up ignition range, the rotation driver, in the reverse rotation start-up operation, may rotate the crankshaft in reverse such that the crank angle exceeds the start-up intake range and reaches the start-up ignition range, the opening closing mechanism, in the reverse rotation start-up operation, may open the intake port of the first cylinder when the crank angle is in the start-up intake range, a fuel injection device corresponding to the first cylinder, in the reverse rotation start-up operation, may inject fuel into an intake passage that leads air to the first cylinder such that, when the crank angle is in the start-up intake range, a fuel-air mixture is introduced into the first cylinder, an ignition device corresponding to the first cylinder, in the reverse rotation start-up operation, may ignite the fuel-air mixture in the first cylinder when the crank angle is in the start-up ignition range, the second expansion range may include a start-up pressure reduction range, and the pressure reduction mechanism, in the reverse rotation start-up operation, may reduce pressure in the second cylinder when the crank angle is in the start-up pressure reduction range.

[0011] In this case, in the reverse rotation start-up operation, the crankshaft is rotated in reverse such that the crank angle passes through the start-up intake range and reaches the start-up ignition range. The intake port of the first cylinder is opened when the crank angle is in the start-up intake range, and the fuel-air mixture is introduced into the first cylinder. Thereafter, the fuel-air mixture in the first cylinder is ignited when the crank angle is in the start-up ignition range. The crankshaft is driven in the forward direction by the energy of combustion of the fuel-air mixture.

[0012] When the crank angle is in the start-up pressure reduction range, the pressure in the second cylinder is reduced by the pressure reduction mechanism. Thus, even in the case where the crank angle becomes close to the angle corresponding to the pressure top dead center of the second cylinder, an increase in pressure in the second cylinder is inhibited. Therefore, an increase in

rotational resistance of the crankshaft is inhibited, so that the reverse rotation of the crankshaft is not prevented.

[0013] Because the pressure in the second cylinder does not prevent the reverse rotation of the crankshaft, the introduction of the fuel-air mixture into the first cylinder and the compression of the fuel-air mixture in the first cylinder can be appropriately performed. Thus, the fuel-air mixture can be appropriately combusted in the first cylinder, and a forward torque of the crankshaft can be sufficiently increased. As a result, the engine can be appropriately started.

(4) At least one of the first compression range and the first intake range may include a reverse rotation start range, and the engine start-up operation may further include a forward rotation positioning operation of adjusting the crank angle in the reverse rotation start range by rotating the crankshaft in the forward direction before the reverse rotation start-up operation.

In this case, because the crank angle is adjusted in the reverse rotation start range before the reverse rotation start-up operation, the speed of the reverse rotation of the crankshaft is increased before the crank angle reaches the start-up intake range in the reverse rotation start-up operation. Therefore, the fuel-air mixture is appropriately introduced into the first cylinder in the start-up intake range, and the crank angle easily reaches the start-up ignition range. Thus, the fuel-air mixture can be appropriately combusted in the first cylinder.

(5) The second compression range may include a positioning pressure reduction range, and the pressure reduction mechanism, in the forward rotation positioning operation, may reduce pressure in the second cylinder when the crank angle is in the positioning pressure reduction range.

In this case, even in the case where the crank angle becomes close to the angle corresponding to the compression top dead center of the second cylinder, an increase in pressure in the second cylinder is inhibited. Therefore, an increase in rotational resistance of the crankshaft is inhibited, so that the forward rotation of the crankshaft is not prevented. Thus, the crank angle can easily be adjusted in the reverse rotation start range.

(6) A difference between the crank angle in the case where a piston reaches a compression top dead center in the first cylinder and the crank angle in the case where a piston reaches a compression top dead center in the second cylinder may be 360 degrees.

In this case, during the normal running of the engine, the combustion of the fuel-air mixture in the first cylinder and the combustion of the fuel-air mixture in the second cylinder are performed at equal intervals. Even in such an engine, the fuel-air mixture can be appropriately combusted in the first cylinder during

the reverse rotation start-up operation. Thus, the engine can be appropriately started.

(7) A fuel injection device corresponding to the second cylinder, in the reverse rotation start-up operation, may inject fuel into an intake passage that leads air to the second cylinder after the crank angle exceeds the start-up intake range and before the crank angle reaches the start-up ignition range.

In this case, when the crank angle reaches the start-up ignition range, and the forward rotation of the crankshaft is started, the second cylinder is in the intake stroke. Therefore, the fuel is injected into the intake passage that leads air to the second cylinder before the crank angle reaches the start-up ignition range, whereby the fuel-air mixture is introduced into the second cylinder right after the start of the forward rotation of the crankshaft. Thus, in a first expansion stroke of the second cylinder, the fuel-air mixture can be combusted in the second cylinder. Therefore, the engine can be quickly started.

(8) A difference between the crank angle in the case where the piston reaches a compression top dead center in the first cylinder and the crank angle in the case where the piston reaches a compression top dead center in the second cylinder may be an angle other than 360 degrees.

In this case, during the normal running of the engine, the combustion of the fuel-air mixture in the first cylinder and the combustion of the fuel-air mixture in the second cylinder are performed at unequal intervals. Even in such an engine, the fuel-air mixture can be appropriately combusted in the first cylinder during the reverse rotation start-up operation. Thus, the engine can be appropriately started.

(9) The engine start-up operation may further include a forward rotation positioning operation of adjusting the crank angle in the reverse rotation start range by rotating the crankshaft in the forward direction before the reverse rotation start-up operation, and the pressure reduction mechanism, in the forward rotation positioning operation, may reduce pressure in at least one cylinder of the first and second cylinders.

[0014] In this case, because the crank angle is adjusted in the reverse rotation start range before the reverse rotation start-up operation, the fuel-air mixture can be appropriately introduced into the first cylinder in the reverse rotation start-up operation, and the fuel-air mixture can be sufficiently compressed. Thus, the fuel-air mixture can be appropriately combusted in the first cylinder.

[0015] Further, in the forward rotation positioning operation, because an increase in rotational resistance of the crankshaft caused by an increase in pressure in at least one cylinder of the first and second cylinders is inhibited, the forward rotation of the crankshaft is not prevented. Thus, the forward rotation positioning operation can be appropriately performed.

(10) The engine may further include an opening closing mechanism that opens and closes an intake port and an exhaust port of each of the first and second cylinders, ranges of a crank angle respectively corresponding to an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke of the first cylinder during normal running may be defined as a first intake range, a first compression range, a first expansion range and a first exhaust range, and ranges of the crank angle respectively corresponding to an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke of the second cylinder during the normal running may be defined as a second intake range, a second compression range, a second expansion range and a second exhaust range, the first intake range may include the reverse rotation start range, the first exhaust range includes a start-up intake range and the first expansion range includes a start-up ignition range, the rotation driver, in the forward rotation positioning operation, may rotate the crankshaft forward such that the crank angle reaches the reverse rotation start range, and in the reverse rotation start-up operation, may rotate the crankshaft in reverse such that the crank angle exceeds the start-up intake range from the reverse rotation start range and reaches the start-up ignition range, the opening closing mechanism, in the reverse rotation start-up operation, may open an intake port of the first cylinder when the crank angle is in the start-up intake range, a fuel injection device corresponding to the first cylinder, in the reverse rotation start-up operation, may inject fuel into an intake passage that leads air to the first cylinder such that, when the crank angle is in the start-up intake range, a fuel-air mixture is introduced into the first cylinder, an ignition device corresponding to the first cylinder, in the reverse rotation start-up operation, may ignite the fuel-air mixture in the first cylinder when the crank angle is in the start-up ignition range, the first compression range may include a positioning pressure reduction range, and the pressure reduction mechanism, in the forward rotation positioning operation, may reduce pressure in the first cylinder when the crank angle is in the positioning pressure reduction range.

[0016] In this case, the crank angle is adjusted in the reverse rotation start range by the forward rotation positioning operation, and then the crankshaft is rotated in reverse by the reverse rotation start-up operation such that the crank angle passes through the start-up intake range from the reverse rotation start range and reaches the start-up ignition range.

[0017] In the reverse rotation start-up operation, the intake port of the first cylinder is opened when the crank angle is in the start-up intake range, and the fuel-air mixture is introduced into the first cylinder. Thereafter, when the crank angle is in the start-up ignition range, the fuel-

air mixture in the first cylinder is ignited, and the crankshaft is driven in the forward direction by the energy of combustion.

[0018] Because the forward rotation positioning operation is performed before the reverse rotation start-up operation, the speed of the reverse rotation of the crankshaft is increased before the crank angle reaches the start-up intake range in the reverse rotation start-up operation. Thus, the fuel-air mixture is appropriately introduced into the first cylinder in the start-up intake range, and the crank angle easily reaches the start-up ignition range.

[0019] From the above, the fuel-air mixture can be appropriately combusted in the first cylinder, and a forward torque of the crankshaft can be sufficiently increased. As a result, the engine can be appropriately started.

[0020] Further, in the forward rotation positioning operation, when the crank angle is in the positioning pressure reduction range, the pressure in the first cylinder is reduced by the pressure reduction mechanism. In this case, even in the case where the crank angle becomes close to the angle corresponding to the compression top dead center of the first cylinder, an increase in pressure in the first cylinder is inhibited. Therefore, because an increase in rotational resistance of the crankshaft is inhibited, the forward rotation of the crankshaft is not prevented. Thus, the crank angle can easily be adjusted in the reverse rotation start range.

(11) At least part of the first intake range may be in the second compression range, and the crank angle, in the reverse rotation start-up operation, may reach the start-up ignition range without passing through an angle corresponding to a compression top dead center of each of the first and second cylinders.

[0021] In this case, in the reverse rotation start-up operation, because the crank angle does not pass through the angle corresponding to the compression top dead center of each of the first and second cylinders, the crankshaft can easily reach the start-up ignition range with no reduction in pressure in each of the first and second cylinders. Thus, the forward rotation positioning operation and the reverse rotation start-up operation can be appropriately performed with the simple configuration.

(12) The plurality of cylinders may further include a third cylinder, and the pressure reduction mechanism, in the reverse rotation operation, may reduce pressure in each of the second and third cylinders. In this case, in the reverse rotation start-up operation, an increase in rotational resistance of the crankshaft caused by an increase in pressure in the second or third cylinder is inhibited, and the reverse rotation of the crankshaft is not prevented. Thus, in the multi-cylinder engine having three or more cylinders, the reverse rotation start-up operation can be appropriately performed, and the engine can be appropriately

started.

(13) The engine start-up operation may include a forward rotation positioning operation of adjusting the crank angle in a predetermined reverse rotation start range by rotating the crankshaft in the forward direction before the reverse rotation start-up operation, and the pressure reduction mechanism, in the forward rotation positioning operation, may reduce pressure in each of the second and third cylinders.

[0022] In this case, because the crank angle is adjusted in the reverse rotation start range before the reverse rotation start-up operation, the fuel-air mixture can be appropriately introduced into the first cylinder in the reverse rotation start-up operation, and the crank angle can easily reach the start-up ignition range. Thus, the fuel-air mixture can be appropriately combusted in the first cylinder.

[0023] Further, in the forward rotation positioning operation, because an increase in rotational resistance of the crankshaft caused by an increase in pressure in the second or third cylinder is inhibited, the forward rotation of the crankshaft is not prevented. Thus, in the multi-cylinder engine having three or more cylinders, the forward rotation positioning operation can be appropriately performed.

(14) The pressure reduction mechanism may include a communication path that connects the second cylinder and the third cylinder to each other, and a communication path opening closing mechanism that switches the communication path between a communicated state and a closed state, and the communication path opening closing mechanism may reduce the pressure in each of the second and third cylinders by keeping the communication path in the communicated state.

In this case, an increase in rotational resistance of the crankshaft caused by an increase in pressure in the second or third cylinder can be inhibited with the simple configuration and by simple control.

(15) The communication path may have a first opening that opens in the second cylinder and a second opening that opens in the third cylinder, the communication path opening closing mechanism may include a first valve that opens and closes the first opening, a second valve that opens and closes the second opening, and a communication driver that integrally drives the first and second valves, and the communication driver may reduce the pressure in each of the second and third cylinders by opening the first and second openings by the first and second valves.

In this case, the communication path can be appropriately switched between the communicated state and the closed state with the simple configuration.

(16) According to another aspect of the present invention, a vehicle includes a main body having a

drive wheel, and the above-mentioned engine system that generates motive power for rotating the drive wheel.

In this vehicle, because the above-mentioned engine system is used, the engine can be appropriately started.

(17) The pressure reduction mechanism may be configured to reduce the pressure in the second cylinder in the start-up pressure reduction range when the crank angle is rotated at a rotation speed lower than a predetermined value.

In this case, the pressure in the second cylinder can be reduced during the reverse rotation start-up operation with the simple configuration.

(18) The pressure reduction mechanism may be configured to reduce the pressure in the first or second cylinder in the positioning pressure reduction range when the crankshaft is rotated at a rotation speed lower than the predetermined value.

[0024] In this case, the pressure in the first or second cylinder can be reduced during the forward rotation positioning operation with the simple configuration.

[Advantageous Effects of Invention]

[0025] The present invention enables the engine to be appropriately started.

[Brief Description of Drawings]

[0026]

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

[FIG. 2] Fig. 2 is a schematic side view for explaining a configuration of an engine system according to a first embodiment.

[FIG. 3] Fig. 3 is a schematic side view for explaining the configuration of the engine system according to the first embodiment.

[FIG. 4] Fig. 4 is a diagram for explaining an operation of an engine during normal running in the first embodiment.

[FIG. 5] Fig. 5 is a diagram for explaining the operation of the engine during the normal running in the first embodiment.

[FIG. 6] Fig. 6 is a diagram for explaining a forward rotation positioning operation of an engine unit in the first embodiment.

[FIG. 7] Fig. 7 is a diagram for explaining a reverse rotation start-up operation of the engine unit in the first embodiment.

[FIG. 8] Fig. 8 is a diagram showing a relationship between a rotational load of a crankshaft and a crank angle in the first embodiment.

[FIG. 9] Fig. 9 is a flow chart for explaining one ex-

ample of an engine start-up process in the first embodiment.

[FIG. 10] Fig. 10 is a flow chart for explaining one example of the engine start-up process in the first embodiment.

[FIG. 11] Fig. 11 is a diagram for explaining another example of the reverse rotation start-up operation in the first embodiment.

[FIG. 12] Fig. 12 is a diagram for explaining the other example of the reverse rotation start-up operation in the first embodiment.

[FIG. 13] Fig. 13 is a schematic side view for explaining a configuration of the engine system according to a second embodiment.

[FIG. 14] Fig. 14 is a diagram for explaining an operation of an engine during normal running in the second embodiment.

[FIG. 15] Fig. 15 is a diagram for explaining a forward rotation positioning operation of an engine unit in the second embodiment.

[FIG. 16] Fig. 16 is a diagram for explaining the forward rotation positioning operation of the engine unit in the second embodiment.

[FIG. 17] Fig. 17 is a diagram for explaining a reverse rotation start-up operation of the engine unit in the second embodiment.

[FIG. 18] Fig. 18 is a diagram for explaining the reverse rotation start-up operation of the engine unit in the second embodiment.

[FIG. 19] Fig. 19 is a diagram showing a relationship between a rotational load of the crankshaft and a crank angle in the second embodiment.

[FIG. 20] Fig. 20 is a flow chart of an engine start-up process in the second embodiment.

[FIG. 21] Fig. 21 is a schematic diagram showing one example of a valve driver in the second embodiment.

[FIG. 22] Fig. 22 is a perspective view showing a decompression mechanism in the second embodiment.

[FIG. 23] Fig. 23 is a schematic cross-sectional view for explaining an operation state of the decompression mechanism in the second embodiment.

[FIG. 24] Fig. 24 is a schematic cross-sectional view for explaining a non-operation state of the decompression mechanism in the second embodiment.

[FIG. 25] Fig. 25 is a diagram for explaining a configuration of an engine unit in a third embodiment.

[FIG. 26] Fig. 26 is a diagram for explaining normal running of an engine in the third embodiment.

[FIG. 27] Fig. 27 is a diagram for explaining the normal running of the engine in the third embodiment.

[FIG. 28] Fig. 28 is a diagram for explaining the normal running of the engine in the third embodiment.

[FIG. 29] Fig. 29 is a diagram showing a relationship between a rotational load of the crankshaft and a crank angle in the third embodiment.

[FIG. 30] Fig. 30 is a diagram for explaining a forward

rotation positioning operation in the third embodiment.

[FIG. 31] Fig. 31 is a diagram for explaining a reverse rotation start-up operation in the third embodiment.

[FIG. 32] Fig. 32 is a diagram showing a specific example of a decompression mechanism in the third embodiment.

[FIG. 33] Fig. 33 is a diagram for explaining an operation in each of second and third cylinders in the third embodiment.

[FIG. 34] Fig. 34 is a schematic diagram for explaining flows of gas during the forward rotation positioning operation in the third embodiment.

[FIG. 35] Fig. 35 is a diagram for explaining operations performed in the second and third cylinders in the third embodiment.

[FIG. 36] Fig. 36 is a schematic diagram for explaining flows of gas during the reverse rotation start-up operation in the third embodiment.

[FIG. 37] Fig. 37 is a diagram showing a relationship between the rotational load of the crankshaft and the crank angle during the forward rotation positioning operation and the reverse rotation start-up operation in the third embodiment.

[FIG. 38] Fig. 38 is a flow chart for explaining a cold start-up process in the third embodiment.

[FIG. 39] Fig. 39 is a flow chart for explaining the cold start-up process in the third embodiment.

[FIG. 40] Fig. 40 is a flow chart for explaining the reverse rotation start-up process in the third embodiment.

[Description of Embodiments]

[0027] An engine system and a vehicle according to embodiments of the present invention will be described below with reference to the drawings.

[A] Vehicle

[0028] Fig. 1 is a schematic side view showing a schematic configuration of a motorcycle according to one embodiment of the present invention. The motorcycle 100 of Fig. 1 is one example of the vehicle. In the motorcycle 100 of Fig. 1, a front fork 2 is provided in a front portion of a vehicle body 1 to be swingable in a left-and-right direction. A handle 4 is attached to the upper end of the front fork 2, and a front wheel 3 is rotatably attached to the lower end of the front fork 2.

[0029] A seat 5 is provided at an upper portion of substantially the center of the vehicle body 1. An ECU (Engine Control Unit) 6 and an engine unit EU are provided below the seat 5. The engine system 200 is constituted by the ECU 6 and the engine unit EU. A rear wheel 7 is rotatably attached to a lower portion of the rear end of the vehicle body 1. The rotation of the rear wheel 7 is driven by motive power generated by the engine unit EU.

[B] Engine System (First Embodiment)

(1) Configuration

[0030] Figs. 2 and 3 are schematic side views for explaining the configuration of the engine system 200 according to the first embodiment of the present invention. As shown in Fig. 2, the engine unit EU includes an engine 10 and an integrated starter generator 14. The engine 10 is a two-cylinder four-cycle engine and includes a first cylinder 31A and a second cylinder 31 B. A piston 11 is provided in each of the first and second cylinders 31A, 31 B. Each piston 11 is connected to a crankshaft 13 via a connecting rod 12. The reciprocating motion of each piston 11 is converted into the rotational motion of the crankshaft 13.

[0031] The integrated starter generator 14 is provided at the crankshaft 13. The integrated starter generator 14 is a generator having a function of a starter motor, drives the rotation of the crankshaft 13 in forward and reverse directions and generates electrical power by the rotation of the crankshaft 13. The forward direction is a rotation direction of the crankshaft 13 during normal running of the engine 10, and the reverse direction is the opposite direction. The integrated starter generator 14 directly transmits a torque to the crankshaft 13 without a reduction gear. The rotation of the rear wheel 7 is driven by the transmission of the rotation of the crankshaft 13 in the forward direction (the forward rotation) to the rear wheel 7. A starter motor and a generator may be independently provided instead of the integrated starter generator 14.

[0032] In Fig. 3, only the first cylinder 31A of the first and second cylinders 31A, 31B is shown. The configuration of the second cylinder 31 B and its peripheral portions is similar to the configuration of the first cylinder 31A and its peripheral portions.

[0033] As shown in Fig. 3, the engine 10 includes an intake valve 15, an exhaust valve 16, an ignition plug 18, an injector 19 and a valve driver 17. The intake valve 15, the exhaust valve 16, the ignition plug 18 and the injector 19 are provided to correspond to each of the first and second cylinders 31A, 31 B, and the valve driver 17 is commonly provided for the first and second cylinders 31A, 31 B.

[0034] In each of the first and second cylinders 31A, 31 B, a combustion chamber 31a is formed above a piston 11. The combustion chamber 31 a communicates with an intake passage 22 via an intake port 21 and communicates with an exhaust passage 24 via an exhaust port 23. The intake port 21 is opened and closed by the intake valve 15, and the exhaust port 23 is opened and closed by the exhaust valve 16. 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 that flows in 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 31a. The injector 19 is

configured to inject the fuel into the intake passage 22.

[0035] The engine 10 includes a decompression mechanism DE for reducing the pressure in the first cylinder 31A. The decompression mechanism DE reduces the pressure in the first cylinder 31A by lifting the exhaust valve 16 corresponding to the first cylinder 31A, for example.

[0036] 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 main switch 40, 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 main switch 40 is provided below the handle 4 of Fig. 1, for example, and the starter switch 41 is provided at the handle 4 of Fig. 1, for example. The main switch 40 and the starter switch 41 are operated by a rider. The intake pressure sensor 42 detects the 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 an electric current flowing in the integrated starter generator 14 (hereinafter referred to as a motor current).

[0037] Operations of the main switch 40 and the starter switch 41 are supplied to the ECU 6 as operation signals, and 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 signals and detection signals.

(2) Operation of Engine System

[0038] For example, the engine 10 is started by turning on the starter switch 41 of Fig. 3, and the engine 10 is stopped by turning off the main switch 40 of Fig. 3. Further, the engine 10 may be automatically stopped by satisfaction of a predetermined idle stop condition, and then the engine 10 may be automatically re-started by satisfaction of a predetermined idle stop release condition. The idle stop condition includes a condition related 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 becomes larger than 0 by an operation of an accelerator grip, for example. Hereinafter, the state of the engine 10 being automatically stopped by satisfaction of the idle stop condition is referred to as an idle stop state.

[0039] In the present embodiment, the engine 10 is started by an engine start-up operation and then shifted to the normal running. The engine start-up operation includes a forward rotation positioning operation and a reverse rotation start-up operation, described below. In the normal running, an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke are periodically repeated in each of the first and second cylinders

31A, 31B.

[0040] In the following description, a top dead center through which the piston 11 passes at the time of shifting from the compression stroke to the expansion stroke is referred to as a compression top dead center, and a top dead center through which the piston 11 passes at the time of shifting from the exhaust stroke to the intake stroke is referred to as an exhaust top dead center. Further, a bottom dead center through which the piston 11 passes at the 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 the time of shifting from the expansion stroke to the exhaust stroke is referred to as an expansion bottom dead center.

[0041] Further, ranges of the crank angles respectively corresponding to the intake stroke, the compression stroke, the expansion stroke and the exhaust stroke of the first cylinder 31A during the normal running are referred to as a first intake range, a first compression range, a first expansion range and a first exhaust range. Further, ranges of the crank angles respectively corresponding to the intake stroke, the compression stroke, the expansion stroke and the exhaust stroke of the second cylinder 31 B during the normal running are referred to as a second intake range, a second compression range, a second expansion range and a second exhaust range.

[0042] The crank angle is indicated in a range of 720 degrees (two rotations of the crankshaft 13). The crank angle sensor 43 of Fig. 3 detects a rotation position in a range of one rotation (360 degrees) of the crankshaft 13. The ECU 6 determines which rotation of the two rotations of the crankshaft 13, that are equivalent to one cycle of the engine 10, the rotation position detected by the crank angle sensor 43 corresponds to based on the pressure in the intake passage 22 detected by the intake pressure sensor 42. Thus, the ECU 6 can acquire the rotation position in the range of two rotations (720 degrees) of the crankshaft 13.

(2-1) Normal Running

[0043] Figs. 4 and 5 are diagrams for explaining the normal running of the engine 10. A relationship between operations performed in the first cylinder 31A and the crank angle is shown in Fig. 4, and a relationship between operations performed in the second cylinder 31 B and the crank angle is shown in Fig. 5. In each of Figs. 4 and 5, and a plurality of subsequent diagrams, the range of 720 degrees of the crank angle is indicated by one circle.

[0044] As shown in Fig. 4, in the first cylinder 31A, the piston 11 is positioned at the compression top dead center when the crank angle is an angle A1, the piston 11 is positioned at the expansion bottom dead center when the crank angle is an angle A2, the piston 11 is positioned at the exhaust top dead center when the crank angle is an angle A3, and the piston 11 is positioned at the intake bottom dead center when the crank angle is an angle A4.

[0045] During the normal running, the crankshaft 13 (Fig. 2) is rotated forward. During the forward rotation of the crankshaft 13, the crank angle changes in a direction of an arrow R1. In the first cylinder 31A, as indicated by arrows P11 to P14, the piston 11 (Fig. 2) falls in a range from the angle A1 to the angle A2, the piston 11 rises in a range from the angle A2 to the angle A3, the piston 11 falls in a range from the angle A3 to the angle A4, and the piston 11 rises in a range from the angle A4 to the angle A1.

[0046] The range from the angle A3 to the angle A4 is equivalent to a first intake range, the range from the angle A4 to the angle A1 is equivalent to a first compression range, the range from the angle A1 to the angle A2 is equivalent to a first expansion range, and the range from the angle A2 to the angle A3 is equivalent to a first exhaust range.

[0047] The intake port 21 (Fig. 3) is opened by the intake valve 15 (Fig. 3) in a range from an angle A11 to an angle A12, and the exhaust port 23 (Fig. 3) is opened by the exhaust valve 16 (Fig. 3) in a range from an angle A13 to an angle A14. The angle A11 is in the first exhaust range and positioned at a further advanced angle than the angle A3 by a constant angle in the forward direction, and the angle A12 is in the first compression range and positioned at a further retarded angle than the angle A4 by a constant angle in the forward direction. The angle A13 is in the first expansion range and positioned at a further advanced angle than the angle A2 by a constant angle in the forward direction, and the angle A14 is in the first intake range and positioned at a further retarded angle than the angle A3 by a constant range in the forward direction.

[0048] The fuel is injected into the intake passage 22 (Fig. 3) by the injector 19 (Fig. 3) at an angle A15 and ignited by the ignition plug 18 (Fig. 2) at an angle A16. The angle A15 is in the first exhaust range and positioned at a further advanced angle than the angle A11 in the forward direction. The angle A16 is in the first compression range and positioned at a further advanced angle than the angle A1 by a constant angle in the forward direction.

[0049] In this case, a fuel-air mixture including the fuel injected at the angle A15 is introduced into the combustion chamber 31a through the intake port 21 in the range from the angle A11 to the angle A12. The fuel-air mixture is compressed in the combustion chamber 31 a and ignited by the ignition plug 18 at the angle A16. Thus, the fuel-air mixture is combusted in the combustion chamber 31a, the piston 11 is driven by the energy of combustion, and the crankshaft 13 is driven in the forward direction. Thereafter, the combusted gas is exhausted from the combustion chamber 31 a through the exhaust port 23 in the range from the angle A13 to the angle A14.

[0050] As shown in Fig. 5, in the second cylinder 31 B, the piston 11 is positioned at an expansion bottom dead center when the crank angle is an angle A1, the piston 11 is positioned at an exhaust top dead center when the

crank angle is an angle A2, the piston 11 is positioned at an intake bottom dead center when the crank angle is an angle A3, and the piston 11 is positioned at a compression top dead center when the crank angle is an angle A4.

[0051] During the normal running, as indicated by arrows P21 to P24, the piston 11 (Fig. 2) 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, the piston 11 rises in a range from the angle A3 to the angle A4, and the piston 11 falls in a range from the angle A4 to the angle A1.

[0052] The range from the angle A2 to the angle A3 is equivalent to a second intake range, the range from the angle A3 to the angle A4 is equivalent to a second compression range, the range from the angle A4 to the angle A1 is equivalent to a second expansion range and the range from the angle A1 to the angle A2 is equivalent to a second exhaust range.

[0053] An intake port 21 (Fig. 3) is opened by an intake valve 15 (Fig. 3) in a range from an angle A21 to an angle A22, and an exhaust port 23 is opened by an exhaust valve 16 (Fig. 3) in a range from an angle A23 to an angle A24. The angle A21 is in the second exhaust range and positioned at a further advanced angle than the angle A2 by a constant angle in the forward direction, and the angle A22 is in the second compression range and positioned at a further retarded angle than the angle A3 by a constant range in the forward direction. The angle A23 is in the second expansion range and positioned at a further advanced angle than the angle A1 by a constant angle in the forward direction, and the angle A24 is in the second intake range and positioned at a further retarded angle than the angle A2 by a constant angle in the forward direction.

[0054] The fuel is injected into an intake passage 22 (Fig. 3) by an injector 19 (Fig. 3) at an angle A25 and ignited by an ignition plug 18 (Fig. 3) at an angle A26. The angle A25 is in the second exhaust range and positioned at a further advanced angle than the angle A21 in the forward direction. The angle A26 is in the second compression range and positioned at a further advanced angle than the angle A4 by a constant angle in the forward direction.

[0055] In this case, the fuel-air mixture including the fuel injected at the angle A25 is introduced into a combustion chamber 31a through the intake port 21 in the range from the angle A21 to the angle A22. The fuel-air mixture is compressed in the combustion chamber 31a and ignited by the ignition plug 18 at the angle A26. Thus, the fuel-air mixture is combusted in the combustion chamber 31a, the piston 11 is driven by the energy of combustion, and the crankshaft 13 is driven in the forward direction. Thereafter, the combusted gas is exhausted through the exhaust port 23 from the combustion chamber 31a in the range from the angle A23 to the angle A24.

[0056] In the present example, a difference between the crank angle in the case where the piston 11 reaches

the compression top dead center in the first cylinder 31A and the crank angle in the case where the piston 11 reaches the compression top dead center in the second cylinder 31 B is 180 degrees. Therefore, during the normal running, the fuel-air mixtures are combusted at unequal intervals in the first and second cylinders 31A, 31B. Specifically, an ignition operation is performed in the first cylinder 31A, and then the crankshaft 13 is rotated by 180 degrees. Thereafter, the ignition operation is performed in the second cylinder 31 B, then the crankshaft 13 is rotated by 540 degrees, and the ignition operation is performed again in the first cylinder 31A.

(2-2) Forward Rotation Positioning Operation and Reverse Rotation Start-up Operation

[0057] The engine unit EU performs the forward rotation positioning operation before the start-up of the engine 10 and performs the reverse rotation start-up operation during the start-up of the engine 10. Fig. 6 is a diagram for explaining the forward rotation positioning operation of the engine unit EU. Fig. 7 is a diagram for explaining the reverse rotation start-up operation of the engine unit EU.

[0058] In each of Figs. 6 and 7, a relationship between the operations performed in the first cylinder 31A and the crank angle is shown. In the present example, main operations related to the forward rotation positioning operation and the reverse rotation start-up operation are performed in the first cylinder 31A. Therefore, the operations performed in the first cylinder 31A will be mainly described.

[0059] As shown in Fig. 6, during the forward rotation positioning operation, the crank angle is adjusted to an angle A30 by the forward rotation of the crankshaft 13 by the integrated starter generator 14 (Fig. 3). The angle A30 is an example of a reverse rotation start range and in the first intake range. The angle A30 is preferably positioned at a further retarded angle than the angle A14 in the forward direction. The reverse rotation start range does not have to be a specific angle but may be a specific angular range.

[0060] At the time of the start of the forward rotation positioning operation, the crank angle is sometimes positioned at a further retarded angle than the angle A4 corresponding to the compression top dead center of the second cylinder 31 B and a further advanced angle than the angle A1 corresponding to the compression top dead center of the first cylinder 31A in the forward direction (an angle A30a of Fig. 6, for example). In this case, it is necessary that the crank angle exceeds the angle A1 corresponding to the compression top dead center of the first cylinder 31A in the forward rotation positioning operation.

[0061] In the forward rotation positioning operation, in the case where it is necessary that the crank angle exceeds the angle A1, the crankshaft 13 is rotated forward while the pressure in the first cylinder 31A is reduced by

the decompression mechanism DE. In the example of Fig. 6, the pressure in the first cylinder 31A is reduced by the decompression mechanism DE in a range from an angle AD1 to an angle AD2. The range from the angle AD1 to the angle AD2 is an example of a positioning pressure reduction range and in the first compression range.

[0062] Thus, even in the case where the crank angle becomes close to the angle A1, an increase in pressure in the first cylinder 31A is inhibited. Therefore, the forward rotation of the crank angle is not prevented, and the crank angle can easily be adjusted to the angle A30. A relationship between the forward rotation positioning operation and the decompression mechanism DE will be described below.

[0063] As shown in Fig. 7, in the reverse rotation start-up operation, the crankshaft 13 starts rotating in reverse with the crank angle in the reverse rotation start range (the angle A30). Thus, the crank angle changes in a direction of an arrow R2. During the reverse rotation of the crankshaft 13, as indicated by arrows P31 to P34, the piston 11 rises in a range from the angle A4 to the angle A3, the piston 11 falls in a range from the angle A3 to the angle A2, the piston 11 rises in a range from the angle A2 to the angle A1, and the piston 11 falls in a range from the angle A1 to the angle A4. The 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.

[0064] The intake port 21 (Fig. 3) is opened by the intake valve 15 (Fig. 3) in a range from an angle A31 to an angle A32. The fuel is injected into the intake passage 22 (Fig. 3) by the injector 19 (Fig. 3) at an angle A33 and ignited by the ignition plug 18 at an angle A34. Further, at the angle A34, the rotation direction of the crankshaft 13 is switched from the reverse direction to the forward direction.

[0065] The range from the angle A31 to the angle A32 is an example of a start-up intake range and in the first exhaust range. The angle A31 is preferably positioned at a further retarded angle than the angle A11 in the reverse direction. The angle A33 may be in the first exhaust range or the first intake range. The angle A33 is preferably positioned at a position further advanced angle than the angle A31 in the reverse direction. The angle A34 is an example of a start-up ignition range and in the first expansion range. The angle A34 is positioned at a further advanced angle than the angle A1 by a constant angle in the reverse direction.

[0066] The angles A31, A32 are in the range from the angle A3 to the angle A2 (the first exhaust range). As described above, the piston 11 falls in the range from the angle A3 to the angle A2. Therefore, a fuel-air mixture including air and the fuel is introduced into the combustion chamber 31 a through the intake port 21 from the intake passage 22 by opening of the intake port 21 in the range from the angle A31 to the angle A32. Thereafter, at the angle A34, the fuel-air mixture introduced into the

combustion chamber 31 a is ignited. Thus, the crankshaft 13 is driven in the forward direction by the energy of combustion of the fuel-air mixture, and a forward torque of the crankshaft 13 is increased.

[0067] Thereafter, the engine 10 is shifted to the normal running of the Figs. 4 and 5. Specifically, the fuel is injected into the intake passage 22 by the injector 19 corresponding to the second cylinder 31 B at an angle A25 right after the switching of the rotation directions of the crankshaft 13 (Fig. 5), and a fuel-air mixture is introduced into the second cylinder 31 B in a range from the angle A21 to the angle A22. Thereafter, the fuel-air mixture in the second cylinder 31 B is ignited by the ignition plug 18 corresponding to the second cylinder 31B at the angle A26.

[0068] In this manner, in the present embodiment, during the start-up of the engine 10, a fuel-air mixture is introduced into the first cylinder 31A while the crankshaft 13 is rotated in reverse by the integrated starter generator 14. Thereafter, in the first cylinder 31A, with the piston 11 close to the compression top dead center (with the crank angle close to the angle A1), the fuel-air mixture in the combustion chamber 31 a is ignited, and the rotation direction of the crankshaft 13 is switched to the forward direction. In this case, a forward torque of the crankshaft 13 is increased by the energy of combustion. Thus, the crank angle can easily exceed each of the angles A1, A4 corresponding to the compression top dead center of each of the first and second cylinders 31A, 31 B, and the engine 10 is stably started.

[0069] In the first cylinder 31A, during the reverse rotation of the crankshaft 13, the intake port 21 may be opened or does not have to be opened in the range of the crank angle that is the same as the range of the crank angle during the forward rotation (the range from the angle A12 to the angle A11 of Fig. 7). During the reverse rotation of the crankshaft 13, because the piston 11 rises in the range from the angle A4 to the angle A3, even if the intake port 21 is opened, air and fuel are hardly introduced into the combustion chamber 31a. Therefore, the reverse rotation start-up operation is hardly affected. Further, during the reverse rotation of the crankshaft 13, the exhaust port 23 may be opened or does not have to be opened in the range of the crank angle that is the same as the range of the crank angle during the forward rotation (the range from the angle A14 to the angle A13 of Fig. 7). Each of the intake port 21 and the exhaust port 23 is opened in the same range of the crank angle during each of the forward rotation and the reverse rotation of the crankshaft 13, whereby the configuration of the valve driver 17 can be simplified.

(3) Rotational Load of Crankshaft

[0070] Fig. 8 is a diagram showing a relationship between the rotational load of the crankshaft 13 and the crank angle. In Fig. 8, the abscissa indicates the crank angle, and the ordinate indicates the rotational load of

the crankshaft 13. The rotational load generated due to the first cylinder 31A is indicated by a solid line, and the rotational load generated due to the second cylinder 31 B is indicated by a one-dot and dash line. The total of the rotational load generated due to the first cylinder 31A and the rotational load generated due to the second cylinder 31 B is exerted on the crankshaft 13.

[0071] As for the first cylinder 31A, the rotational load is maximized at the angle A1 corresponding to the compression top dead center. Further, as for the second cylinder 31 B, the rotational load is maximized at the angle A4 corresponding to the compression top dead center.

[0072] Further, in the case where the valve driver 17 of Fig. 3 is made of a camshaft, a reaction force applied to the valve driver 17 when the valve driver 17 drives the intake valves 15 and the exhaust valves 16 becomes the rotational load of the valve driver 17. Because the valve driver 17 is rotated by the crankshaft 13, the rotational load of the valve driver 17 is the rotational load of the crankshaft 13.

[0073] In the example of Fig. 8, as for the first cylinder 31A, the rotational load of the crankshaft 13 increases in order to drive the intake valve 15 (Fig. 3) in the range from the angle A3 to the angle A4, and the rotational load of the crankshaft 13 increases in order to drive the exhaust valve 16 (Fig. 3) in the range from the angle A2 to the angle A3. Further, as for the second cylinder 31 B, the rotational load of the crankshaft 13 increases in order to drive the intake valve 15 in the range from the angle A2 to the angle A3, and the rotational load of the crankshaft 13 increases in order to drive the exhaust valve 16 in the range from the angle A1 to the angle A2.

[0074] When the engine 10 is stopped, the rotation of the crankshaft 13 is likely to be stopped in the case where the rotational load is large. Thus, the rotation of the crankshaft 13 is likely to be stopped mainly when the crank angle becomes close to each of the angles A1, A4 corresponding to the compression top dead center. Further, the rotation of the crankshaft 13 is sometimes stopped by the load for driving the intake valve 15 or the exhaust valve 16.

[0075] For example, the rotation of the crankshaft 13 is sometimes stopped with the crank angle positioned at a further retarded angle than the angle A33 and further advanced angle than the angle A34 in the reverse direction. If the reverse rotation start-up operation is started in that state, the crank angle does not pass through the angle A33. Therefore, the fuel is not injected, and a fuel-air mixture is not introduced into the first cylinder 31A. In the reverse rotation start-up operation, in order to inject the fuel and introduce a fuel-air mixture into the first cylinder 31A, it is necessary for the crankshaft 13 to be rotated in reverse such that the crank angle passes through a range from the angle A33 to the angle A32.

[0076] Further, in the reverse rotation start-up operation, in order to effectively introduce a fuel-air mixture into the first cylinder 31A, the rotation speed of the crankshaft 13 is preferably increased by the time when the

crank angle reaches the angle A31. Further, also in order to reliably let the crank angle reach the angle A34, the rotation speed of the crankshaft 13 is preferably and sufficiently increased. Thus, in the reverse direction, the reverse rotation start-up operation is preferably performed with the crank angle positioned at a more sufficiently further advanced angle than the angle A33.

[0077] On the other hand, the rotation of the crankshaft 13 is sometimes stopped with the crank angle positioned at a further retarded angle than the angle A1 and further advanced angle than the angle A4 in the reverse direction (with the crank angle positioned at the angle A30a of Figs. 6 and 8, for example). If the reverse rotation start-up operation is started in that state, a large rotational load is applied to the crankshaft 13 as the crank angle becomes close to the angle A4 corresponding to the compression top dead center of the second cylinder 31 B. Therefore, the reverse rotation of the crankshaft 13 is prevented.

[0078] Before the reverse rotation start-up operation, the crank angle is adjusted to the angle A30 by the forward rotation positioning operation. The angle A30 is positioned at a sufficiently further advanced angle than the angle A33 in the reverse direction. Therefore, in the case where the reverse rotation of the crankshaft 13 is started with the crank angle positioned at the angle A30, the crank angle passes through the range from the angle A33 to the angle A32, and the rotation speed of the crankshaft 13 is sufficiently increased at a time point at which the crank angle reaches the angle A31. Therefore, a fuel-air mixture is sufficiently introduced into the combustion chamber 31a in the range from the angle A31 to the angle A32, and the crank angle easily reaches the angle A34.

[0079] Further, because the angle A30 is positioned at a further retarded angle than the angle A4 in the reverse direction, the reverse rotation of the crankshaft 13 is not prevented during the reverse rotation start-up operation. Therefore, the fuel-air mixture can be appropriately combusted, and a forward torque of the crankshaft 13 can be sufficiently increased.

[0080] Further, as described above, in the forward rotation positioning operation, in the case where it is necessary for the crank angle to exceed the angle A1 corresponding to the compression top dead center of the first cylinder 31A, the crankshaft 13 is rotated forward while the pressure in the first cylinder 31 A is reduced by the decompression mechanism DE. Thus, the forward rotation of the crankshaft 13 is not prevented, and the crank angle can easily be adjusted to the angle A30.

[0081] The decompression mechanism DE may be configured to be switched between an operation state and a non-operation state by a centrifugal governor. For example, in the case where the rotation speed of the crankshaft 13 is lower than a constant threshold value, the decompression mechanism DE enters the operation state and lifts the exhaust valve 16 in the first compression range. Further, when the rotation speed of the crankshaft 13 becomes the constant threshold value or higher,

the decompression mechanism DE enters the non-operation state and does not lift the exhaust valve 16. In this case, the pressure in the first cylinder 31A can be reduced during the forward rotation positioning operation with the simple configuration.

[0082] Further, the decompression mechanism DE is preferably configured not to reduce the pressure in the first cylinder 31A with the crank angle positioned at a further advanced angle than the angle A1 in the reverse direction (the first expansion range). In this case, during the above-mentioned reverse rotation start-up operation, when the crank angle becomes close to the angle A1, the pressure in the first cylinder 31A is not reduced by the decompression mechanism DE. Thus, a reduction in energy acquired by the combustion of the fuel-air mixture is prevented.

[0083] Further, the decompression mechanism DE may be configured to reduce the pressure in the first cylinder 31A in a constant angular range only in the case where the rotation speed of the crankshaft 13 is lower than the constant threshold value and the crankshaft 13 is rotated forward. Furthermore, in this case, during the reverse rotation start-up operation, a reduction in pressure in the first cylinder 31A is prevented.

[0084] When the engine 10 is stopped, the rotation of the crankshaft 13 is sometimes stopped with the crank angle in the reverse rotation start range or near the reverse rotation start range. In that case, the forward rotation positioning operation does not have to be performed.

(4) Engine Start-up Process

[0085] The ECU 6 performs the engine start-up process based on a control program stored in advance in a memory. Figs. 9 and 10 are flow charts for explaining one example of the engine start-up process. The engine start-up process is performed in the case where the main switch 40 or the starter switch 41 of Fig. 3 is turned on, or the case where the engine 10 is shifted to the idle stop state.

[0086] As shown in Fig. 9, the ECU 6 first determines whether the current crank angle is stored in the memory (step S11). For example, the current crank angle is not stored right after the main switch 40 is turned on, and the current crank angle is stored during the idle stop state.

[0087] In the case where the current crank angle is not stored, the ECU 6 controls the integrated starter generator 14 such that the crank angle 13 is rotated forward (step S12). In this case, a torque of the integrated starter generator 14 is adjusted based on a detection signal from the current sensor 44 (Fig. 3) such that the crank angle does not reach the angle A4 (Fig. 8) corresponding to the compression top dead center of the second cylinder 31 B.

[0088] In the step S12, in the case where the crank angle passes through the angle A1 corresponding to the compression top dead center of the first cylinder 31A, the pressure in the first cylinder 31A is reduced by the

decompression mechanism DE as described above such that the forward rotation of the crankshaft 13 is not prevented.

[0089] Next, the ECU 6 determines whether a specified time period has elapsed since the start of the rotation of the crankshaft 13 in the step S12 (step S13). In the case where the specified time period has not elapsed, the ECU 6 controls the integrated starter generator 14 such that the rotation of the crankshaft 13 in the forward direction continues (step S12). In the case where the specified time period has elapsed, the ECU 6 controls the integrated starter generator 14 such that the rotation of the crankshaft 13 is stopped (step S14). Thus, the crank angle is adjusted in the reverse rotation start range (the angle A30 of Fig. 6).

[0090] In the step S12, the crank angle may be detected when the crankshaft 13 is rotated forward, and the crank angle may be adjusted in the reverse rotation start range based on the detected value.

[0091] On the other hand, in the step S11, in the case where the current crank angle is stored, the ECU 6 determines whether the current crank angle is in the reverse rotation start range (step S15). In the case where the current crank angle is not in the reverse rotation start range, the ECU 6 controls the integrated starter generator 14 such that the crankshaft 13 is rotated forward (step S16). In this case, a torque of the integrated starter generator 14 is adjusted based on a detection signal from the current sensor 44 (Fig. 3) such that the crank angle does not reach the angle A4 corresponding to the compression top dead center of the second cylinder 31 B (Fig. 8).

[0092] Similarly to the above-mentioned step S12, in the step S16, in the case where the crank angle passes through the angle A1 corresponding to the compression top dead center of the first cylinder 31A, the pressure in the first cylinder 31A is reduced by the decompression mechanism DE such that the forward rotation of the crankshaft 13 is not prevented.

[0093] Next, the ECU 6 determines whether the current angle has reached the reverse rotation start range based on detection signals from the intake pressure sensor 42 and the crank angle sensor 43 (step S17). In the case where the current crank angle has not reached the reverse rotation start range, the ECU 6 controls the integrated starter generator 14 such that the rotation of the crankshaft 13 in the forward direction continues (step S16). In the case where the current crank angle has reached the reverse rotation start range, the ECU 6 controls the integrated starter generator 14 such that the rotation of the crankshaft 13 is stopped (step S14). Thus, the crank angle is adjusted in the reverse rotation start range.

[0094] In the process of the steps S16, S17, as compared to the process of the above-mentioned steps S12, S13, the crank angle is accurately adjusted, and power consumption by the integrated starter generator 14 is inhibited.

[0095] The crank angle is adjusted in the reverse rotation start range by the forward rotation of the crankshaft 13, and then the process of the step S21 of Fig. 10 is performed. Further, in the step S15, in the case where the current crank angle is in the reverse rotation start range, the process of the step S21 of Fig. 10 is performed as it is.

[0096] As shown in Fig. 10, in the step S21, the ECU 6 determines whether a predetermined start-up condition of the engine 10 is satisfied. The start-up condition of the engine 10 is that the starter switch 41 (Fig. 3) is turned on, or that the idle stop release condition is satisfied, for example.

[0097] In the case where the start-up condition of the engine 10 is satisfied, the ECU 6 controls the integrated starter generator 14 such that the crankshaft 13 is rotated in reverse (step S22). Next, the ECU 6 determines whether the current crank angle has reached the angle A33 of Fig. 7 based on detection signals from the intake pressure sensor 42 (Fig. 3) and the crank angle sensor 43 (Fig. 3) (step S23). The ECU 6 repeats the process of the step S23 until the current crank angle reaches the angle A33.

[0098] When the current crank angle reaches the angle A33, the ECU 6 controls the injector 19 corresponding to the first cylinder 31 A such that the fuel is injected into the intake passage 22 (Fig. 3) (step S24). In this case, a pulse signal may be supplied to the ECU 6 from the crank angle sensor 43 when the crank angle reaches the angle A33, and the ECU 6 may control the injector 19 such that the fuel is injected in response to the pulse signal.

[0099] Next, the ECU 6 determines whether the motor current has reached a predetermined threshold value based on a detection signal from the current sensor 44 (step S25). In this case, the closer the crank angle is to the angle A1 of Fig. 7, the larger the motor current is. In the present example, when the crank angle reaches the angle A34 of Fig. 7, the motor current reaches the threshold value. In the case where the motor current has not reached the threshold value, the ECU 6 repeats the process of the step S25.

[0100] In the case where the motor current reaches the predetermined threshold value, the ECU 6 controls the integrated starter generator 14 such that the reverse rotation of the crankshaft 13 is stopped (step S26), and the fuel-air mixture in the combustion chamber 31a is ignited by the ignition plug 18 corresponding to the first cylinder 31 A (step S27). Further, the ECU 6 controls the integrated starter generator 14 such that the crankshaft 13 is rotated forward (step S28). Thus, the ECU 6 ends the engine start-up process, and the engine 10 is shifted to the normal running. The driving of the crankshaft 13 by the integrated starter generator 14 is stopped after a constant time period has elapsed since the process of the step S28, for example.

[0101] In the present example, whether the crank angle has reached the start-up ignition range (the angle A34) is determined based on the motor current. However, the present invention is not limited to this. For example,

whether the crank angle has reached the start-up ignition range may be determined based on the current crank angle detected by the intake pressure sensor 42 (Fig. 3) and the crank angle sensor 43 (Fig. 3).

[0102] Further, in the case where the reverse rotation of the crankshaft 13 is started in the step S22 and then a predetermined time period has elapsed with the crank angle not reaching the start-up ignition range, it is determined that the trouble with the engine unit EU has occurred, so that the reverse rotation start-up operation may be stopped. The trouble with the engine unit EU includes an operational problem with the integrated starter generator 14 or an operational problem with the valve driver 17.

(5) Effects

[0103] In the engine system 200 according to the present embodiment, a fuel-air mixture is led into the first cylinder 31A while the crankshaft 13 is rotated in reverse, and the fuel-air mixture is ignited with the piston 11 close to the compression top dead center, by the reverse rotation start-up operation. The crankshaft 13 is driven in the forward direction by the energy of combustion of the fuel-air mixture. In this case, because a time period from the time when the fuel-air mixture is introduced into the first cylinder 31A until the time when the fuel-air mixture is ignited is short, a fuel-air ratio at the time of ignition can be appropriately adjusted.

[0104] Further, before the reverse rotation start-up operation, the crank angle is adjusted in the reverse rotation start range (the angle A30) by the forward rotation positioning operation. Thus, a fuel-air mixture can be appropriately introduced into the first cylinder 31A in the reverse rotation start-up operation, and the crank angle can easily reach the start-up ignition range (the angle A34).

[0105] From the above, the fuel-air mixture can be appropriately combusted in the first cylinder 31A, and a forward torque of the crankshaft 13 can be sufficiently increased. As a result, the engine 10 can be appropriately started.

[0106] Further, in the forward rotation positioning operation, when the crank angle is in the positioning pressure reduction range (the range from the angle AD1 to the angle AD2), the pressure in the first cylinder 31A is reduced by the decompression mechanism DE. In this case, even if the crank angle becomes close to the angle A1 corresponding to the compression top dead center of the first cylinder 31A, an increase in pressure in the first cylinder 31A is inhibited. Therefore, an increase in rotational resistance of the crankshaft 13 is inhibited, and the forward rotation of the crankshaft 13 is not prevented. Thus, the crank angle can easily be adjusted in the reverse rotation start range.

[0107] Further, in the reverse rotation start-up operation of the present embodiment, because the crank angle does not pass through the angles A1, A4 respectively

corresponding to the compression top dead centers of the first and second cylinders 31A, 31 B, the crank angle can easily reach the start-up ignition range (the angle A34) with no reduction in pressure in the first and second cylinders 31A, 31B. Thus, the forward rotation positioning operation and the reverse rotation start-up operation can be appropriately performed with the simple configuration.

(6) Another Example of Reverse Rotation Start-up Operation

[0108] In the case where the engine 10 is stopped with the crank angle in the first compression range, the reverse rotation start-up operation may be performed without the forward rotation positioning operation. Figs. 11 and 12 are diagrams for explaining another example of the reverse rotation start-up operation. In the examples of Figs. 11 and 12, the reverse rotation start-up operation is performed with the crank angle at an angle A70 in the first compression range. As indicated by arrows P71 to P74, in the second cylinder 31 B, during the reverse rotation of the crankshaft 13, the piston 11 rises in the range from the angle A1 to the angle A4, the piston 11 falls in the range from the angle A4 to the angle A3, the piston 11 rises in the range from the angle A3 to the angle A2, and the piston 11 falls in the range from the angle A2 to the angle A1.

[0109] In this case, it is necessary for the crank angle to exceed the angle A4 corresponding to the compression top dead center of the second cylinder 31 B. The crankshaft 13 is rotated in reverse while the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE. In the example of Fig. 12, the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE in a range from an angle AD7 to an angle AD8. The range from the angle AD7 to the angle AD8 is an example of a start-up pressure reduction range and in the second expansion range. Thus, even in the case where the crank angle becomes close to the angle A4, an increase in pressure in the second cylinder 31 B is inhibited. Therefore, the reverse rotation of the crankshaft 13 is not prevented.

[0110] The angle A70 is positioned at a sufficiently further advanced angle than the angle A31 of Fig. 11 in the reverse direction. Therefore, the reverse rotation of the crankshaft 13 is started with the crank angle at the angle A70, whereby the crank angle passes through the range from the angle A33 to the angle A32 of Fig. 11, and the rotation speed of the crankshaft 13 is sufficiently increased at a time point at which the crank angle reaches the angle A31. Therefore, a fuel-air mixture is sufficiently introduced into the combustion chamber 31a in the range from the angle A31 to the angle A32, and the crank angle easily reaches the angle A34.

[0111] In this manner, also in the present embodiment, during the start-up of the engine 10, a fuel-air mixture is led into the first cylinder 31A while the crankshaft 13 is rotated in reverse by the integrated starter generator 14.

Thereafter, in the first cylinder 31A, with the piston 11 close to the compression top dead center, the fuel-air mixture in the combustion chamber 31 a is ignited, and the rotation direction of the crankshaft 13 is switched to the forward direction. In this case, a forward torque of the crankshaft 13 is increased by the energy of combustion. Thus, the crank angle can easily exceed each of the angles A1, A4 corresponding to the compression top dead center of each of the first and second cylinders 31A, 31 B, and the engine 10 is appropriately started.

[0112] As shown in the examples of Figs. 11 and 12, in the case where the engine 10 is stopped with the crank angle in the first compression range (the second expansion range), the crank angle may be adjusted to the angle A30 of Fig. 6 by the reverse rotation of the crankshaft 13 before the start-up of the engine 10 (before the reverse rotation start-up operation). In this case, the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE while the crankshaft 13 is rotated in reverse, whereby the crank angle exceeds the angle A4 corresponding to the compression top dead center of the second cylinder 31 B. Thus, the crank angle can be adjusted to the angle A30. Therefore, similarly to the example of Fig. 6, the reverse rotation start-up operation can be started with the crank angle at the angle A30.

[C] Engine System (Second Embodiment)

[0113] As for the engine system according to the second embodiment of the present invention, differences from the above-mentioned first embodiment will be described. Fig. 13 is a schematic side view for explaining the configuration of the engine system 200 according to the second embodiment. In the engine system 200 of Fig. 13, a difference between a crank angle in the case where the piston 11 reaches the compression top dead center in the first cylinder 31A and a crank angle in the case where the piston 11 reaches the compression top dead center in the second cylinder 31 B is 360 degrees. Therefore, in a top-and-bottom direction (a reciprocating direction of the pistons 11), a position of the piston 11 in the first cylinder 31A and a position of the piston 11 in the second cylinder 31 B coincide with each other.

(1) Normal Running

[0114] Fig. 14 is a diagram for explaining the normal running of the engine 10. A relationship between operations performed in the first cylinder 31A and the crank angle is shown in Fig. 14(a), and a relationship between operations performed in the second cylinder 31 B and the crank angle is shown in Fig. 14(b).

[0115] As shown in Fig. 14(a), a relationship between the operations performed in the first cylinder 31A and the crank angle during the normal running is the same as the example of Fig. 4 in the first embodiment. As shown in Fig. 14(b), in the second cylinder 31B, the piston 11 is positioned at the exhaust top dead center when the crank

angle is the angle A1, the piston 11 is positioned at the intake bottom dead center when the crank angle is the angle A2, the piston 11 is positioned at the compression top dead center when the crank angle is the angle A3, and the piston 11 is positioned at the expansion bottom dead center when the crank angle is the angle A4.

[0116] During the normal running, as indicated by arrows P41 to P44, the piston 11 (Fig. 2) falls in the range from the angle A1 to the angle A2, the piston 11 rises in the range from the angle A2 to the angle A3, the piston 11 falls in the range from the angle A3 to the angle A4, and the piston 11 rises in the range from the angle A4 to the angle A1.

[0117] The range from the angle A1 to the angle A2 is equivalent to the second intake range, the range from the angle A2 to the angle A3 is equivalent to the second compression range, the range from the angle A3 to the angle A4 is equivalent to the second expansion range, and the range from the angle A4 to the angle A1 is equivalent to the second exhaust range.

[0118] The intake port 21 (Fig. 3) is opened by the intake valve 15 (Fig. 3) in a range from an angle A41 to an angle A42, and the exhaust port 23 (Fig. 3) is opened by the exhaust valve 16 (Fig. 3) in a range from an angle A43 to an angle A44. The angle A41 is in the second exhaust range and positioned at a further advanced angle than the angle A1 by a constant angle in the forward direction, and the angle A42 is in the second compression range and positioned at a further retarded angle than the angle A2 by a constant angle in the forward direction. The angle A43 is in the second expansion range and positioned at a further advanced angle than the angle A4 by a constant angle in the forward direction, and the angle A44 is in the second intake range and positioned at a further retarded angle than the angle A1 by a constant angle in the forward direction.

[0119] The fuel is injected into the intake passage 22 (Fig. 3) by the injector 19 (Fig. 3) at an angle A45 and ignited by the ignition plug 18 (Fig. 3) at an angle A46. The angle A45 is in the second exhaust range and positioned at a further advanced angle than the angle A41 in the forward direction. The angle A46 is in the second compression range and positioned at a further advanced angle than the angle A3 by a constant angle in the forward direction.

[0120] In this case, a fuel-air mixture including the fuel injected at the angle A45 is introduced into the combustion chamber 31a through the intake port 21 in the range from the angle A41 to the angle A42. The fuel-air mixture is compressed in the combustion chamber 31 a and ignited by the ignition plug 18 at the angle A46. Thus, the fuel-air mixture is combusted in the combustion chamber 31a, the piston 11 is driven by the energy of combustion, and the crankshaft 13 is driven in the forward direction. Thereafter, the combusted gas is exhausted through the exhaust port 23 from the combustion chamber 31a in the range from the angle A43 to the angle A44.

[0121] In this manner, in the second embodiment, the

difference between the crank angle in the case where the piston 11 reaches the compression top dead center in the first cylinder 31A and the crank angle in the case where the piston 11 reaches the compression top dead center in the second cylinder 31 B is 360 degrees. Therefore, during the normal running, a fuel-air mixture is combusted at equal intervals in the first and second cylinders 31A, 31B. Specifically, the ignition operation is performed in the first cylinder 31A, the crankshaft 13 is rotated by 360 degrees, and then the ignition operation is performed in the second cylinder 31 B. Further, the crankshaft 13 is rotated by 360 degrees, and then the ignition operation is performed again in the first cylinder 31A.

(2) Forward Rotation Positioning Operation and Reverse Rotation Start-up Operation

[0122] Figs. 15 and 16 are diagrams for explaining the forward rotation positioning operation of the engine unit EU. Figs. 17 and 18 are diagrams for explaining the reverse rotation start-up operation of the engine unit EU. In each of Figs. 15 and 17, a relationship between operations performed in the first cylinder 31A and the crank angle is shown. In each of Figs. 16 and 18, a relationship between operations performed in the second cylinder 31 B and the crank angle is shown.

[0123] As shown in Fig. 15, in the forward rotation positioning operation, the crank angle is adjusted to an angle A50 by the forward rotation of the crankshaft 13 by the integrated starter generator 14 (Fig. 3). The angle A50 is an example of the reverse rotation start range and in the first compression range. The reverse rotation start range does not have to be a specific angle but may be a specific angular range. The reverse rotation start range may be in the first intake range or be a constant angular range from an angle in the first intake range to an angle in the first compression range.

[0124] At the time of the start of the forward rotation positioning operation, the crank angle is sometimes positioned at a further retarded angle than the angle A1 corresponding to the compression top dead center of the first cylinder 31A and a further advanced angle than the angle A3 corresponding to the compression top dead center of the second cylinder 31B (an angle A50a of Fig. 15, for example) in the forward direction. In this case, in the forward rotation positioning operation, it is necessary for the crank angle to exceed the angle A3 corresponding to the compression top dead center of the second cylinder 31 B.

[0125] In the second embodiment, the decompression mechanism DE of Fig. 3 is configured to reduce the pressure in the second cylinder 31 B. The decompression mechanism DE reduces the pressure in the second cylinder 31 B by lifting the exhaust valve 16 corresponding to the second cylinder 31 B, for example.

[0126] In the forward rotation positioning operation, in the case where it is necessary for the crank angle to exceed the angle A3, the crankshaft 13 is rotated forward

while the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE. In the example of Fig. 16, the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE in a range from an angle AD3 to an angle AD4 while the crankshaft 13 is rotated forward. The range from the angle AD3 to the angle AD4 is an example of the positioning pressure reduction range and in the second compression range.

[0127] Thus, even if the crank angle becomes close to the angle A3, an increase in pressure in the second cylinder 31 B is inhibited. Therefore, the forward rotation of the crankshaft 13 is not prevented, and the crank angle can easily be adjusted to the angle A50.

[0128] As shown in each of Figs. 17 and 18, in the reverse rotation start-up operation, the crankshaft 13 is rotated in reverse with the crank angle in the reverse rotation start range (the angle A50). As indicated by arrows P51 to P54 of Fig. 18, in the second cylinder 31 B, the piston 11 rises in the range from the angle A4 to the angle A3, the piston 11 falls in the range from the angle A3 to the angle A2, the piston 11 rises in the range from the angle A2 to the angle A1, and the piston 11 falls in the range from the angle A1 to the angle A4.

[0129] In the first cylinder 31A, similarly to the above-mentioned embodiment, the intake port 21 (Fig. 3) is opened by the intake valve 15 (Fig. 3) in the range from the angle A31 to the angle A32 of Fig. 17, and the fuel is injected into the intake passage 22 (Fig. 3) by the injector 19 (Fig. 3) at the angle A33. Further, at the angle A34, the fuel is ignited by the ignition plug 18, and the rotation direction of the crankshaft 13 is switched from the reverse direction to the forward direction. Thus, the fuel-air mixture is combusted in the first cylinder 31A, and the crankshaft 13 is driven in the forward direction by the energy of combustion of the fuel-air mixture.

[0130] In the reverse rotation start-up operation, it is necessary for the crank angle to exceed the angle A3 corresponding to the compression top dead center of the second cylinder 31 B. The crankshaft 13 is rotated in reverse while the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE. In the example of Fig. 18, the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE in a range from an angle AD5 to an angle AD6 while the crankshaft 13 is rotated in reverse. The range from the angle AD5 to the angle AD6 is an example of the start-up pressure reduction range and in the second expansion range. Thus, even in the case where the crank angle becomes close to the angle A3, an increase in pressure in the second cylinder 31 B is inhibited. Therefore, the reverse rotation of the crankshaft 13 is not prevented.

[0131] The angle A50 is positioned at a sufficiently further advanced angle than the angle A31 (Fig. 17) in the reverse direction. Therefore, the reverse rotation of the crankshaft 13 is started with the crank angle at the angle A50, whereby the crank angle passes through the range from the angle A33 to the angle A32, and the rotation speed of the crankshaft 13 is sufficiently increased at a

time point at which the crank angle reaches the angle A31. Therefore, a fuel-air mixture is sufficiently introduced into the combustion chamber 31 a in the range from the angle A31 to the angle A32, and the crank angle easily reaches the angle A34.

[0132] Further, as shown in Fig. 18, in the reverse rotation start-up operation, when the crank angle reaches an angle A47, the fuel is injected into the intake passage 22 by the injector 19 (Fig. 3) corresponding to the second cylinder 31B. The angle A47 is in the second intake range and positioned at a further advanced angle than the angle A34 in the reverse direction.

[0133] At the angle A34, the rotation direction of the crankshaft 13 is switched from the reverse direction to the forward direction. At this time, the second cylinder 31 B is in the intake stroke. Therefore, the fuel-air mixture including the fuel injected at the angle A47 is introduced into the second cylinder 31 B right after the rotation direction of the crankshaft 13 is switched to the forward direction at the angle A34. Thus, in a first expansion stroke after the rotation direction of the crankshaft 13 is switched to the forward direction, the fuel-air mixture can be combusted in the second cylinder 31 B. Therefore, the engine 10 can be quickly shifted to the normal running of Fig. 14.

[0134] In this manner, also in the present embodiment, during the start-up of the engine 10, a fuel-air mixture is led into the first cylinder 31A while the crankshaft 13 is rotated in reverse by the integrated starter generator 14. Thereafter, in the first cylinder 31A, with the piston 11 close to the compression top dead center, the fuel-air mixture in the combustion chamber 31a is ignited, and the rotation direction of the crankshaft 13 is switched to the forward direction. In this case, a forward torque of the crankshaft 13 is increased by the energy of combustion. Thus, the crank angle can easily exceed each of the angles A1, A3 corresponding to the compression top dead center of each of the first and second cylinders 31A, 31B, and the engine 10 is stably started.

(3) Rotational Load of Crankshaft

[0135] Fig. 19 is a diagram showing the relationship between the rotational load of the crankshaft 13 and the crank angle. As for the example of Fig. 19, differences from the example of Fig. 8 will be explained. In the example of Fig. 19, as for the second cylinder 31 B, the rotational load is maximized at the angle A3 corresponding to the compression top dead center. Further, in the case where the valve driver 17 of Fig. 3 is made of a camshaft, as for the second cylinder 31 B, the rotational load of the crankshaft 13 is increased in order to drive the intake valve 15 in the range from the angle A1 to the angle A2, and the rotational load of the crankshaft 13 is increased in order to drive the exhaust valve 16 in the range from the angle A4 to the angle A1.

[0136] When the engine 10 is stopped, the rotation of the crankshaft 13 is likely to be stopped in the case where

the rotational load is large. Thus, the rotation of the crankshaft 13 is likely to be stopped mainly when the crank angle becomes close to each of the angles A1, A3 corresponding to the compression top dead center.

[0137] Similarly to the first embodiment, in the reverse direction, the reverse rotation start-up operation is preferably performed with the crank angle positioned at a sufficiently further advanced angle than the angle A33. Thus, before the reverse rotation start-up operation, the crank angle is adjusted to the angle A50 by the forward rotation positioning operation. The angle A50 is positioned at a sufficiently further advanced angle than the angle A33 in the reverse direction. Therefore, when the reverse rotation of the crankshaft 13 is started with the crank angle at the angle A50, the crank angle passes through the range from the angle A33 to the angle A32, and the rotation speed of the crankshaft 13 is sufficiently increased at a time point at which the crank angle reaches the angle A31. Therefore, a fuel-air mixture is sufficiently introduced into the combustion chamber 31a in the range from the angle A31 to the angle A32, and the crank angle easily reaches the angle A34.

[0138] Further, in the forward rotation positioning operation, in the case where it is necessary for the crank angle to exceed the angle A3 corresponding to the compression top dead center of the second cylinder 31 B, the crankshaft 13 is rotated forward while the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE. Thus, the forward rotation of the crankshaft 13 is not prevented and the crank angle can easily be adjusted to the angle A50.

[0139] Similarly to the first embodiment, the decompression mechanism DE may be configured to be switched between the operation state and the non-operation state by the centrifugal governor. For example, in the case where the rotation speed of the crankshaft 13 is lower than the constant threshold value, the decompression mechanism DE enters the operation state and lifts the exhaust valve 16 in the second compression range. Further, when the rotation speed of the crankshaft 13 is the constant threshold value or higher, the decompression mechanism DE enters the non-operation state and does not lift the exhaust valve 16. In this case, the pressure in the second cylinder 31B can be reduced during the forward rotation positioning operation with the simple configuration.

[0140] When the engine 10 is stopped, the rotation of the crankshaft 13 is sometimes stopped with the crank angle in the reverse rotation start range or near the reverse rotation start range. In this case, the forward rotation positioning operation does not have to be performed.

(4) Engine Start-up Process

[0141] As for the engine start-up process in the second embodiment, differences from the example of Figs. 9 and 10 of the first embodiment will be described. Fig. 20 is a flow chart of part of the engine start-up process in the

second embodiment.

[0142] First, the crank angle is adjusted in the reverse rotation start range by the process of the steps S11 to S17 of Fig. 9. In the steps S12, S16 of Fig. 9, in the case where the crank angle passes through the angle A3 corresponding to the compression top dead center of the second cylinder 31 B, the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE such that the forward rotation of the crankshaft 13 is not prevented.

[0143] Subsequently, the process of the step S21 of Fig. 20 is performed. The example of Fig. 20 is different from the example of Fig. 10 in that the process of the steps S31, S32 is performed after the process of the step S24 and before the process of the step S25.

[0144] In the step S31, the ECU 6 determines whether the current crank angle has reached the angle A47 of Fig. 18 based on detection signals from the intake pressure sensor 42 (Fig. 3) and the crank angle sensor 43 (Fig. 3). The ECU 6 repeats the process of the step S31 until the current crank angle reaches the angle A47.

[0145] When the current crank angle reaches the angle A47, the ECU 6 controls the injector 19 corresponding to the second cylinder 31 B such that the fuel is injected into the intake passage 22 (Fig. 3) (step S32). In this case, a pulse signal may be supplied from the crank sensor 43 to the ECU 6 when the crank angle reaches the angle A47, and the ECU 6 may control the injector 19 such that the fuel is injected in response to the pulse signal.

[0146] Thus, as described above, a fuel-air mixture is introduced into the second cylinder 31 B right after the rotation direction of the crankshaft 13 is switched to the forward direction at the angle A34. Therefore, the engine 10 can be quickly shifted to the normal running.

(5) Specific Example of Decompression Mechanism

[0147] The specific example of the decompression mechanism DE in the second embodiment will be described. Fig. 21 is a schematic diagram showing one example of the valve driver 17. The valve driver 17 of Fig. 21 includes an intake camshaft 171 and an exhaust camshaft 172. Each of the intake camshaft 171 and the exhaust camshaft 172 is rotated in conjunction with the crankshaft 13. The intake camshaft 171 includes a plurality of intake cams 173 that respectively drive the intake valves 15 of the first and second cylinders 31A, 31B. The exhaust camshaft 172 includes a plurality of exhaust cams 174 that respectively drive the exhaust valves 16 of the first and second cylinders 31A, 31 B. In Fig. 21, only one intake cam 173 and one exhaust cam 174 are shown.

[0148] In the present example, the decompression mechanism DE is provided in the exhaust cam 174. Fig. 22 is a perspective view of the decompression mechanism DE. In Fig. 22, part of the exhaust cam 174 is shown in a transmissive manner.

[0149] The exhaust cam 174 of Fig. 22 drives the exhaust valve 16 (Fig. 21) corresponding to the second cylinder 31 B. The exhaust cam 174 of Fig. 22 includes a cam member CA and the decompression mechanism DE. The cam member CA lifts the exhaust valve 16 corresponding to the second cylinder 31 B in the range from the angle A43 to the angle A44 of Fig. 14(b).

[0150] The decompression mechanism DE includes a rotation member 61, decompression pins 62, 63, a coupling member 64, a decompression weight 65 and a stopper pin 66. The rotation member 61 and the decompression pins 62, 63 are stored inside of the cam member CA. The rotation member 61 is substantially columnar and provided to be rotatable about a straight line parallel to a rotational center axis of the exhaust cam 174 with respect to the cam member CA. Each of the decompression pins 62, 63 is provided to abut against an outer peripheral surface of the rotation member 61.

[0151] The coupling member 64, the decompression weight 65 and the stopper pin 66 are provided on one surface of the cam member CA. One end of the coupling member 64 is fixed to the rotation member 61. A projection pin 64a is provided at the other end of the coupling member 64.

[0152] The decompression weight 65 is substantially U-shaped. One end of the decompression weight 65 is attached to the cam member CA via a swing shaft 65a. The decompression weight 65 is swingable with respect to the cam member CA by being centered at the swing shaft 65a. An oval through hole 65b is provided at the other end of the decompression weight 65. The projection pin 64a of the coupling member 64 is inserted into the through hole 65b.

[0153] The decompression weight 65 swings with respect to the cam member CA, whereby the coupling member 64 swings in conjunction with the decompression weight 65, and the rotation member 61 is rotated with respect to the cam member CA. The stopper pin 66 is provided between the coupling member 64 and the decompression weight 65. Swing ranges of the coupling member 64 and the decompression weight 65 are limited by the stopper pin 66.

[0154] The rotation speed of the exhaust camshaft 172 of Fig. 21 depends on the rotation speed of the crankshaft 13. The decompression mechanism DE is switched between the operation state and the non-operation state depending on the rotation speed of the exhaust camshaft 172, that is, the rotation speed of the crankshaft 13. In the case where the rotation speed of the crankshaft 13 is lower than the constant threshold value, the decompression mechanism DE is kept in the operation state. In the case where the rotation speed of the crankshaft 13 is the constant threshold value or higher, the decompression mechanism DE is kept in the non-operation state.

[0155] The operation of the decompression mechanism DE will be described. Fig. 23 is a schematic cross-sectional view for explaining the operation state of the

decompression mechanism DE. Fig. 24 is a schematic cross-sectional view for explaining the non-operation state of the decompression mechanism DE. In each of Figs. 23 and 24, a cross-section of the cam member CA is indicated by a dotted pattern. Further, the decompression weight 65 and the stopper pin 66 are indicated by dotted lines.

[0156] As shown in each of Figs. 23 and 24, in the cam member CA, a storage hole CAa in which the rotation member 61 is stored, and storage holes CAb, CAc in which the decompression pins 62, 63 are respectively stored are formed. One end of the storage hole CAb and one end of the storage hole CAc respectively open on an outer peripheral surface of the cam member CA, and the other ends of the storage hole CAb and the storage hole CAc respectively open on an inner peripheral surface of the storage hole CAa. The one end of the storage hole CAb and the one end of the storage hole CAc are provided at different positions in a rotation direction of the cam member CA.

[0157] A flange-shape abutment portion 62a is provided at one end of the decompression pin 62, and a flange-shape abutment portion 63a is provided at one end of the decompression pin 63. At the other end of the storage hole CAb, an expanded portion CAB in which the abutment portion 62a can be stored is provided. At the other end of the storage hole CAc, an expanded portion CAC in which the abutment portion 63a can be stored is provided. A spring SP1 is arranged in the expanded portion CAB, and a spring SP2 is arranged in the expanded portion CAC. The abutment portion 62a of the decompression pin 62 is pushed against the outer peripheral surface of the rotation member 61 by the spring SP1, and the abutment portion 63a of the decompression pin 63 is pushed against the outer peripheral surface of the rotation member 61 by the spring SP2.

[0158] The outer peripheral surface of the rotation member 61 has curved portions 61 a, 61 b and planar portions 61 c, 61 d. The curved portions 61 a, 61 b are respectively included in a columnar plane centered at a rotational center axis of the rotation member 61. The planar portion 61 c is provided to connect one side of the curved portion 61 a to one side of the curved portion 61 b, and the planar portion 61 d is provided to connect another side of the curved portion 61 a to another side of the curved portion 61 b. The coupling member 64 is biased in one direction DR1 by a biasing member (not shown).

[0159] In the case where the rotation speed of the crankshaft 13 is lower than the constant threshold value, the decompression mechanism DE is kept in the operation state of Fig. 23. As shown in Fig. 23, in the operation state, the decompression weight 65 abuts against the stopper pin 66 by the biasing force exerted on the coupling member 64. In this case, the abutment portion 62a of the decompression pin 62 abuts against the curved portion 61 a of the rotation member 61, and the abutment portion 63a of the decompression pin 63 abuts against

the curved portion 61 b of the rotation member 61. Thus, a tip end of the decompression pin 62 projects from the outer peripheral surface of the cam member CA, and a tip end of the decompression pin 63 projects from the outer peripheral surface of the cam member CA.

[0160] When the crank angle is in the range from the angle AD3 to the angle AD4 of Fig. 16, the decompression pin 62 lifts the exhaust valve 16 (Fig. 21) corresponding to the second cylinder 31 B. Thus, in the forward rotation positioning operation, when the crank angle becomes close to the angle A3 corresponding to the compression top dead center of the second cylinder 31 B, the pressure in the second cylinder 31 B can be reduced. Therefore, the crank angle can easily exceed the angle A3.

[0161] When the crank angle is in the range from the angle AD5 to the angle AD6 of Fig. 18, the decompression pin 63 lifts the exhaust valve 16 (Fig. 21) corresponding to the second cylinder 31 B. Thus, in the reverse rotation start-up operation, when the crank angle becomes close to the angle A3 corresponding to the compression top dead center of the second cylinder 31 B, the pressure in the second cylinder 31 B can be reduced. Therefore, the crank angle can easily exceed the angle A3.

[0162] In the case where the rotation speed of the crankshaft 13 is the constant threshold value or higher, the decompression mechanism DE is kept in the non-operation state of Fig. 24. As shown in Fig. 24, in the non-operation state, the decompression weight 65 is moved away from the rotational center axis of the exhaust cam 174 by a centrifugal force. Thus, the coupling member 64 abuts against the stopper pin 66. In this case, the abutment portion 62a of the decompression pin 62 abuts against the planar portion 61 c of the rotation member 61, and the abutment portion 63a of the decompression pin 63 abuts against the planar portion 61 d of the rotation member 61. Thus, the tip end of the decompression pin 62 is stored in the storage hole CAa, and the tip end of the decompression pin 63 is stored in the storage hole CAb. Therefore, during the normal running, the decompression pins 62, 63 do not lift the exhaust valve 16 (Fig. 21).

[0163] In this manner, during the forward rotation positioning operation and the reverse rotation start-up operation, the decompression mechanism DE is kept in the operation state, and the exhaust valve 16 corresponding to the second cylinder 31 B is lifted in a constant range of the crank angle by the decompression pins 62, 63. On the other hand, during the normal running, the decompression mechanism DE is kept in the non-operation state, and the exhaust valve 16 is not lifted by the decompression pins 62, 63.

[0164] The similar configuration to that of the decompression mechanism DE of Figs. 22 to 24 can be applied to the decompression mechanism DE of the above-mentioned first embodiment. In this case, the decompression mechanism DE is provided in each exhaust cam 174 that

drives the exhaust valve 16 corresponding to the first cylinder 31 A. Further, a decompression pin that lifts the exhaust valve 16 in the range from the angle AD1 to the angle AD2 of Fig. 6 is provided instead of the decompression pins 62, 63.

[0165] By such a configuration, during the forward rotation positioning operation, the decompression mechanism DE enters the operation state. When the crank angle becomes close to the angle A1 corresponding to the compression top dead center of the first cylinder 31A, the pressure in the first cylinder 31A is reduced by the decompression mechanism DE. Further, during the reverse rotation start-up operation, the pressure in each of the first and second cylinders 31A, 31B is not reduced by the decompression mechanism DE. During the normal running, the decompression mechanism DE enters the non-operation state, and the pressure in each of the first and second cylinders 31A, 31B is not reduced by the decompression mechanism DE. Therefore, in the first embodiment, the forward rotation start-up operation and the reverse rotation start-up operation can be appropriately performed while the configuration of the decompression mechanism DE is simplified as compared to the second embodiment.

(6) Effects

[0166] Furthermore, in the engine system 200 according to the present embodiment, similarly to the first embodiment, the engine 10 is started by the reverse rotation start-up operation. Thus, a fuel-air ratio at the time of ignition can be appropriately adjusted. Further, when the crank angle is in the start-up pressure reduction range (the range from the angle AD5 to the angle AD6), the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE. In this case, even if the crank angle becomes close to the angle A3 corresponding to the compression top dead center of the second cylinder 31B, an increase in pressure in the second cylinder 31 B is inhibited. Therefore, an increase in rotational resistance of the crankshaft 13 is inhibited, and the reverse rotation of the crankshaft 13 is not prevented.

[0167] Because the pressure in the second cylinder 31 B does not prevent the reverse rotation of the crankshaft 13, the introduction of a fuel-air mixture into the first cylinder 31A and the compression of a fuel-air mixture in the first cylinder 31A can be appropriately performed. Thus, the fuel-air mixture can be appropriately combusted in the first cylinder 31A, and a forward torque of the crankshaft 13 can be sufficiently increased. As a result, the engine 10 can be appropriately started.

[0168] Further, before the reverse rotation start-up operation, the crank angle is adjusted in the reverse rotation start range (the angle A50) by the forward rotation positioning operation. Thus, a fuel-air mixture can be appropriately introduced into the first cylinder 31A in the reverse rotation start-up operation, and the crank angle can easily reach the start-up ignition range (the angle

A34).

[0169] Further, in the forward rotation positioning operation, when the crank angle is in the positioning pressure reduction range (the range from the angle AD3 to the angle AD4), the pressure in the second cylinder 31 B is reduced by the decompression mechanism DE. Thus, an increase in rotational resistance of the crankshaft 13 is inhibited, and the forward rotation of the crankshaft 13 is not prevented. Thus, the crank angle can easily be adjusted in the reverse rotation start range.

(7) Modified Example

[0170] In the above-mentioned first embodiment, the difference between the crank angle in the case where the piston 11 reaches the compression top dead center in the first cylinder 31A and the crank angle in the case where the piston 11 reaches the compression top dead center in the second cylinder 31 B is 180 degrees. In the above-mentioned second embodiment, the difference is 360 degrees. However, the present invention is not limited to this.

[0171] For example, the difference between the crank angle in the case where the piston 11 reaches the compression top dead center in the first cylinder 31A and the crank angle in the case where the piston 11 reaches the compression top dead center in the second cylinder 31B may be 270 degrees. In this case, similarly to the first embodiment, the pressure in the first cylinder 31A may be reduced by the decompression mechanism DE in the forward rotation positioning operation. Alternatively, similarly to the second embodiment, the pressure in the second cylinder 31 B may be reduced by the decompression mechanism DE in the forward rotation positioning operation and the reverse rotation start-up operation.

[D] Engine System (Third Embodiment)

[0172] As for the engine system according to the third embodiment of the present invention, differences from the above-mentioned first embodiment will be described.

(1) Configuration

[0173] Fig. 25 is a diagram for explaining the configuration of an engine unit EU used in the third embodiment. The engine unit EU of Fig. 25 includes an engine 10A instead of the engine 10 of Fig. 2. The engine 10A is a three-cylinder four-cycle engine and includes first, second and third cylinders 31 P, 31 Q, 31 R. A piston 11 is provided in each of the first, second and third cylinders 31P, 31Q, 31R, and a combustion chamber 31a is provided above each piston 11. Each piston 11 is connected to a crankshaft 13 via a connecting rod 12.

[0174] At each of the first, second and third cylinders 31P, 31Q, 31R, an intake port 21 and an exhaust port 23 are provided. Each intake port 21 is opened and closed by an intake valve 15, and each exhaust port 23 is opened

and closed by an exhaust valve 16. An intake camshaft 171 and an exhaust camshaft 172 are respectively and commonly provided for the first, second and third cylinders 31 P, 31 Q, 31 R. The intake camshaft 171 includes a plurality of intake cams 173, and the exhaust camshaft 172 includes a plurality of exhaust cams 174. Each intake cam 173 and each exhaust cam 174 respectively drive the intake valve 15 and the exhaust valve 16. The ignition plug 18 and the injector 19 of Fig. 3 are provided to correspond to each of the first, second and third cylinders 31 P, 31 Q, 31 R.

[0175] A decompression mechanism DEa is provided between the second cylinder 31 Q and the third cylinder 31 R. An increase in pressure in each of the second and third cylinders 31 Q, 31 R is inhibited by the decompression mechanism DEa. Details of the decompression mechanism DEa will be described below.

(2) Normal Running

[0176] Figs. 26 and 27 are diagrams for explaining the normal running of the engine 10A. A relationship between operations performed in the first cylinder 31 P and the crank angle is shown in Fig. 26, a relationship between operations performed in the second cylinder 32Q and the crank angle is shown in Fig. 27, and a relationship between operations performed in the third cylinder 32R and the crank angle is shown in Fig. 28.

[0177] As shown in Fig. 26, the relationship between the operations performed in the first cylinder 31 P and the crank angle during the normal running is the same as the relationship between the operations performed in the first cylinder 31A and the crank angle in the above-mentioned first embodiment. Specifically, as shown in Fig. 26, the piston 11 is positioned at the compression top dead center when the crank angle is the angle A1, the piston 11 is positioned at the expansion bottom dead center when the crank angle is the angle A2, the piston 11 is positioned at the exhaust top dead center when the crank angle is the angle A3, and the piston 11 is positioned at the intake bottom dead center when the crank angle is the angle A4. The piston 11 (Fig. 25) falls in the range from the angle A1 to the angle A2, the piston 11 rises in the range from the angle A2 to the angle A3, the piston 11 falls in the range from the angle A3 to the angle A4, and the piston 11 rises in the range from the angle A4 to the angle A1.

[0178] The intake port 21 (Fig. 25) is opened by the intake valve 15 (Fig. 25) in the range from the angle A11 to the angle A12, and the exhaust port 23 (Fig. 25) is opened by the exhaust valve 16 (Fig. 25) in the range from the angle A13 to the angle A14. Further, the fuel is injected into the intake passage 22 (Fig. 3) by the injector 19 (Fig. 3) at the angle A15 and ignited by the ignition plug 18 (Fig. 3) at the angle A16.

[0179] As shown in Fig. 27, in the second cylinder 31 Q, the piston 11 is positioned at the compression top dead center when the crank angle is an angle A101, the

piston 11 is positioned at the expansion bottom dead center when the crank angle is an angle A102, the piston 11 is positioned at the exhaust top dead center when the crank angle is an angle A103, and the piston 11 is positioned at the intake bottom dead center when the crank angle is an angle A104. The piston 11 falls in a range from the angle A101 to the angle A102, the piston 11 rises in a range from the angle A102 to the angle A103, the piston 11 falls in a range from the angle A103 to the angle A104, and the piston 11 rises in a range from the angle A104 to the angle A101. In the forward direction, the angles A101 to A104 of Fig. 27 are respectively positioned at further retarded angles than the angles A1 to A4 of Fig. 26 by 240 degrees.

[0180] The intake port 21 (Fig. 25) is opened by the intake valve 15 (Fig. 25) in a range from an angle A111 to an angle A112, and the exhaust port 23 (Fig. 25) is opened by the exhaust valve 16 (Fig. 25) in a range from an angle A113 to an angle A114. Further, the fuel is injected into the intake passage 22 (Fig. 3) by the injector 19 (Fig. 3) at an angle A115 and ignited by the ignition plug 18 (Fig. 3) at an angle A116.

[0181] As shown in Fig. 28, in the third cylinder 31 R, the piston 11 is positioned at the compression top dead center when the crank angle is an angle A201, the piston 11 is positioned at the expansion bottom dead center when the crank angle is an angle A202, the piston 11 is positioned at the exhaust top dead center when the crank angle is an angle A203, and the piston 11 is positioned at the intake bottom dead center when the crank angle is an angle A204. The piston 11 falls in a range from the angle A201 to the angle A202, the piston 11 rises in a range from the angle A202 to the angle A203, the piston 11 falls in a range from the angle A203 to the angle A204, and the piston 11 rises in a range from the angle A204 to the angle A201. In the forward direction, the angles A201 to A204 of Fig. 28 are respectively positioned at further retarded angles than the angles A101 to A104 of Fig. 27 by 240 degrees.

[0182] The intake port 21 (Fig. 25) is opened by the intake valve 15 (Fig. 25) in a range from an angle A211 to an angle A212, and the exhaust port 23 (Fig. 25) is opened by the exhaust valve 16 (Fig. 25) in a range from an angle A213 to an angle A214. Further, the fuel is injected into the intake passage 22 (Fig. 3) by the injector 19 (Fig. 3) at an angle A215 and ignited by the ignition plug 18 (Fig. 3) at an angle A216. The angles A211 to A216 of Fig. 27 are respectively different from the angles A11 to A16 of Fig. 26 by 480 degrees.

[0183] Fig. 29 is a diagram showing a relationship between a rotational load of the crankshaft 13 and the crank angle. In Fig. 29, the abscissa indicates the crank angle, and the ordinate indicates the rotational load of the crankshaft 13. The rotational load generated due to the first cylinder 31 P is shown in Fig. 29(a), the rotational load generated due to the second cylinder 31 Q is shown in Fig. 29(b) and the rotational load generated due to the third cylinder 31 R is shown in Fig. 29(c). In Fig. 29(d),

the total of the rotational loads generated due to the first, second and third cylinders 31 P, 31 Q, 31 R is shown.

[0184] As shown in Figs. 29(a) to 29(c), as for the first, second and third cylinders 31 P, 31 Q, 31 R, the rotational loads are respectively maximized at the angles A1, A101, A201 respectively corresponding to the compression top dead centers. As described above, in the forward direction, the angle A101 is different from the angle A1 by 240 degrees, and the angle A201 is different from the angle A101 by 240 degrees. Thus, as shown in Fig. 29(d), the rotational load of the crankshaft 13 is increased every time the crank angle is changed by 240 degrees.

[0185] As described above, when the engine 10 is stopped, the rotation of the crankshaft 13 is likely to be stopped in the case where the rotational load is large. Therefore, in the present example, the rotation of the crankshaft 13 is likely to be stopped when the crank angle becomes close to the angle A1, when the crank angle becomes close to the angle A101 or when the crank angle becomes close to the angle A201.

(3) Forward Rotation Positioning Operation and Reverse Rotation Start-up Operation

[0186] Fig. 30 is a diagram for explaining the forward rotation positioning operation of the engine unit EU, and Fig. 31 is a diagram for explaining the reverse rotation start-up operation of the engine unit EU. In each of Figs. 30 and 31, a relationship between operations performed in the first cylinder 31 P and the crank angle is shown.

[0187] In the forward rotation start-up operation, as shown in Fig. 30, the crank angle is adjusted to an angle A300 by the forward rotation of the crankshaft 13. The angle A300 is an example of the reverse rotation start range. The angle A300 is positioned at a further retarded angle than the angle A4 and a further advanced angle than the angle A1 in the forward direction. In the case where the engine 10 is stopped with the crank angle near the angle A300, the forward rotation start-up operation does not have to be performed.

[0188] In the reverse rotation start-up operation, as shown in Fig. 31, the crankshaft 13 is rotated in reverse with the crank angle in the reverse rotation start range (the angle A300). In the first cylinder 31 P, similarly to the first embodiment, the intake port 21 (Fig. 25) is opened by the intake valve 15 (Fig. 25) in the range from the angle A31 to the angle A32, and the fuel is injected into the intake passage 22 (Fig. 3) by the injector 19 (Fig. 3) at the angle A33. Further, at the angle A34, the fuel is ignited by the ignition plug 18, and the rotation direction of the crankshaft 13 is switched from the reverse direction to the forward direction. Thus, a fuel-air mixture is combusted in the first cylinder 31A, and the crankshaft 13 is driven in the forward direction by the energy of combustion of the fuel-air mixture.

[0189] In the case where the crank angle is between the angle A101 and the angle A201 of Fig. 29 when the engine 10 is stopped, it is necessary for the crank angle

to exceed the angle A201 corresponding to the compression top dead center of the third cylinder 31 R during the forward rotation positioning operation. Further, in the case where the crank angle is between the angle A1 and the angle A101 of Fig. 29 when the engine 10 is stopped, it is necessary for the crank angle to exceed both of the angle A101 corresponding to the compression top dead center of the second cylinder 31 Q and the angle A201 corresponding to the compression top dead center of the third cylinder 31 R during the forward rotation positioning operation. Further, during the reverse rotation start-up operation, it is necessary for the crank angle to exceed both of the angle A201 corresponding to the compression top dead center of the third cylinder 31 R and the angle A101 corresponding to the compression top dead center of the second cylinder 31 Q. During the forward rotation positioning operation and the reverse rotation start-up operation, the pressure in each of the second and third cylinders 31 Q, 31 R is reduced by the decompression mechanism DEa (Fig. 25). Fig. 32 is a diagram showing a specific example of the decompression mechanism DEa.

[0190] The decompression mechanism DEa of Fig. 32 includes a communication path 210, auxiliary valves 212a, 212b, valve springs 213a, 213b and an auxiliary valve driver 220. The communication path 210 is provided to connect the combustion chamber 31 a of the second cylinder 31 Q and the combustion chamber 31 a of the third cylinder 31 R to each other. In the second cylinder 31Q, an opening 211a at one end of the communication path 210 is provided, and the auxiliary valve 212a is arranged to open and close the opening 211 a. In the third cylinder 31 R, an opening 211b at the other end of the communication path 210 is provided, and the auxiliary valve 212b is arranged to open and close the opening 211b.

[0191] The auxiliary valve 212a is biased in a direction in which the opening 211 a is closed by the valve spring 213a. The auxiliary valve 212b is biased in a direction in which the opening 211b is closed by the valve spring 213b. The auxiliary valves 212a, 212b are coupled to each other by a coupling member 215. The auxiliary valve driver 220 is a solenoid actuator, for example, and switches the communication path 210 between a communicated state and a closed state by integrally driving the auxiliary valves 212a, 212b. The communicated state means the state where the openings 211 a, 211 b are respectively opened by the auxiliary valves 212a, 212b, and the closed state means the state where the openings 211a, 211b are respectively closed by the auxiliary valves 212a, 212b. In the present embodiment, during the forward rotation positioning operation and the reverse rotation start-up operation, the communication path 210 is kept in the communicated state by the auxiliary valve driver 220.

[0192] Changes in pressure in each of the second and third cylinders 31 Q, 31 R during the forward rotation positioning operation will be described. Fig. 33 is a diagram for explaining the operations in each of the second

and third cylinders 31 Q, 31 P during the forward rotation of the crankshaft 13. Fig. 34 is a schematic diagram for explaining flows of gas during the forward rotation positioning operation. In Fig. 33, the abscissa indicates the crank angle. Further, in Fig. 33(a), the timing for opening and closing the intake port 21 and the exhaust port 23 in the second cylinder 31 Q and the moving direction of the piston 11 are shown. In Fig. 33(b), timing for opening and closing the intake port 21 and the exhaust port 23 in the third cylinder 31 R and the moving direction of the piston 11 are shown.

[0193] As shown in Fig. 33(a), in the second cylinder 31 Q, when the crank angle is in a range from the angle A112 to the angle A101, the piston 11 rises with the intake port 21 and the exhaust port 23 both closed. Thus, in the case where the communication path 210 is in the closed state, the pressure in the second cylinder 31 Q is increased. On the other hand, as shown in Fig. 33(b), in the third cylinder 31 R, when the crank angle is in the range from the angle A112 to the angle A101, at least one of the intake port 21 and the exhaust port 23 is opened. In this case, if the communication path 210 is in the communicated state, an increase in pressure in the second cylinder 31 Q is inhibited by a flow of the gas in the second cylinder 31Q to the third cylinder 31 R through the communication path 210 of Fig. 32.

[0194] For example, when the crank angle is in a range from the angle A214 to the angle A101, the piston 11 falls with the intake port 21 opened in the third cylinder 31 R. In this case, as shown in Fig. 34(a), the gas in the second cylinder 31 Q flows into the third cylinder 31 R through the communication path 210 while the gas flows into the third cylinder 31 R through the intake port 21 of the third cylinder 31 R. Therefore, the gas is not compressed in the second cylinder 31Q, and an increase in pressure in the second cylinder 31Q is inhibited.

[0195] Further, as shown in Fig. 33(b), in the third cylinder 31 R, when the crank angle is in a range from the angle A212 to the angle A201, the piston 11 rises with the intake port 21 and the exhaust port 23 both closed. Therefore, in the case where the communication path 210 is in the closed state, the pressure in the third cylinder 31 R is increased. On the other hand, as shown in Fig. 33(a), in the second cylinder 31 Q, when the crank angle is in a range from the angle A212 to the angle A113, the piston 11 falls with the intake port 21 and the exhaust port 23 both closed. In this case, if the communication path 210 is in the communicated state, the gas in the third cylinder 31 R flows into the second cylinder 31Q through the communication path 210 as shown in Fig. 34(b). Thus, the gas is not compressed in the third cylinder 31 R, and an increase in pressure in the third cylinder 31 R is inhibited.

[0196] Further, as shown in Fig. 33(a), when the crank angle is in a range from the angle A113 to the angle A201, the exhaust port 23 of the second cylinder 31Q is opened. Therefore, in the case where the communication path 210 is in the communicated state, an increase in pressure

in the third cylinder 31R is inhibited by a flow of the gas in the third cylinder 31 R to the second cylinder 31 Q through the communication path 210.

[0197] For example, when the crank angle is in a range from the angle A102 to the angle A201, the piston 11 rises with the exhaust port 23 opened in the second cylinder 31 Q. In this case, as shown in Fig. 34(c), the gas in the second cylinder 31Q flows out through the exhaust port 23 while the gas in the third cylinder 31 R flows into the second cylinder 31Q through the communication path 210. Therefore, the gas is not compressed in the third cylinder 31R, and an increase in pressure in the third cylinder 31 R is inhibited.

[0198] Changes in pressure in each of the second and third cylinders 31 Q, 31 R during the reverse rotation start-up operation will be described. Fig. 35 is a diagram for explaining operations performed in each of the second and third cylinders 31 Q, 31 P during the reverse rotation of the crankshaft 13. Fig. 36 is a schematic diagram for explaining flows of gas during the reverse rotation start-up operation. In Fig. 35, the abscissa indicates the crank angle. Further, in Fig. 35(a), timing for opening and closing the intake port 21 and the exhaust port 23 in the second cylinder 31 Q and the moving direction of the piston 11 are shown. In Fig. 35(b), timing for opening and closing the intake port 21 and the exhaust port 23 in the third cylinder 31 R and the moving direction of the piston 11 are shown.

[0199] As shown in Fig. 35(b), in the third cylinder 31 R, when the crank angle is in a range from the angle A213 to the angle A201, the piston 11 rises with the intake port 21 and the exhaust port 23 both closed. Therefore, in the case where the communication path 210 is in the closed state, the pressure in the third cylinder 31 R is increased. On the other hand, as shown in Fig. 35(a), in the second cylinder 31 Q, when the crank angle is in a range from the angle A213 to the angle A201, at least one of the intake port 21 and the exhaust port 23 is opened. In this case, if the communication path 210 is in the communicated state, an increase in pressure in the third cylinder 31 R is inhibited by a flow of the gas in the third cylinder 31 R to the second cylinder 31 Q through the communication path 210.

[0200] For example, when the crank angle is in a range from the angle A111 to the angle A201, the piston 11 falls with the exhaust port 23 opened in the second cylinder 31 Q. In this case, as shown in Fig. 36(a), the gas in the third cylinder 31 R flows into the second cylinder 31Q through the communication path 210 while the gas flows into the second cylinder 31Q through the exhaust port 23 of the second cylinder 31Q. Therefore, the gas is not compressed in the third cylinder 31R, and an increase in pressure in the third cylinder 31 R is inhibited.

[0201] Further, as shown in Fig. 35(a), in the second cylinder 31 Q, when the crank angle is in a range from the angle A113 to the angle A101, the piston 11 rises with the intake port 21 and the exhaust port 23 both closed. Therefore, in the case where the communication

path 210 is in the closed state, the pressure in the second cylinder 31Q is increased. On the other hand, as shown in Fig. 35(b), in the third cylinder 31 R, when the crank angle is in a range from the angle A113 to the angle A212, the piston 11 falls with the intake port 21 and the exhaust port 23 both closed. In this case, in the case where the communication path 210 is in the communicated state, as shown in Fig. 36(b), the gas in the second cylinder 31 Q flows into the third cylinder 31 R through the communication path 210. Thus, the gas is not compressed in the second cylinder 31Q, and an increase in pressure in the second cylinder 31 Q is inhibited.

[0202] Further, as shown in Fig. 35(b), when the crank angle is in a range from the angle A212 to the angle A101, the intake port 21 of the third cylinder 31R is opened. Therefore, in the case where the communication path 210 is in the communicated state, an increase in pressure in the second cylinder 31Q is inhibited by a flow of the gas in the second cylinder 31Q to the third cylinder 31 R through the communication path 210.

[0203] For example, when the crank angle is in a range from the angle A204 to the angle A101, the piston 11 rises with the intake port 21 opened in the third cylinder 31 R. In this case, as shown in Fig. 36(c), the gas in the third cylinder 31 R flows out through the intake port 21 while the gas in the second cylinder 31 Q flows into the third cylinder 31 R through the communication path 210. Therefore, the gas is not compressed in the second cylinder 31Q, and an increase in pressure in the second cylinder 31Q is inhibited.

[0204] Fig. 37 is a diagram showing a relationship between the rotational load of the crankshaft 13 and the crank angle during the forward rotation positioning operation and the reverse rotation start-up operation. Similarly to Fig. 29, the rotational loads generated due to the first, second and third cylinders 31 P, 31 Q, 31 R are respectively shown in Figs. 37(a) to 37(c), and the total of the rotational loads generated due to the first, second and third cylinders 31P, 31Q, 31R is shown in Fig. 37(d). As described above, during the forward rotation positioning operation and the reverse rotation start-up operation, an increase in pressure in each of the second and third cylinders 31Q, 31 R is inhibited. Specifically, as shown in Fig. 37(b), even in the case where the crank angle becomes close to the angle A101 corresponding to the compression top dead center of the second cylinder 31Q, an increase in rotational resistance generated due to the second cylinder 31Q is inhibited. Further, as shown in Fig. 37(c), even in the case where the crank angle becomes close to the A201 corresponding to the compression top dead center of the third cylinder 31 R, an increase in rotational resistance generated due to the third cylinder 31 R is inhibited. Thus, as shown in Fig. 37(d), the rotational load of the crankshaft 13 is increased only near the angle A1 corresponding to the compression top dead center of the first cylinder 31 P, and the forward rotation and the reverse rotation of the crankshaft 13 are not prevented in other angular ranges. Therefore, the forward

rotation positioning operation of Fig. 30 and the reverse rotation start-up operation of Fig. 31 can be appropriately performed.

5 (4) Engine Start-up Process

[0205] The ECU 6 performs the engine start-up process based on a control program stored in advance in a memory. In the present example, the engine start-up process includes a cold start-up process, an idle stop process and a reverse rotation start-up process. Fig. 38 is a flow chart for explaining the cold start-up process. Fig. 39 is a flow chart for explaining the idle stop process. Fig. 40 is a flow chart for explaining the reverse rotation start-up process.

[0206] When the main switch 40 of Fig. 3 is turned on, the ECU 6 starts the cold start-up process of Fig. 38. In this case, the current crank angle is not stored in the ECU 6. First, the ECU 6 controls the auxiliary valve driver 220 such that the communication path 210 is in the communicated state (step S101). Then, the ECU 6 controls the integrated starter generator 14 such that the crankshaft 13 is rotated forward (step S102). In this case, because the communication path 210 is kept in the communicated state, an increase in pressure in each of the second and third cylinders 31 Q, 31 R is inhibited. Thus, the forward rotation of the crankshaft 13 is not prevented. Further, a torque of the integrated starter generator 14 is adjusted based on a detection signal from the current sensor 44 (Fig. 3) such that the crank angle does not reach the angle A1 (Fig. 30) corresponding to the compression top dead center of the first cylinder 31 P.

[0207] Next, the ECU 6 determines whether a specified time period has elapsed since the start of the forward rotation of the crankshaft 13 in the step S102 (step S103). In the case where the specified time period elapses, the ECU 6 controls the integrated starter generator 14 such that the forward rotation of the crankshaft 13 is stopped (step S104). Thus, the crank angle is adjusted in the reverse rotation start range (the angle A300 of Fig. 30). Thereafter, the ECU 6 controls the auxiliary valve driver 220 such that the communication path 210 is in the closed state (step S105) and ends the cold start-up process.

[0208] On the other hand, in the case where the above-mentioned idle stop condition is satisfied, the ECU 6 starts the idle stop process of Fig. 39. First, the ECU 6 stops the injection of fuel by each injector 19 (Fig. 3) and the ignition by each ignition plug 18 (Fig. 3) such that combustion is stopped in each of the first, second and third cylinders 31 P, 31 Q, 31R (step S111).

[0209] Then, the ECU 6 determines whether the rotation speed of the crankshaft 13 is a specified value or lower than the specified value based on the detection signal from the crank angle sensor 43 of Fig. 3 (step S112). This specified value is sufficiently lower than the rotational speed of the crankshaft 13 during idling. In the case where the rotation speed of the crankshaft 13 is larger than the specified value, the ECU 6 repeats the

process of the step S112 until the rotation speed of the crankshaft 13 is the specified value or lower than the specified value.

[0210] When the rotation speed of the crankshaft 13 is the specified value or lower than the specified value, the ECU 6 controls the auxiliary valve driver 220 such that the communication path 210 is in the communicated state (step S113). In this case, because an increase in pressure in each of the second and third cylinders 31 Q, 31 R is inhibited, the rotation of the crankshaft 31 is likely to be stopped when the crank angle becomes close to the angle A1 corresponding to the compression top dead center of the first cylinder 31 P. Thus, the rotation of the crankshaft 13 is likely to be stopped with the crank angle in the reverse rotation start range or near the reverse rotation start range.

[0211] Next, the ECU 6 determines whether the rotation of the crankshaft 13 is stopped based on the detection signal from the crank angle sensor 43 (step S114). In the case where the rotation of the crankshaft 13 is not stopped, the ECU 6 repeats the process of the step S114 until the rotation of the crankshaft 13 is stopped.

[0212] When the rotation of the crankshaft 13 is stopped, the ECU 6 determines whether the current crank angle is in the reverse rotation start range (step S115). In the case where the current crank angle is not in the reverse rotation start range, the ECU 6 controls the integrated starter generator 14 such that the crankshaft 13 is rotated forward (step S116). Similarly to the step S102 of Fig. 38, because the communication path 210 is kept in the communicated state, an increase in pressure in each of the second and third cylinders 31 Q, 31 R is inhibited. Thus, the forward rotation of the crankshaft 13 is not prevented.

[0213] Next, the ECU 6 determines whether the crank angle has reached the reverse rotation start range based on the detection signal from the crank angle sensor 43 (step S117). The ECU 6 repeats the process of the step S117 until the crank angle reaches the reverse rotation start range. When the crank angle reaches the reverse rotation start range, the ECU 6 controls the integrated starter generator 14 such that the forward rotation of the crankshaft 13 is stopped (step S118). Thereafter, the ECU 6 controls the auxiliary valve driver 220 such that the communication path 210 is in the closed state (step S119), and ends the idle stop process. On the other hand, in the step S115, in the case where the current crank angle is in the reverse rotation start range, the ECU 6 does not perform the forward rotation positioning operation, controls the auxiliary valve driver 220 such that the communication path 210 is in the closed state (step S119), and ends the idle stop process.

[0214] In the case where the starter switch 41 of Fig. 3 is turned on after the end of the cold start-up process, the ECU 6 starts the reverse rotation start-up process of Fig. 40. Further, in the case where the above-mentioned idle stop release condition is satisfied after the end of the idle stop process, the ECU 6 starts the reverse rotation

start-up process of Fig. 40.

[0215] In the reverse rotation start-up process of Fig. 40, the ECU 6 first controls the auxiliary valve driver 220 such that the communication path 210 is in the communicated state (step S121). Then, the ECU 6 controls the integrated starter generator 14 such that the crankshaft 13 is rotated in reverse (step S122). In this case, because the communication path 210 is kept in the communicated state, an increase in pressure in each of the second and third cylinders 31 Q, 31 R is inhibited. Thus, the reverse rotation of the crankshaft 13 is not prevented.

[0216] Next, the ECU 6 determines whether the crank angle has reached the angle A33 of Fig. 31 based on the detection signal from the crank angle sensor 43 (step S123). The ECU 6 repeats the process of the step S123 until the crank angle reaches the angle A33. When the crank angle reaches the angle A33, the ECU 6 controls the injector 19 corresponding to the first cylinder 31 P such that the fuel is injected into the intake passage 22 (step S124). The ECU 6 then determines whether the motor current has reached a predetermined threshold value based on the detection signal from the current sensor 44 (step S125). In the case where the motor current has not reached the threshold value, the ECU 6 repeats the process of the step S125 until the motor current reaches the threshold value.

[0217] When the motor current reaches the threshold value, the ECU 6 controls the integrated starter generator 14 such that the reverse rotation of the crankshaft 13 is stopped (step S126). Further, the ECU 6 controls the ignition plug 18 corresponding to the first cylinder 31 P such that a fuel-air mixture in the first cylinder 31 P is ignited (step S127). At the time of the ignition or right after the ignition in the step S127, the rotation of the crankshaft 13 may be driven in the forward direction by the integrated starter generator 14.

[0218] Then, the ECU 6, based on the detection signal from the crank angle sensor 43, determines whether the rotation speed of the crankshaft 13 has reached a predetermined initial explosion determination value before a constant time period has elapsed since the ignition in the step S127 (step S128). In the case where the fuel-air mixture is appropriately combusted in the first cylinder 31 P by the ignition in the step S127, the rotation speed of the crankshaft 13 reaches the initial explosion determination value before the crank angle reaches the angle A2 corresponding to the first compression top dead center of the first cylinder 31 P.

[0219] In the step S128, in the case where the rotation speed of the crankshaft 13 reaches the initial explosion determination value in the constant time period, the ECU 6 controls the auxiliary valve driver 220 such that the communication path 210 is in the closed state (step S129), and ends the reverse rotation start-up process.

[0220] On the other hand, in the case where the fuel-air mixture is not appropriately combusted in the first cylinder 31 P by the ignition in the step S127, the rotation speed of the crankshaft 13 does not reach the initial ex-

plosion determination value. In this case, the crank angle does not exceed the angle A2, and the rotation of the crankshaft 13 is stopped or the crankshaft 13 is rotated in reverse by the rotational resistance caused by the pressure in the first cylinder 31 P. In the present example, in the case where the fuel-air mixture is not appropriately combusted in this manner, the reverse rotation start-up operation is repeated.

[0221] In the step S128, in the case where the rotation speed of the crankshaft 13 does not reach the initial explosion determination value in the constant time period, the ECU 6 determines whether the rotation of the crankshaft 13 is stopped and whether the crankshaft 13 is rotated in reverse (step S130). In the case where the rotation of the crankshaft 13 is not stopped and the crankshaft 13 is not rotated in reverse, the forward rotation of the crankshaft 13 is continued. Therefore, the ECU 6 repeats the process of the step S130 until the rotation of the crankshaft 13 is stopped or the crankshaft 13 is rotated in reverse.

[0222] When the rotation of the crankshaft 13 is stopped or the crankshaft 13 is rotated in reverse, the ECU 6 determines whether the reverse rotation start-up operation has been repeated a specified number of times (step S131). In the case where the reverse rotation start-up operation has not been repeated the specified number of times, the ECU 6 returns to the step S122. In the case where the reverse rotation start-up operation has been repeated the specified number of times, the trouble with the engine system 200 may have occurred. The trouble with the engine system 200 includes an operational problem with the engine unit EU or a problem with each type of sensor, for example. Therefore, the ECU 6 warns a rider (step S132). Specifically, the rider is informed of the possibility of an occurrence of trouble with the engine system 200 by a warning lamp and the like. Thereafter, the ECU 6 controls the auxiliary valve driver 220 such that the communication path 210 is in the closed state (step S129), and ends the reverse rotation start-up process.

[0223] Also in the examples of Figs. 9 and 10 or the example of Fig. 20, similarly to the example of Fig. 40, whether the fuel-air mixture has been appropriately combusted in the first cylinder 31A may be determined based on the rotation speed of the crankshaft 13. Further, in the case where it is determined that the fuel-air mixture has not been appropriately combusted, the reverse rotation start-up operation may be repeated.

(5) Effects

[0224] In the engine system 200 according to the present embodiment, an increase in pressure in each of the second and third cylinders 31 Q, 31 R is inhibited by the decompression mechanism DEa during the forward rotation positioning operation and the reverse rotation start-up operation. Thus, an increase in rotational resistance of the crankshaft 13 caused by an increase in pres-

sure in each of the second and third cylinders 31 Q, 31 R is inhibited. Therefore, the forward rotation positioning operation and the reverse rotation start-up operation are smoothly performed with the rotation of the crankshaft 13 not prevented. Therefore, the fuel-air mixture can be appropriately combusted in the first cylinder 31 P, and the engine 10 can be appropriately started. Further, because the integrated starter generator 14 is required to generate a smaller torque, the size of each of the integrated starter generator 14 and a battery (not shown) can be reduced.

[0225] Further, in the present embodiment, an increase in pressure in each of the second and third cylinders 31 Q, 31 R is inhibited by communication between the second cylinder 31Q and the third cylinder 31 R through the communication path 210. Thus, an increase in rotational resistance of the crankshaft 13 caused by an increase in pressure in each of the second and third cylinders 31 Q, 31 R can be inhibited with the simple configuration and by the simple control.

[0226] Further, in the present embodiment, the openings 211a, 211b of the communication path 210 are opened and closed by integral driving of the auxiliary valves 212a, 212b. Thus, the communication path 210 can be appropriately switched between the communicated state and the closed state with the simple configuration.

(6) Other Examples of Decompression Mechanism

[0227] While the communication path 210 is kept in the communicated state during the forward rotation positioning operation and the reverse rotation start-up operation in the above-mentioned third embodiment, the present invention is not limited to this. The communication path 210 may be in the communicated state only during a constant period of time. For example, the communication path 210 may be in the communicated state only during a period in which the intake port 21 and the exhaust port 23 are closed in each of the second and third cylinders 31 Q, 31 R and the piston 11 rises.

[0228] While an increase in pressure in each of the second and third cylinders 31 Q, 31 R is inhibited by communication between the second cylinder 31 Q and the third cylinder 31 R through the communication path 210 in the above-mentioned third embodiment, the present invention is not limited to this. For example, the pressure in the second cylinder 31 Q may be reduced by lifting of the exhaust valve 16 corresponding to the second cylinder 31Q, and the pressure in the third cylinder 31 R may be reduced by lifting of the exhaust valve 16 corresponding to the third cylinder 31 R. In this case, the decompression mechanism having the similar configuration to that of the Figs. 22 to 24 may be provided to correspond to each of the second and third cylinders 31 Q, 31 R.

[E] Other Embodiments

[0229] While the above-mentioned first to third embodiments are the examples where the present invention is applied to a two-cylinder engine and a three-cylinder engine, the present invention may be applied to a multi-cylinder engine having four or more cylinders. In this case, in the reverse rotation start-up operation, a fuel-air mixture is combusted in one cylinder. Further, in the engine start-up operation including the reverse rotation start-up operation, the pressure in the one or each of other cylinders is reduced such that an increase in rotational resistance of the crankshaft caused by an increase in pressure in the one or each of other cylinders is inhibited. Thus, the engine can be appropriately started.

[0230] While the present invention is applied to the motorcycle in the above-mentioned embodiment, the invention is not limited to this. The present invention may be applied to another straddled vehicle such as a motor tri-cycle or an ATV (All Terrain Vehicle) or another vehicle such as a four-wheeled automobile.

[F] Correspondences between Constituent Elements in Claims and Parts in Preferred Embodiments

[0231] 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.

[0232] In the above-mentioned embodiment, the engine system 200 is an example of an engine system, the engine unit EU is an example of an engine unit, the engine 10 is an example of an engine, the first cylinders 31A, 31P are examples of a first cylinder, the second cylinders 31 B, 31 Q are examples of a second cylinder, the third cylinder 31 R is an example of a third cylinder, the integrated starter generator 14 is an example of a rotation driver, the ECU 6 is an example of a controller, the valve driver 17 is an example of an opening closing mechanism, the decompression mechanisms DE, DEa are examples of a pressure reduction mechanism, the injector 19 is an example of a fuel injection device, and the ignition plug 18 is an example of an ignition device. Further, the communication path 210 is an example of a communication path, the auxiliary valves 212a, 212b and the auxiliary valve driver 220 are examples of a communication path opening closing mechanism, the opening 211 a is an example of a first opening, the opening 211b is an example of a second opening, the auxiliary valve 212a is an example of a first valve, the auxiliary valve 212b is an example of a second valve, and the auxiliary valve driver 220 is an example of a communication driver. Further, the motorcycle 100 is an example of a vehicle, the rear wheel 7 is an example of a drive wheel and the vehicle body 1 is an example of a main body.

[0233] 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]

[0234] The present invention can be applied to various types of engine systems and vehicles.

Claims

1. An engine system comprising:

an engine having a plurality of cylinders;
a rotation driver that rotates a crankshaft of the engine in forward and reverse directions; and
a controller that controls the engine and the rotation driver such that an engine start-up operation including at least a reverse rotation start-up operation is performed, wherein
the plurality of cylinders include first and second cylinders,
a fuel-air mixture is introduced into the first cylinder while the crankshaft is rotated in the reverse direction, and the crankshaft is driven in the forward direction by combustion of the fuel-air mixture in the first cylinder, in the reverse rotation start-up operation,
the engine includes a pressure reduction mechanism that reduces pressure in at least one cylinder of the first and second cylinders, and
the pressure reduction mechanism, in the engine start-up operation, reduces the pressure in the at least one cylinder such that an increase in rotational resistance of the crankshaft is caused by an increase in pressure in the at least one cylinder.

2. The engine system according to claim 1, wherein the pressure reduction mechanism, in the reverse rotation start-up operation, reduces the pressure in the at least one cylinder.

3. The engine system according to claim 2, wherein the engine further includes an opening closing mechanism that opens and closes an intake port and an exhaust port of each of the first and second cylinders, ranges of a crank angle respectively corresponding to an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke of the first cylinder during normal running are defined as a first intake range, a first compression range, a first expansion range and a first exhaust range, and ranges of the crank angle respectively corresponding to an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke of the second cylinder during the normal running are defined as a second intake range, a second compression range, a second expansion range and a second exhaust range,

- the first exhaust range includes a start-up intake range, and the first expansion range includes a start-up ignition range,
the rotation driver, in the reverse rotation start-up operation, rotates the crankshaft in reverse such that the crank angle exceeds the start-up intake range and reaches the start-up ignition range,
the opening closing mechanism, in the reverse rotation start-up operation, opens the intake port of the first cylinder when the crank angle is in the start-up intake range,
a fuel injection device corresponding to the first cylinder, in the reverse rotation start-up operation, injects fuel into an intake passage that leads air to the first cylinder such that, when the crank angle is in the start-up intake range, a fuel-air mixture is introduced into the first cylinder,
an ignition device corresponding to the first cylinder, in the reverse rotation start-up operation, ignites the fuel-air mixture in the first cylinder when the crank angle is in the start-up ignition range,
the second expansion range includes a start-up pressure reduction range, and the pressure reduction mechanism, in the reverse rotation start-up operation, reduces pressure in the second cylinder when the crank angle is in the start-up pressure reduction range.
4. The engine system according to claim 3, wherein at least one of the first compression range and the first intake range includes a reverse rotation start range, and
the engine start-up operation further includes a forward rotation positioning operation of adjusting the crank angle in the reverse rotation start range by rotating the crankshaft in the forward direction before the reverse rotation start-up operation.
5. The engine system according to claim 4, wherein the second compression range includes a positioning pressure reduction range, and
the pressure reduction mechanism, in the forward rotation positioning operation, reduces pressure in the second cylinder when the crank angle is in the positioning pressure reduction range.
6. The engine system according to any one of claims 3 to 5, wherein
a difference between the crank angle in the case where a piston reaches a compression top dead center in the first cylinder and the crank angle in the case where a piston reaches a compression top dead center in the second cylinder is 360 degrees.
7. The engine system according to claim 6, wherein
a fuel injection device corresponding to the second cylinder, in the reverse rotation start-up operation, injects fuel into an intake passage that leads air to
- the second cylinder after the crank angle exceeds the start-up intake range and before the crank angle reaches the start-up ignition range.
8. The engine system according to any one of claims 3 to 5, wherein
a difference between the crank angle in the case where the piston reaches a compression top dead center in the first cylinder and the crank angle in the case where the piston reaches a compression top dead center in the second cylinder is an angle other than 360 degrees.
9. The engine system according to claim 1, wherein the engine start-up operation further includes a forward rotation positioning operation of adjusting the crank angle in the reverse rotation start range by rotating the crankshaft in the forward direction before the reverse rotation start-up operation, and
the pressure reduction mechanism, in the forward rotation positioning operation, reduces pressure in at least one cylinder of the first and second cylinders.
10. The engine system according to claim 9, wherein the engine further includes an opening closing mechanism that opens and closes an intake port and an exhaust port of each of the first and second cylinders, ranges of a crank angle respectively corresponding to an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke of the first cylinder during normal running are defined as a first intake range, a first compression range, a first expansion range and a first exhaust range, and ranges of the crank angle respectively corresponding to an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke of the second cylinder during the normal running are defined as a second intake range, a second compression range, a second expansion range and a second exhaust range,
the first intake range includes a reverse rotation start range, the first exhaust range includes a start-up intake range and the first expansion range includes a start-up ignition range,
the rotation driver, in the forward rotation positioning operation, rotates the crankshaft forward such that the crank angle reaches the reverse rotation start range, and in the reverse rotation start-up operation, rotates the crankshaft in reverse such that the crank angle exceeds the start-up intake range from the reverse rotation start range and reaches the start-up ignition range,
the opening closing mechanism, in the reverse rotation start-up operation, opens an intake port of the first cylinder when the crank angle is in the start-up intake range,
a fuel injection device corresponding to the first cylinder, in the reverse rotation start-up operation, injects fuel into an intake passage that leads air to the

first cylinder such that, when the crank angle is in the start-up intake range, a fuel-air mixture is introduced into the first cylinder,
 an ignition device corresponding to the first cylinder, in the reverse rotation start-up operation, ignites the fuel-air mixture in the first cylinder when the crank angle is in the start-up ignition range,
 the first compression range includes a positioning pressure reduction range, and the pressure reduction mechanism, in the forward rotation positioning operation, reduces pressure in the first cylinder when the crank angle is in the positioning pressure reduction range.

11. The engine system according to claim 10, wherein at least part of the first intake range is in the second compression range, and the crank angle, in the reverse rotation start-up operation, reaches the start-up ignition range without passing through an angle corresponding to a compression top dead center of each of the first and second cylinders.
12. The engine system according to claim 2, wherein the plurality of cylinders further includes a third cylinder, and the pressure reduction mechanism, in the reverse rotation operation, reduces pressure in each of the second and third cylinders.
13. The engine system according to claim 12, wherein the engine start-up operation includes a forward rotation positioning operation of adjusting the crank angle in a predetermined reverse rotation start range by rotating the crankshaft in the forward direction before the reverse rotation start-up operation, and the pressure reduction mechanism, in the forward rotation positioning operation, reduces pressure in each of the second and third cylinders.
14. The engine system according to claim 12 or 13, wherein the pressure reduction mechanism includes a communication path that connects the second cylinder and the third cylinder to each other, and a communication path opening closing mechanism that switches the communication path between a communicated state and a closed state, and the communication path opening closing mechanism reduces the pressure in each of the second and third cylinders by keeping the communication path in the communicated state.
15. The engine system according to claim 14, wherein the communication path has a first opening that opens in the second cylinder and a second opening that opens in the third cylinder, the communication path opening closing mechanism

includes a first valve that opens and closes the first opening,
 a second valve that opens and closes the second opening, and
 a communication driver that integrally drives the first and second valves, and
 the communication driver reduces the pressure in each of the second and third cylinders by opening the first and second openings by the first and second valves.

16. A vehicle comprising:

a main body having a drive wheel, and
 the engine system according to any one of claims 1 to 15 that generates motive power for rotating the drive wheel.

FIG. 1

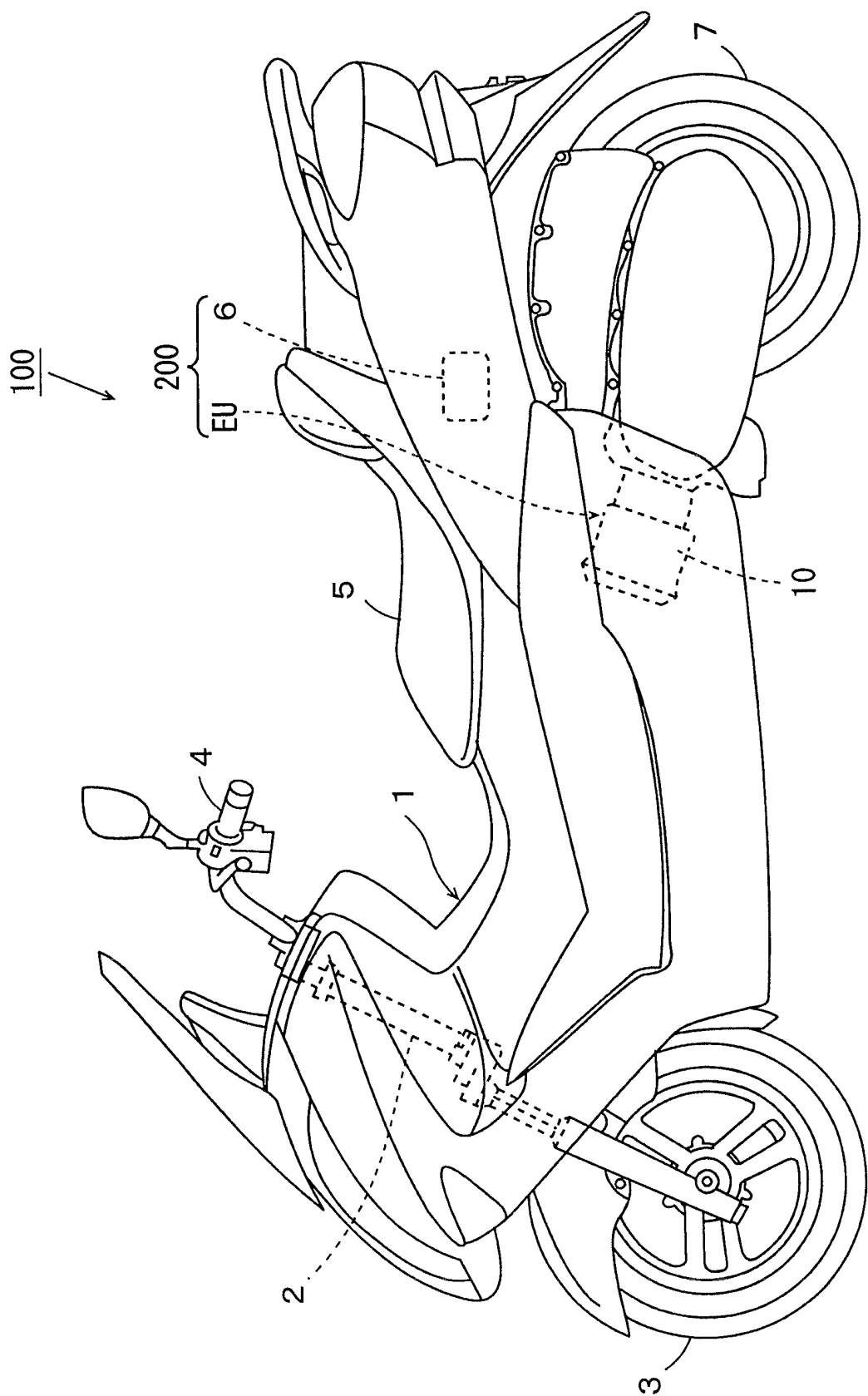


FIG. 2

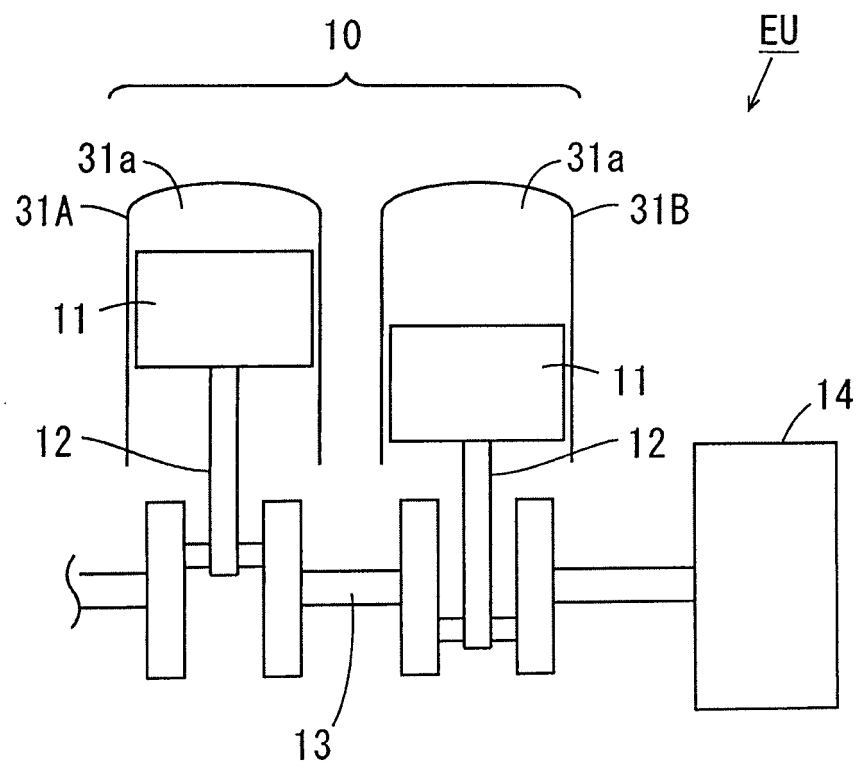


FIG. 3

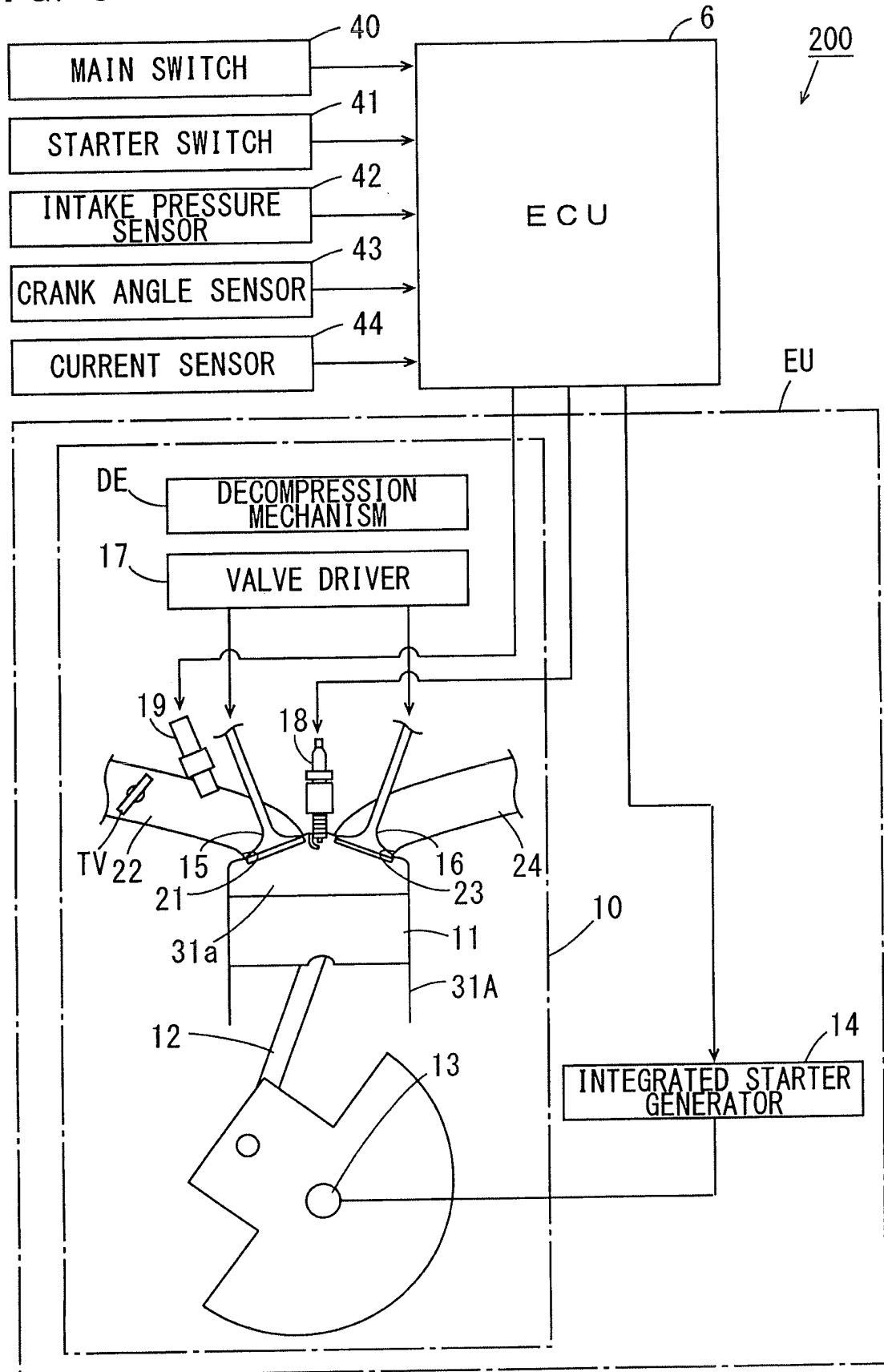


FIG. 4

FIRST CYLINDER
NORMAL RUNNING
(FORWARD ROTATION)

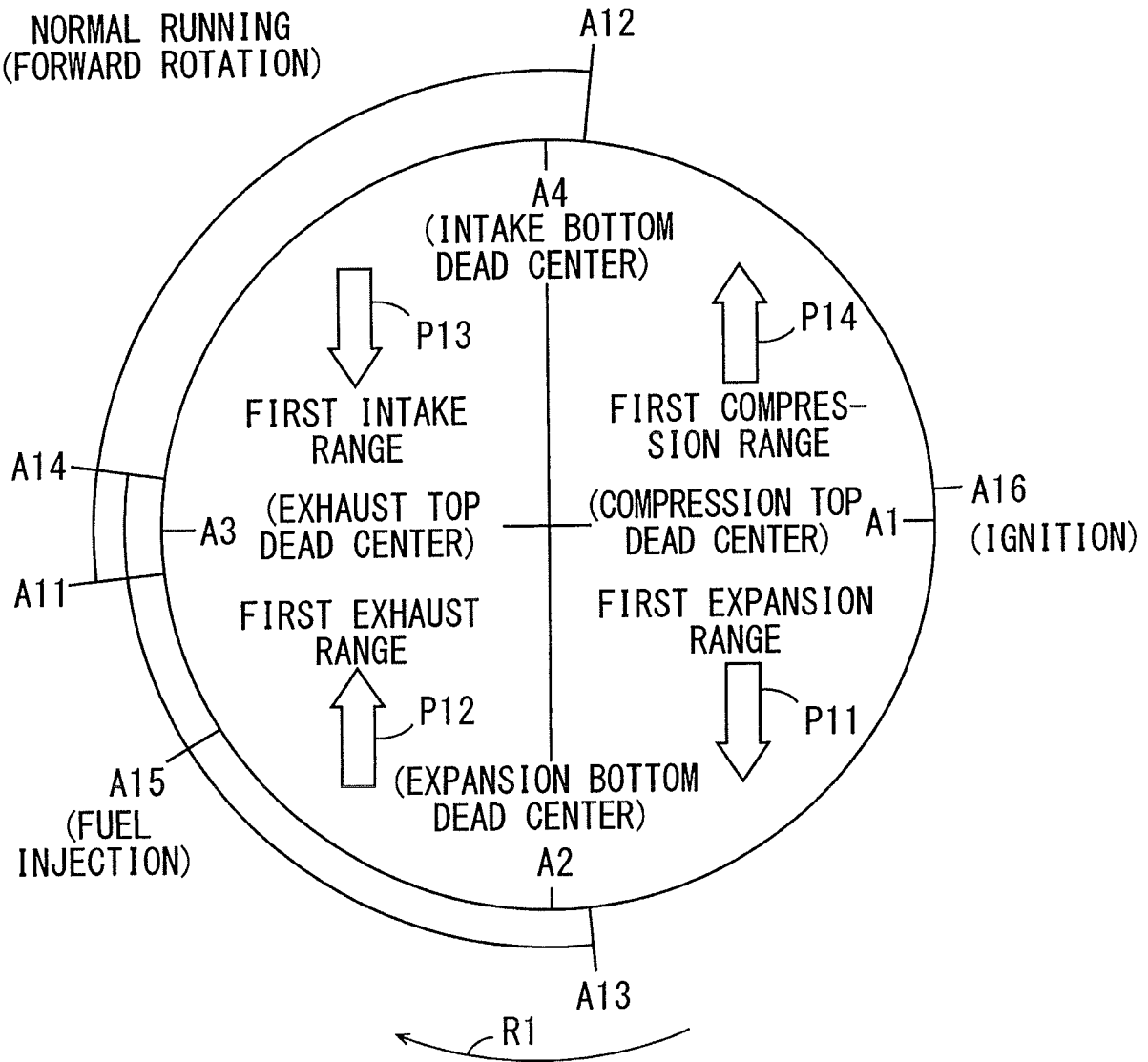


FIG. 5

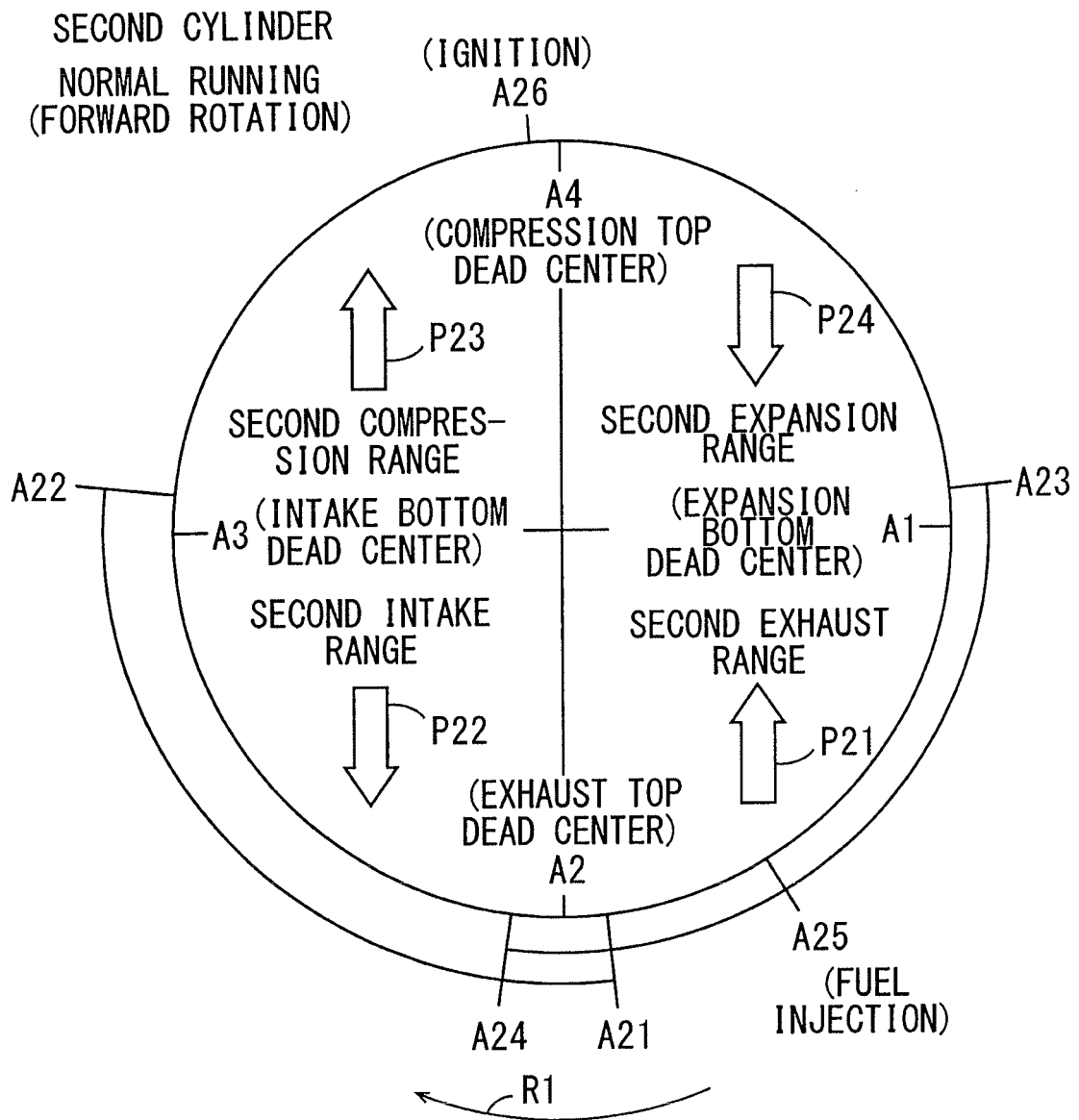


FIG. 6

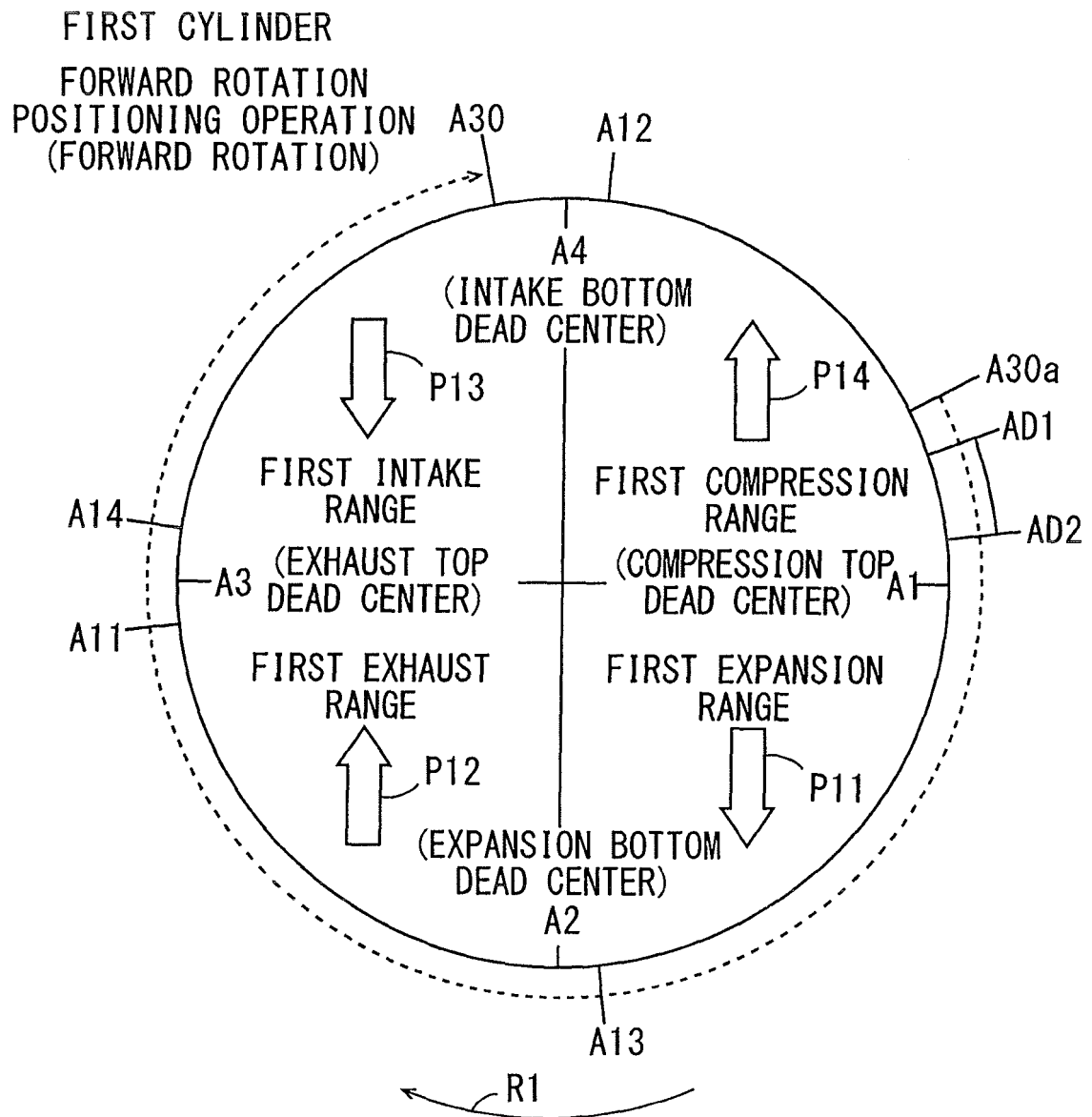


FIG. 7

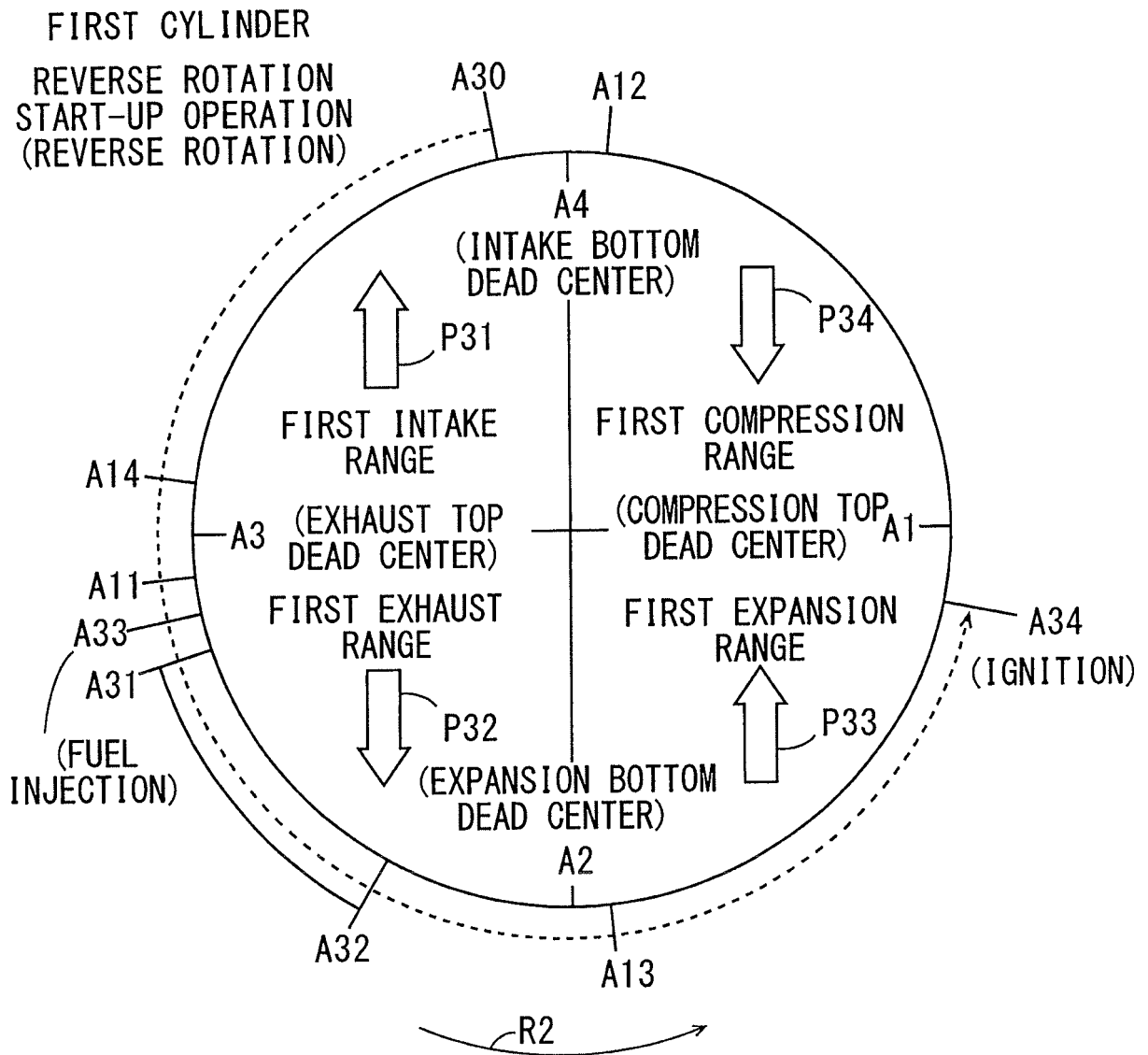


FIG. 8

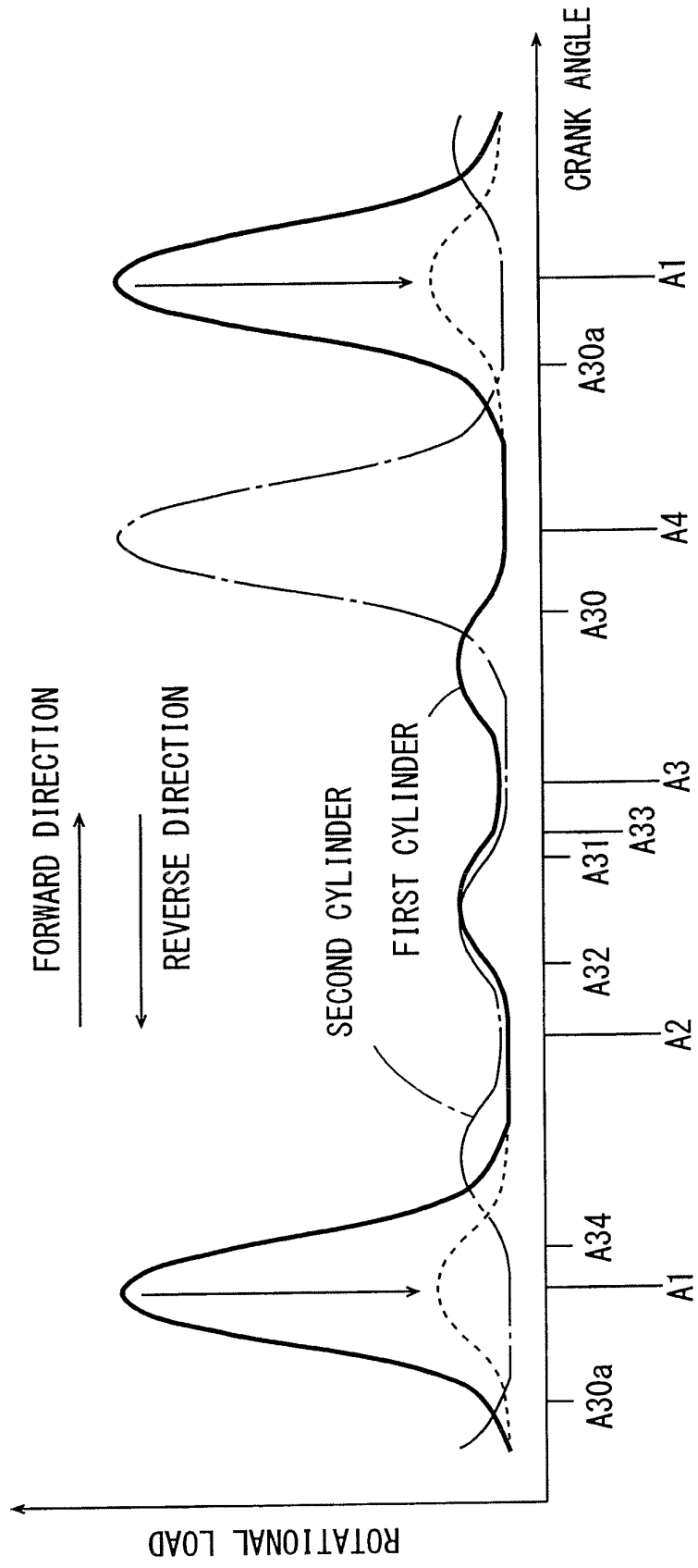


FIG. 9

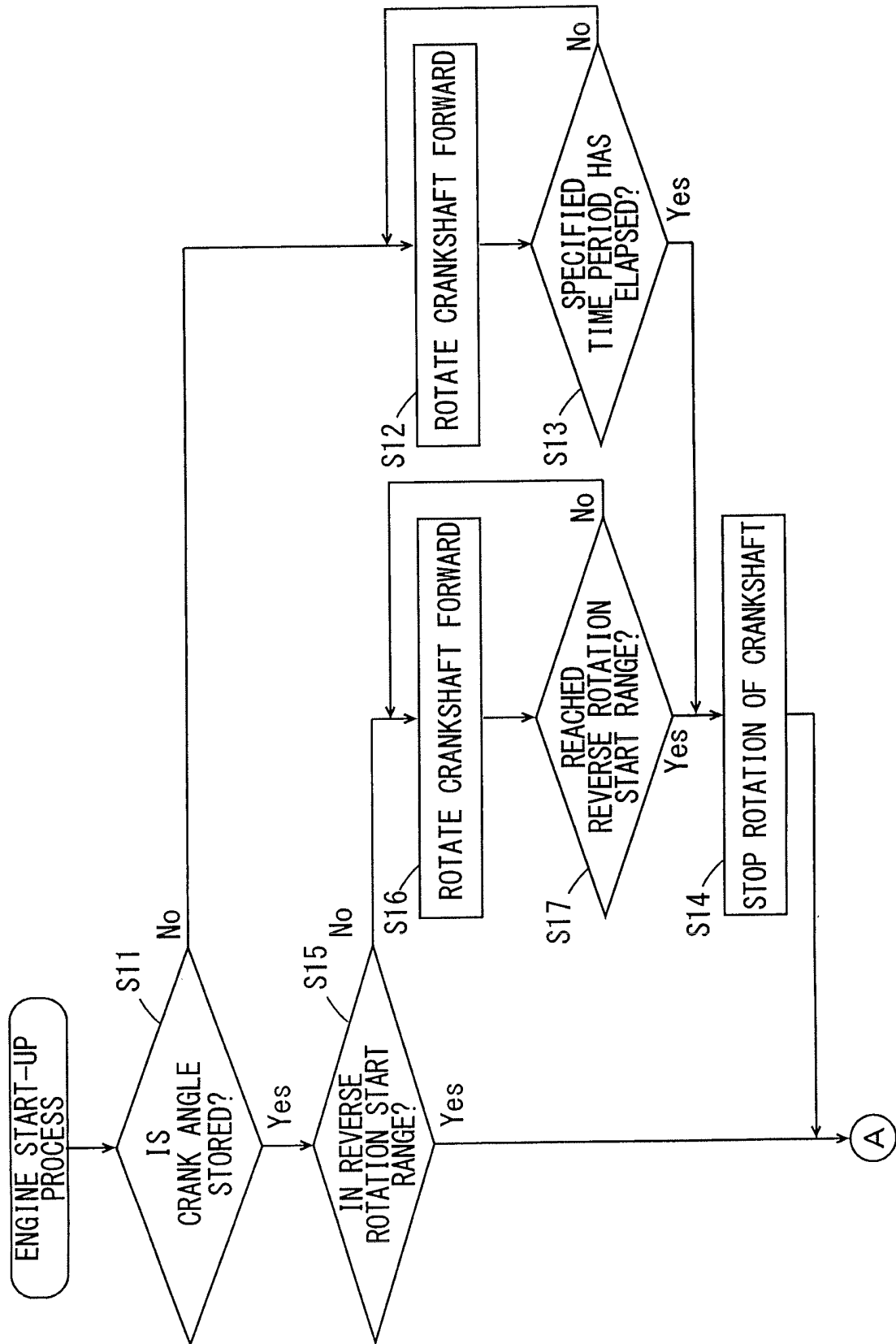


FIG. 10

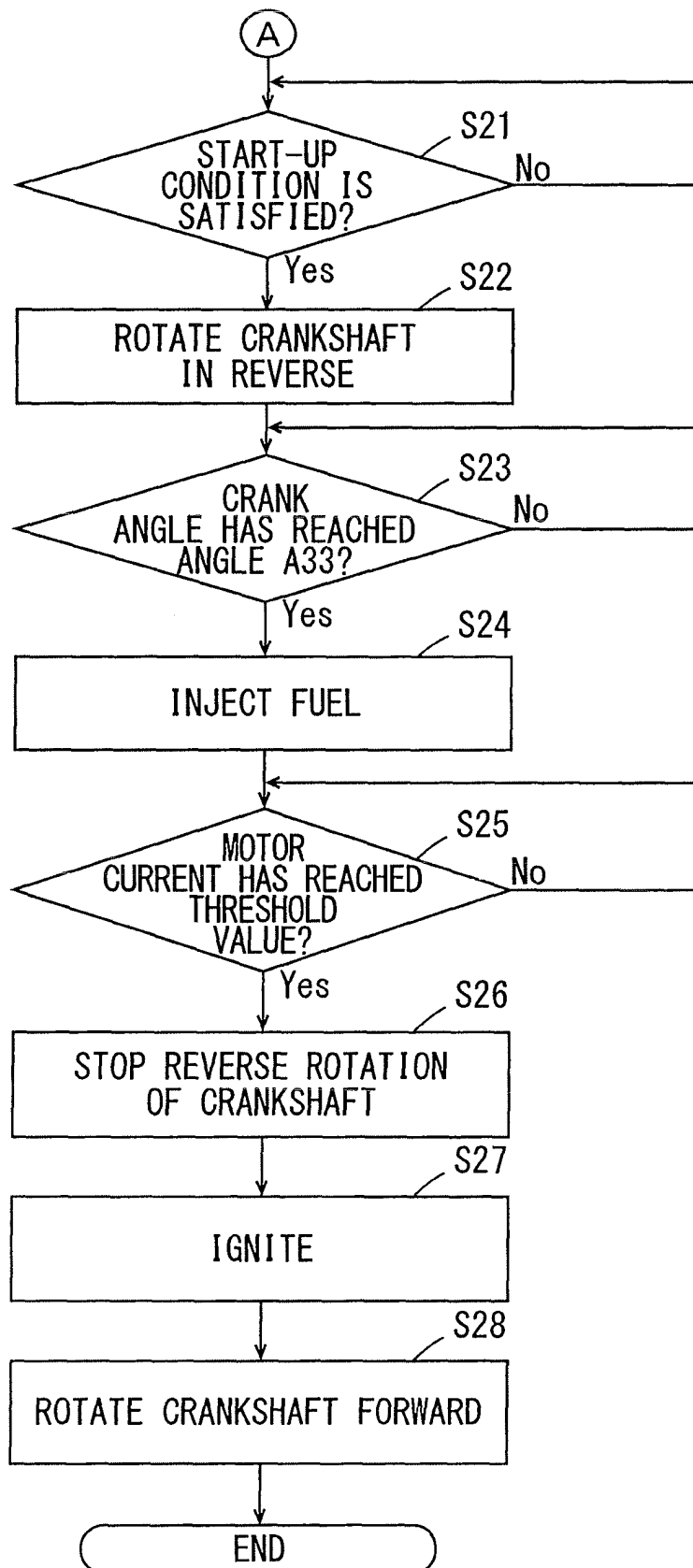


FIG. 11

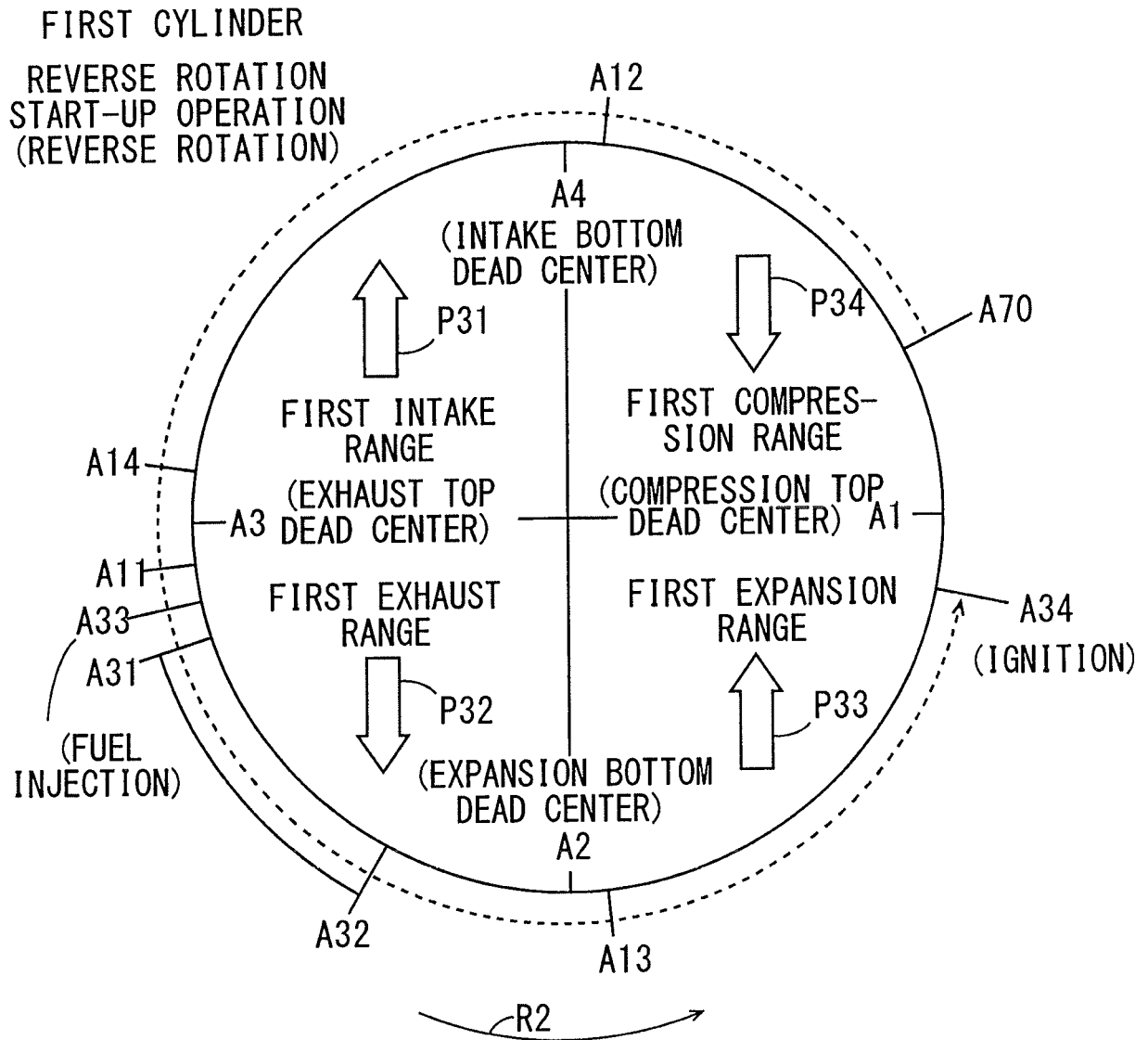


FIG. 12

SECOND CYLINDER
REVERSE ROTATION
START-UP OPERATION
(REVERSE ROTATION)

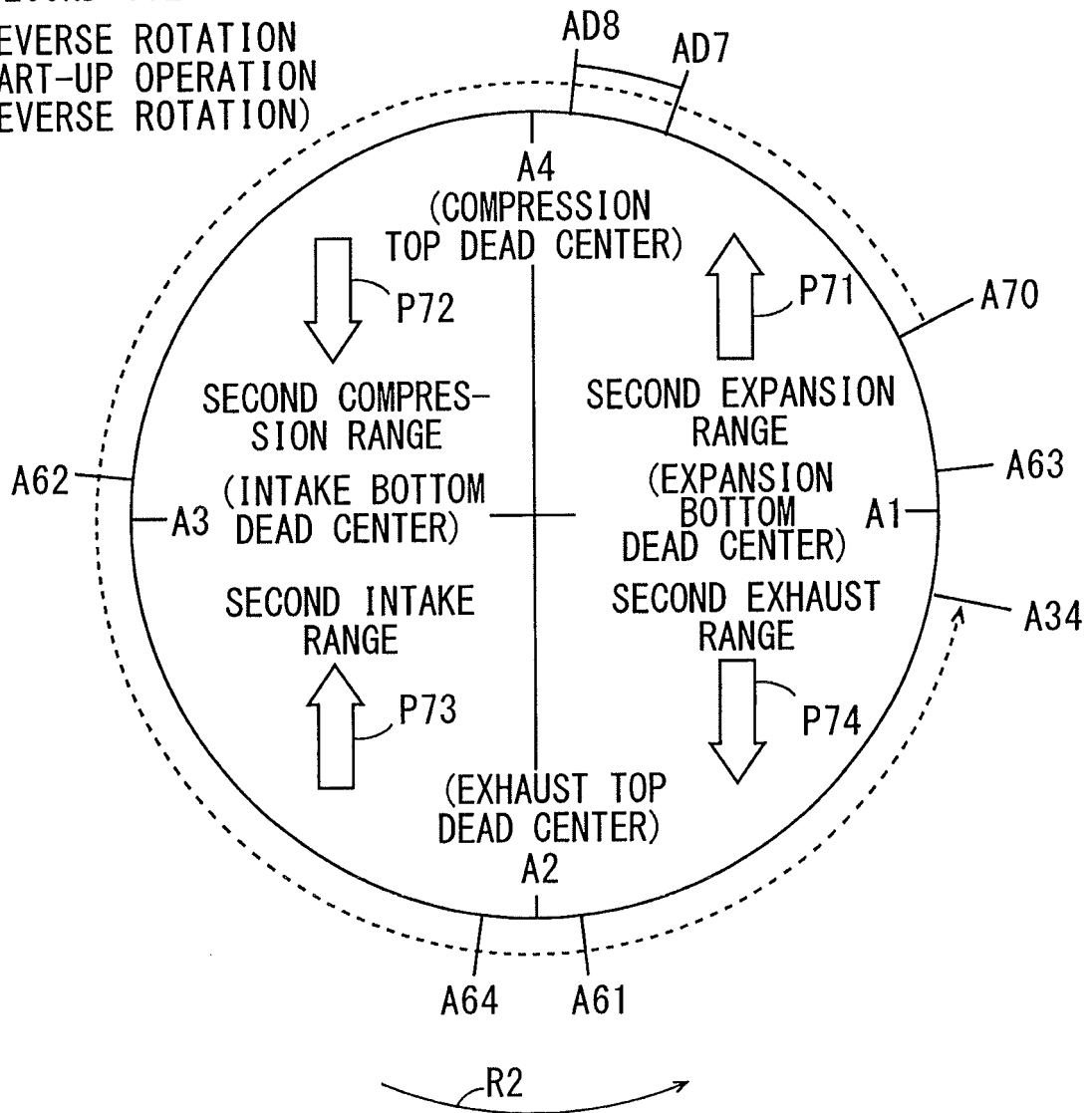


FIG. 13

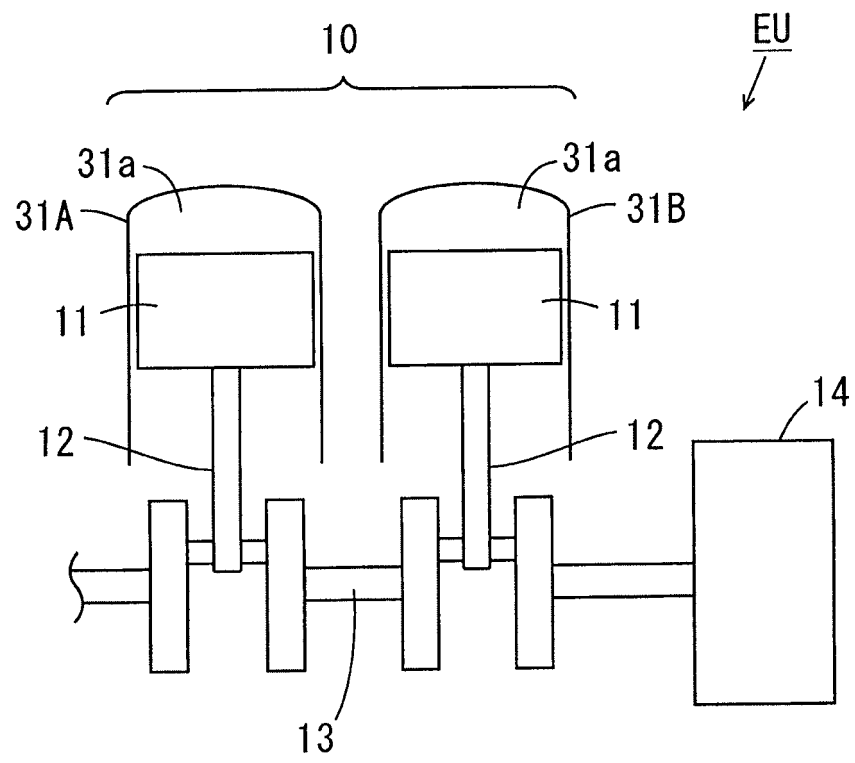


FIG. 14

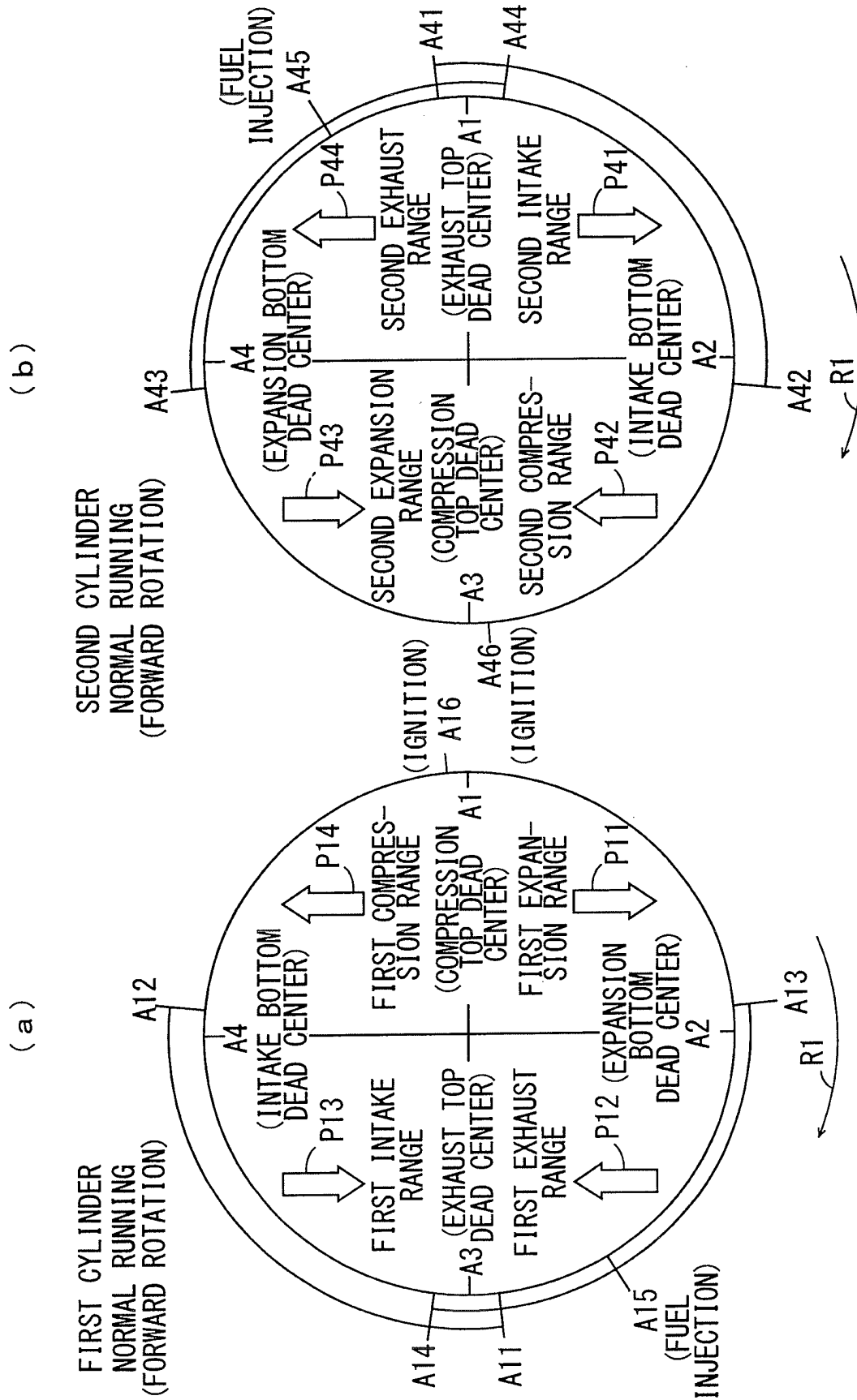


FIG. 15

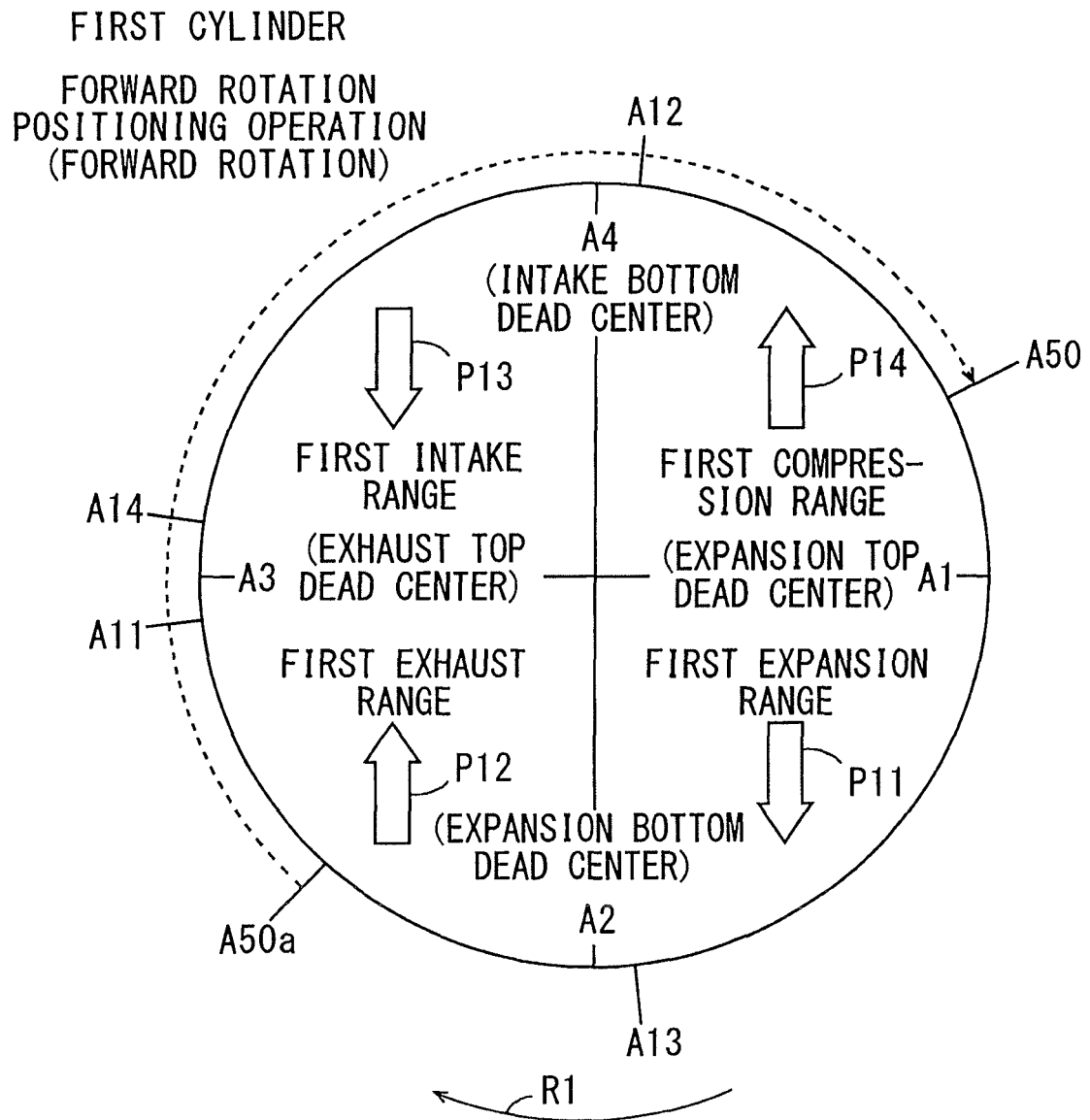


FIG. 16

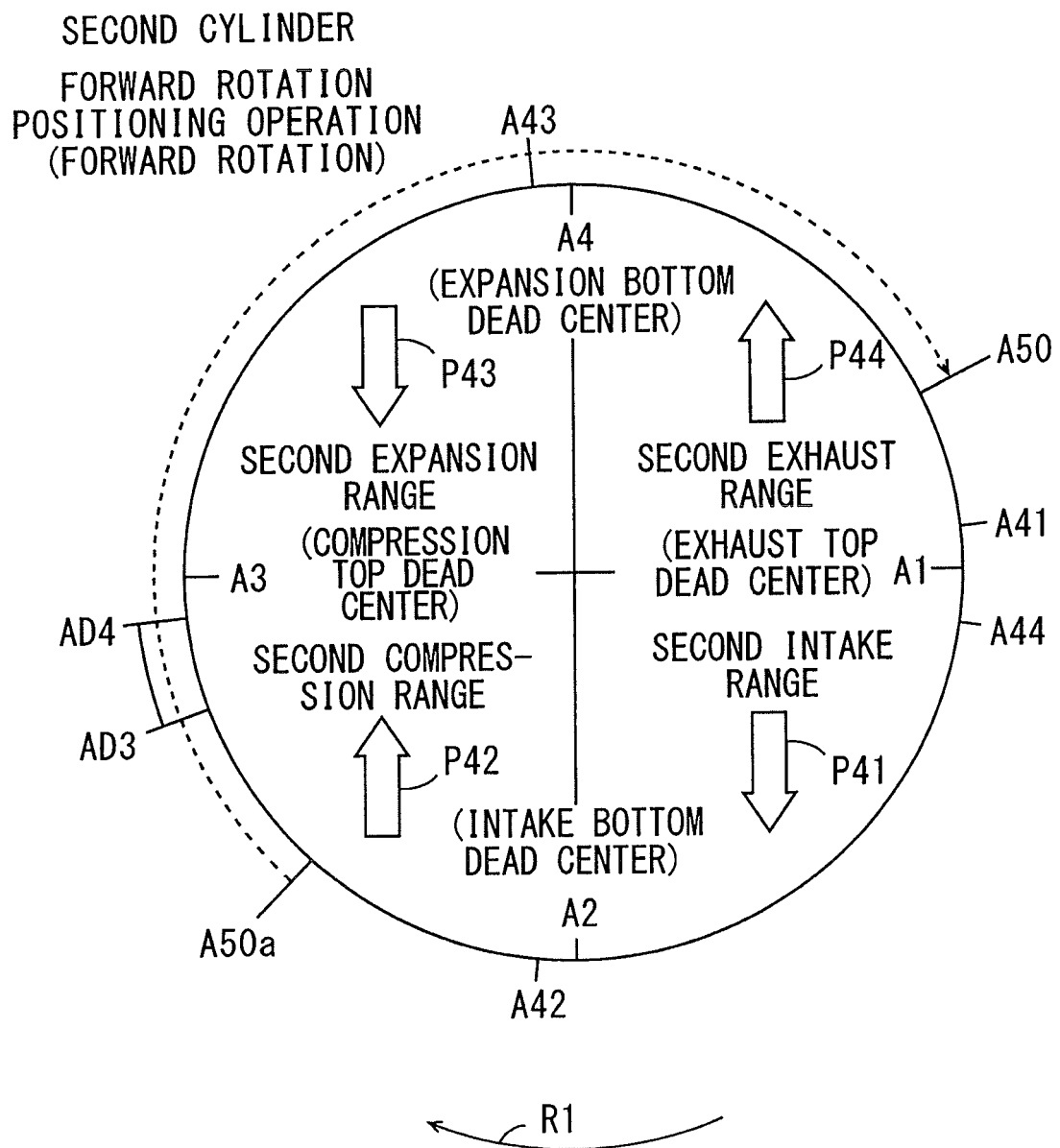


FIG. 17

FIRST CYLINDER
REVERSE ROTATION
START-UP OPERATION
(REVERSE ROTATION)

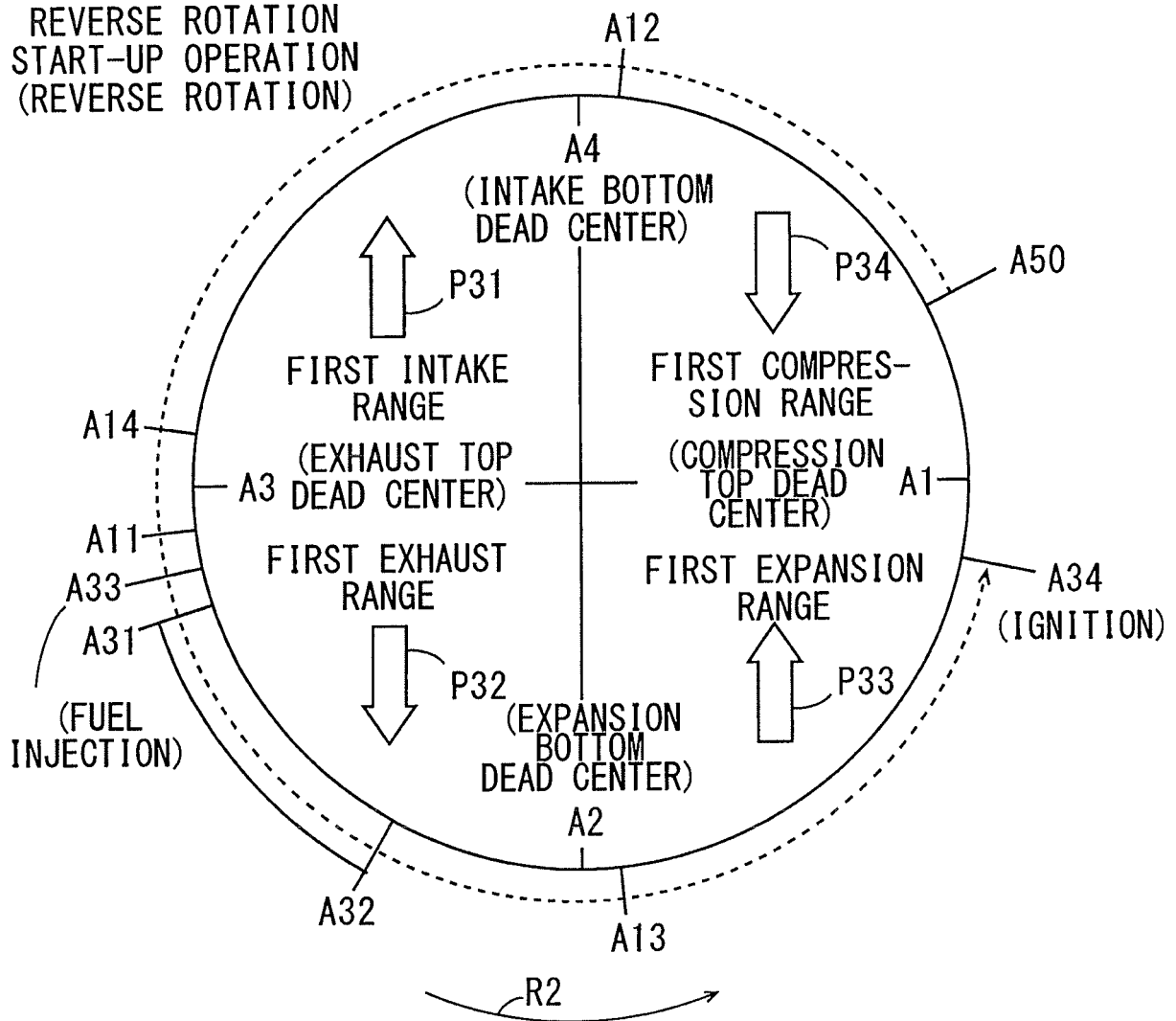


FIG. 18

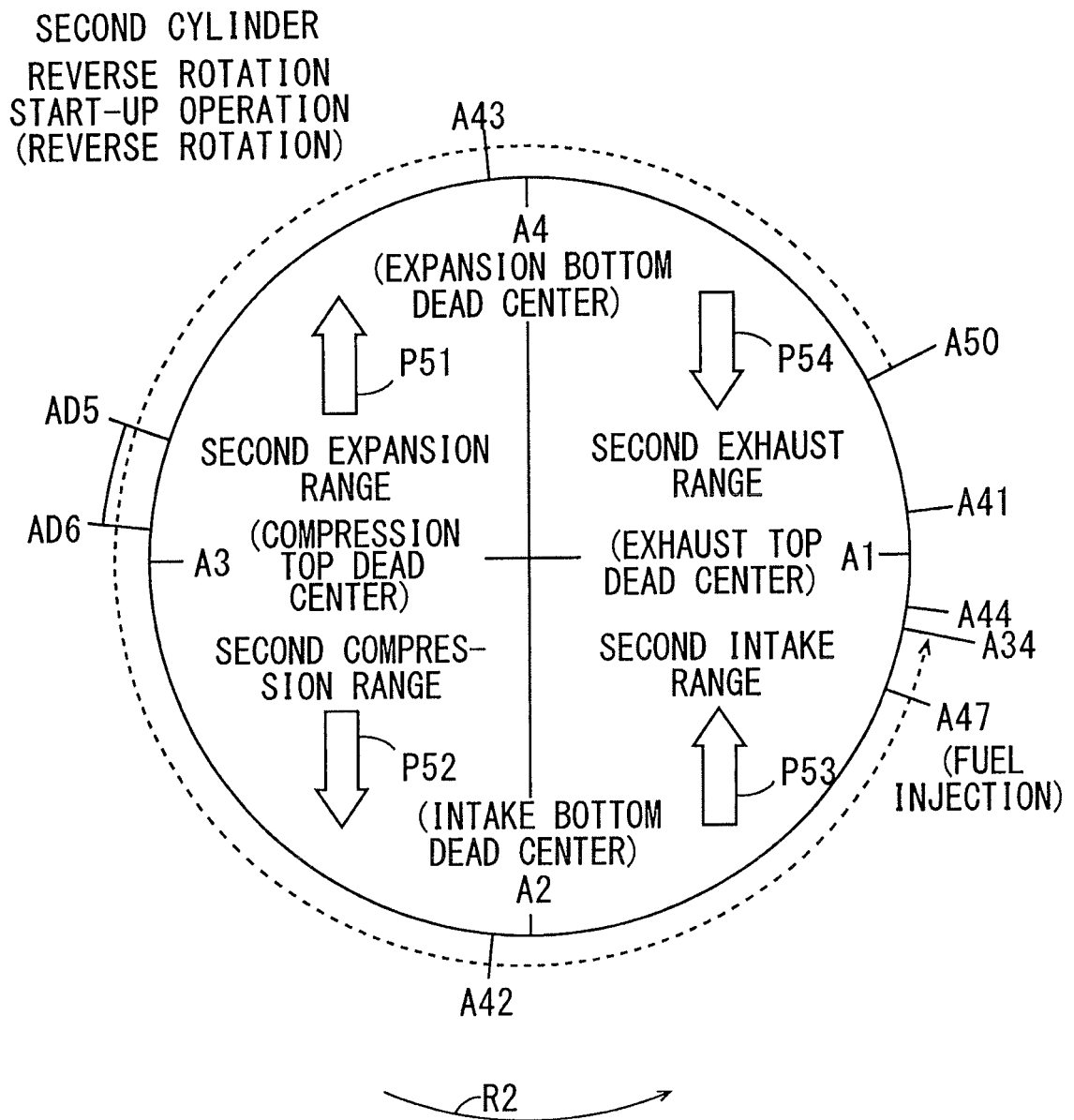


FIG. 19

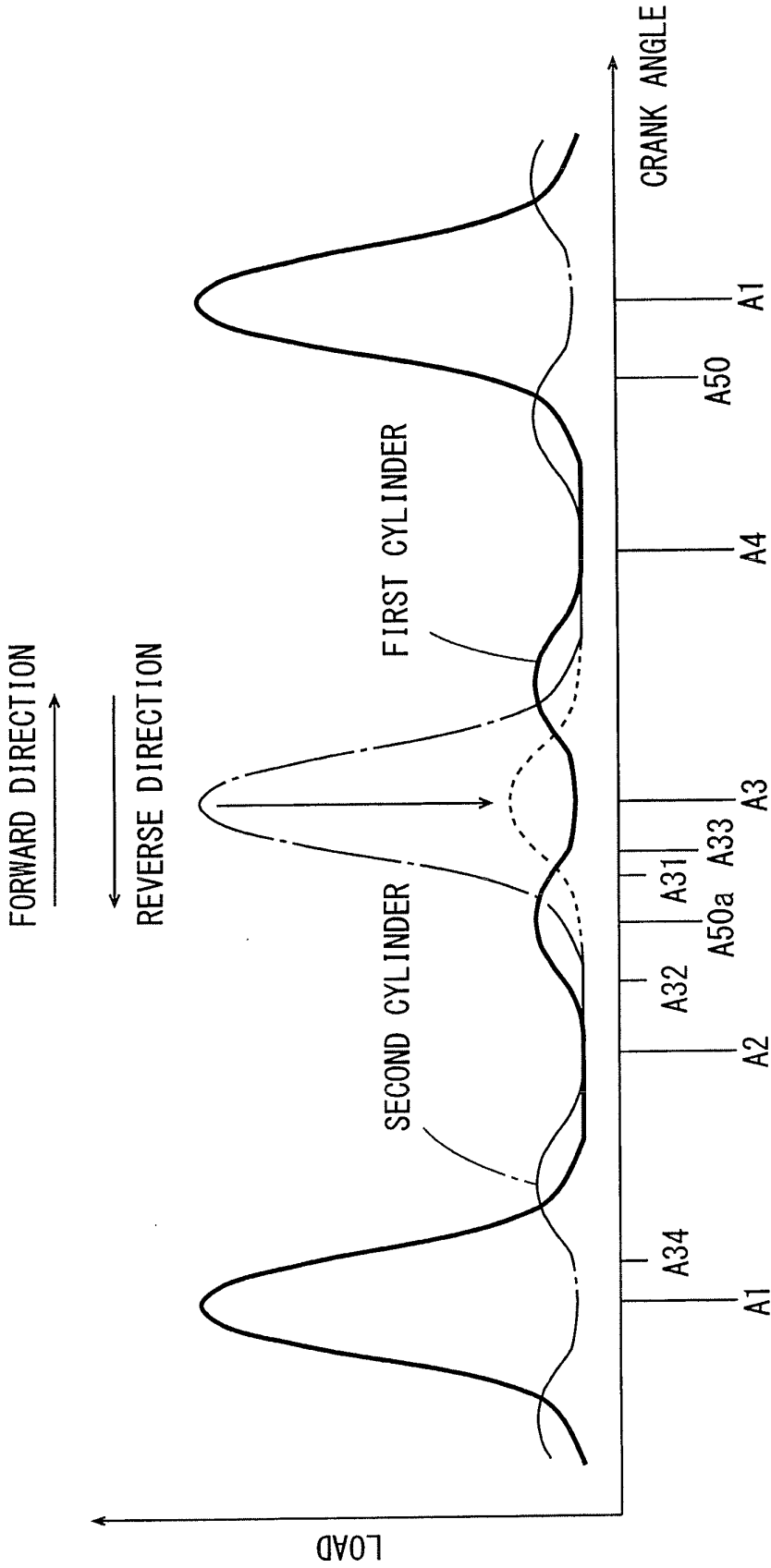


FIG. 20

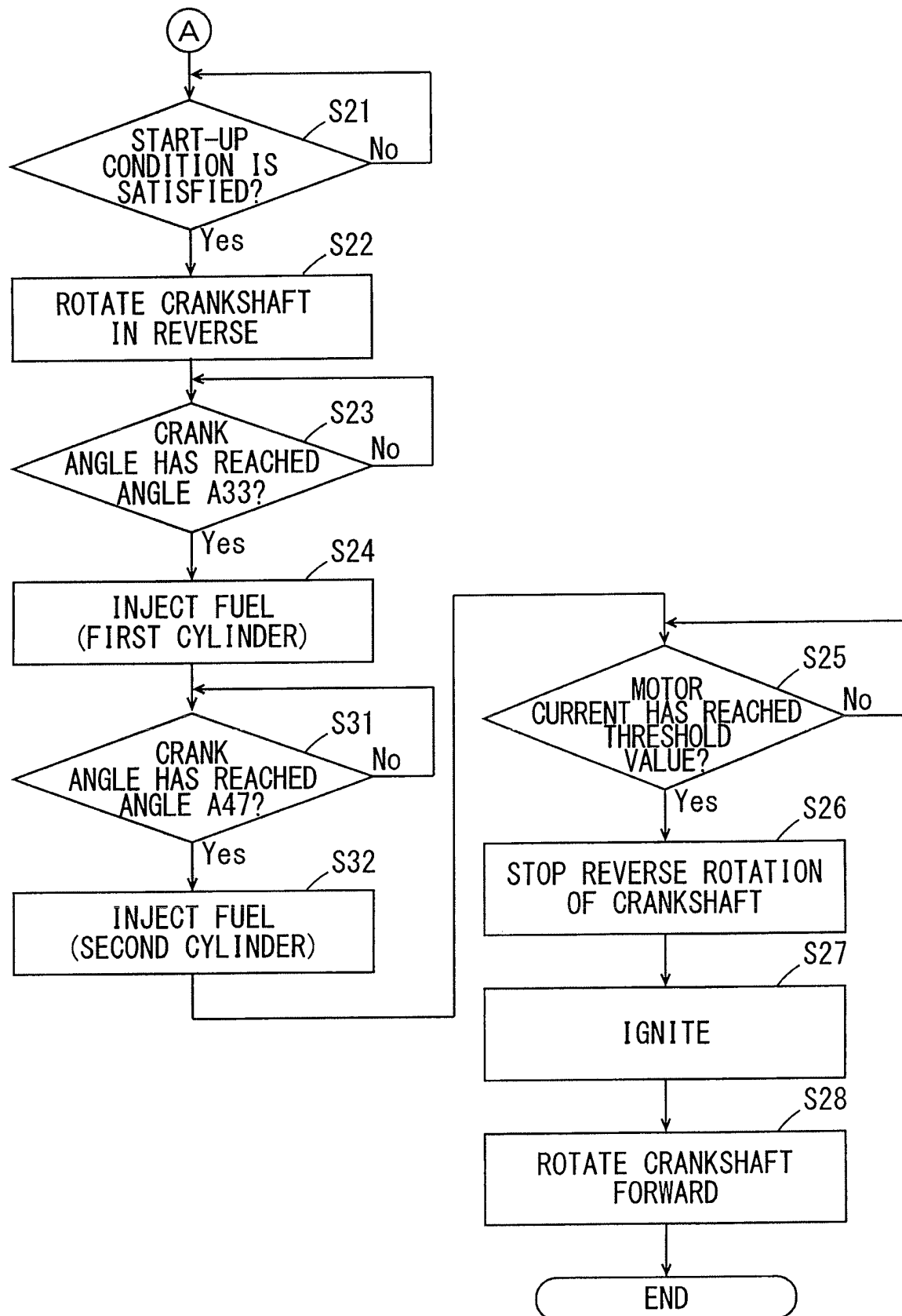


FIG. 21

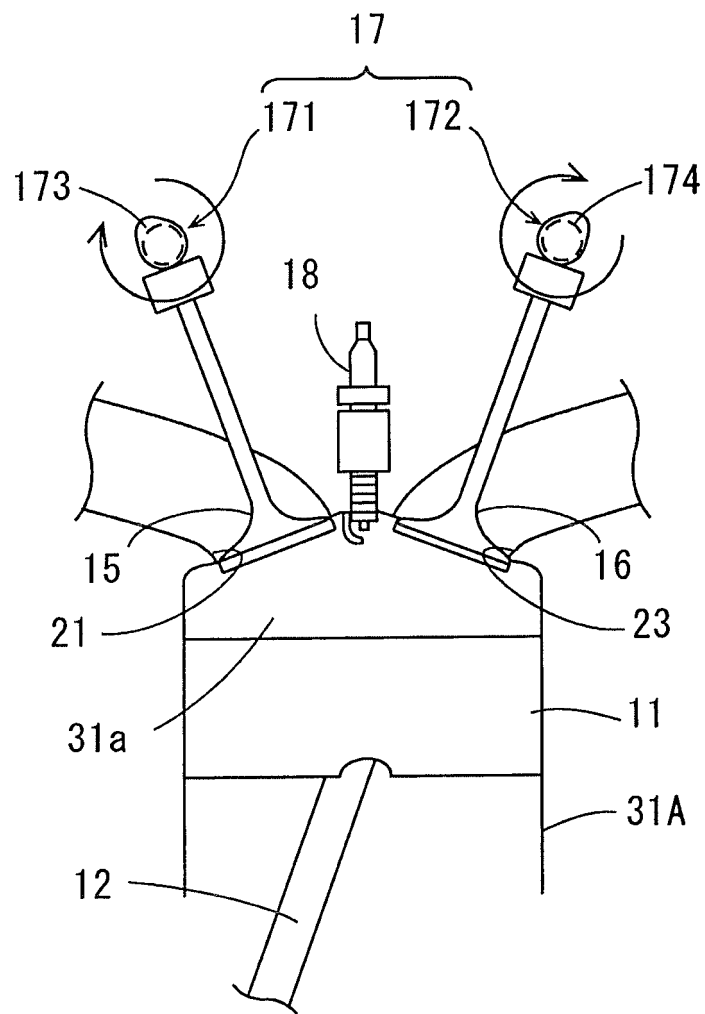


FIG. 22

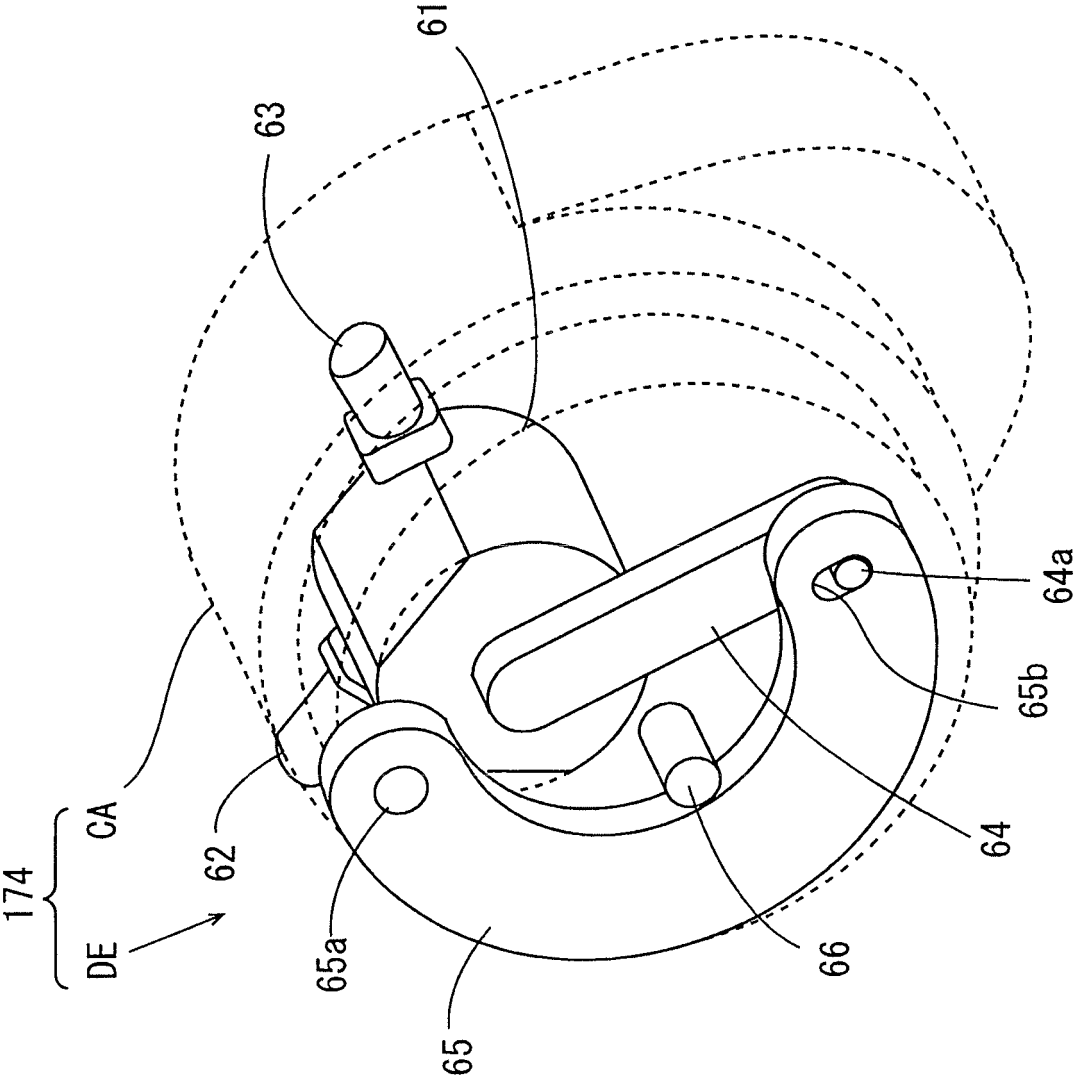
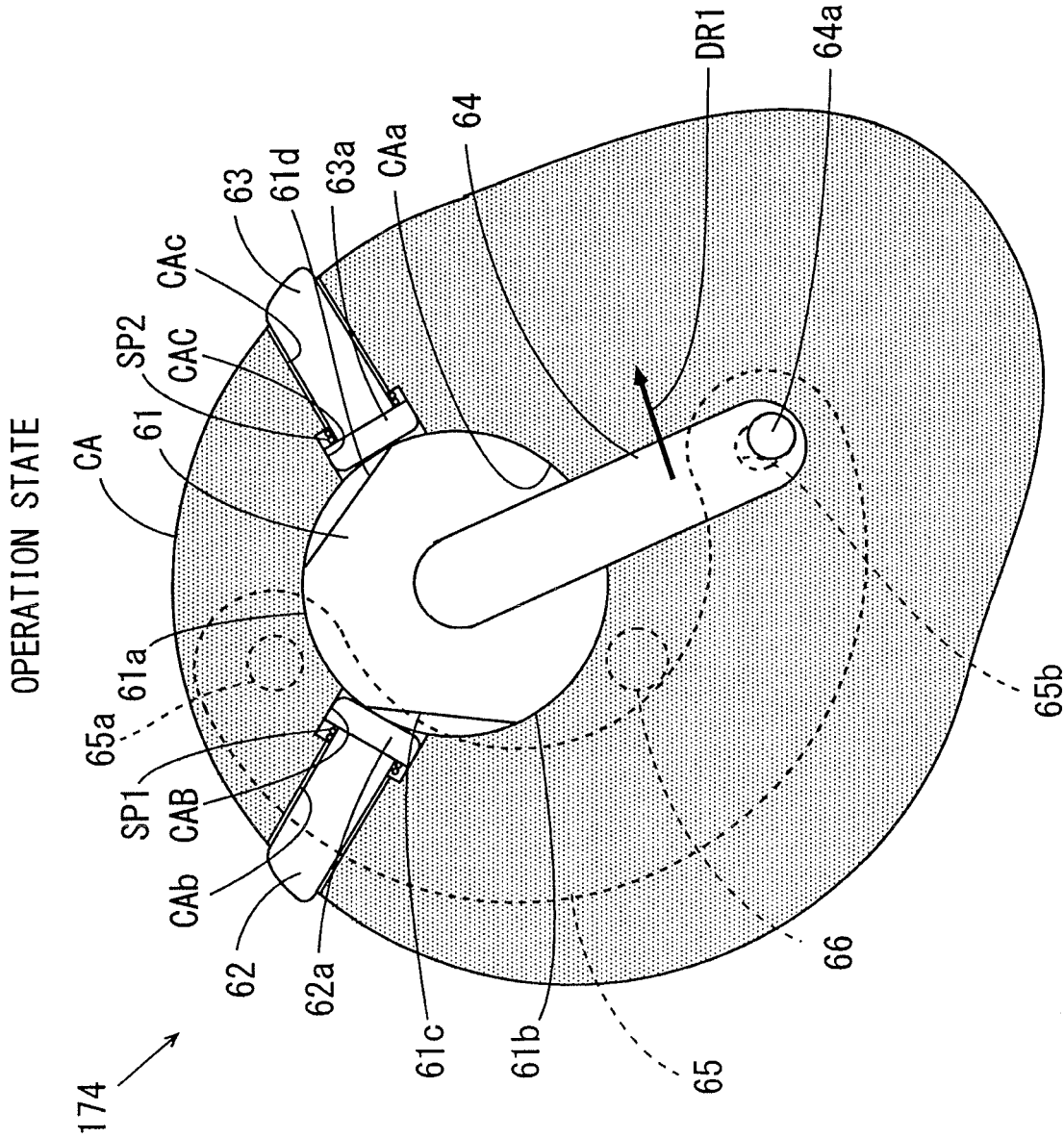


FIG. 23



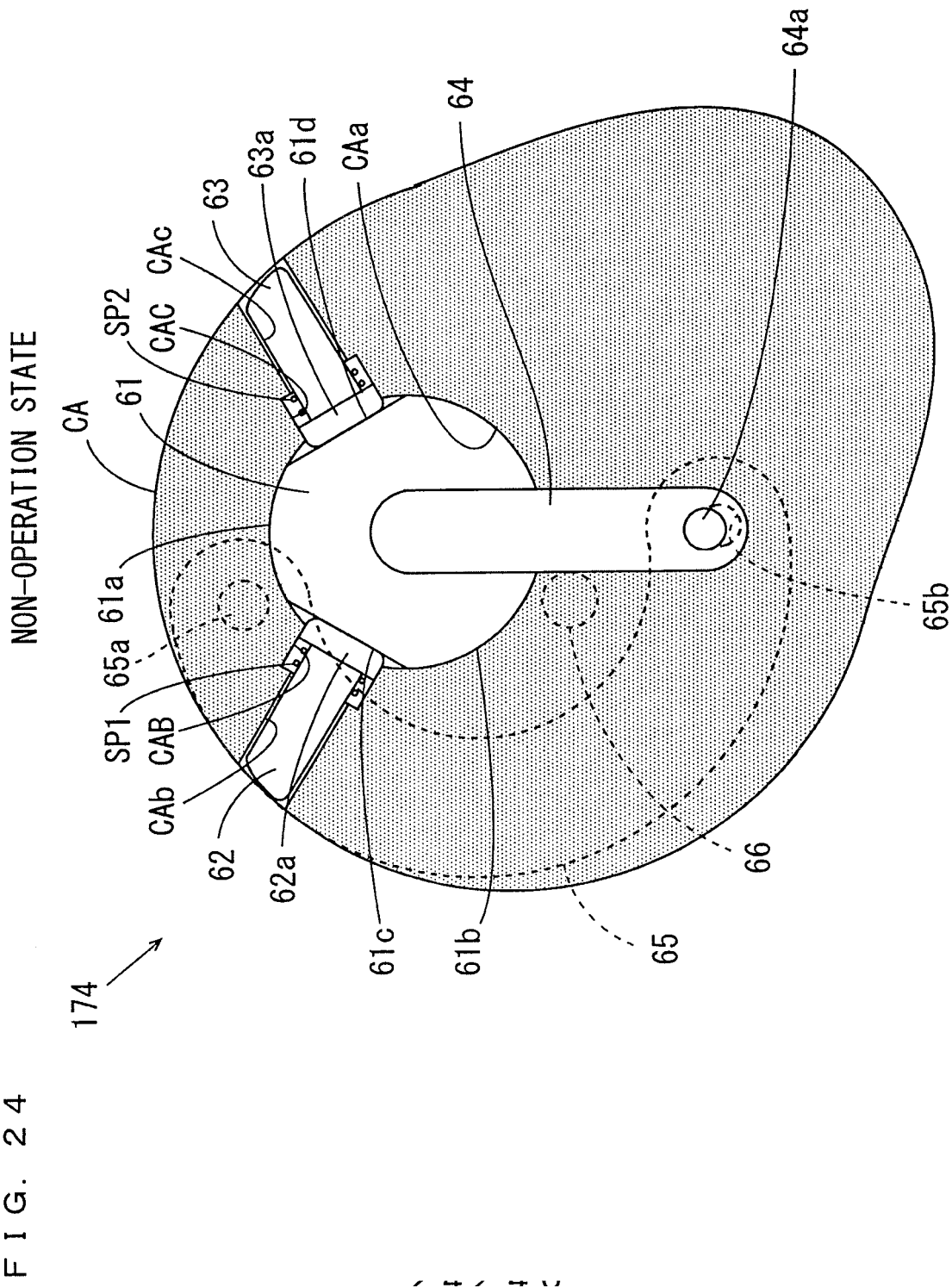


FIG. 25

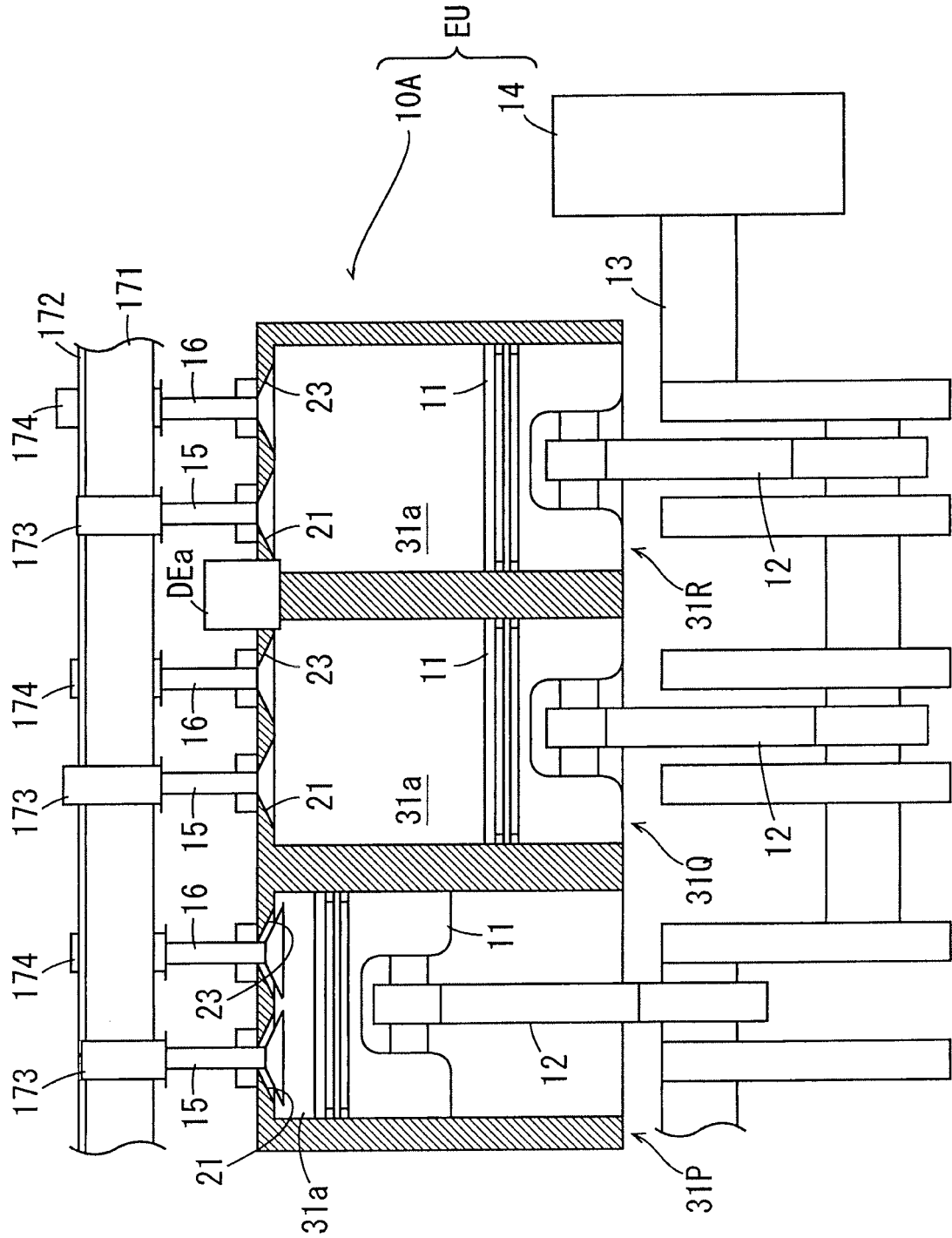


FIG. 26

FIRST CYLINDER
NORMAL RUNNING
(FORWARD ROTATION)

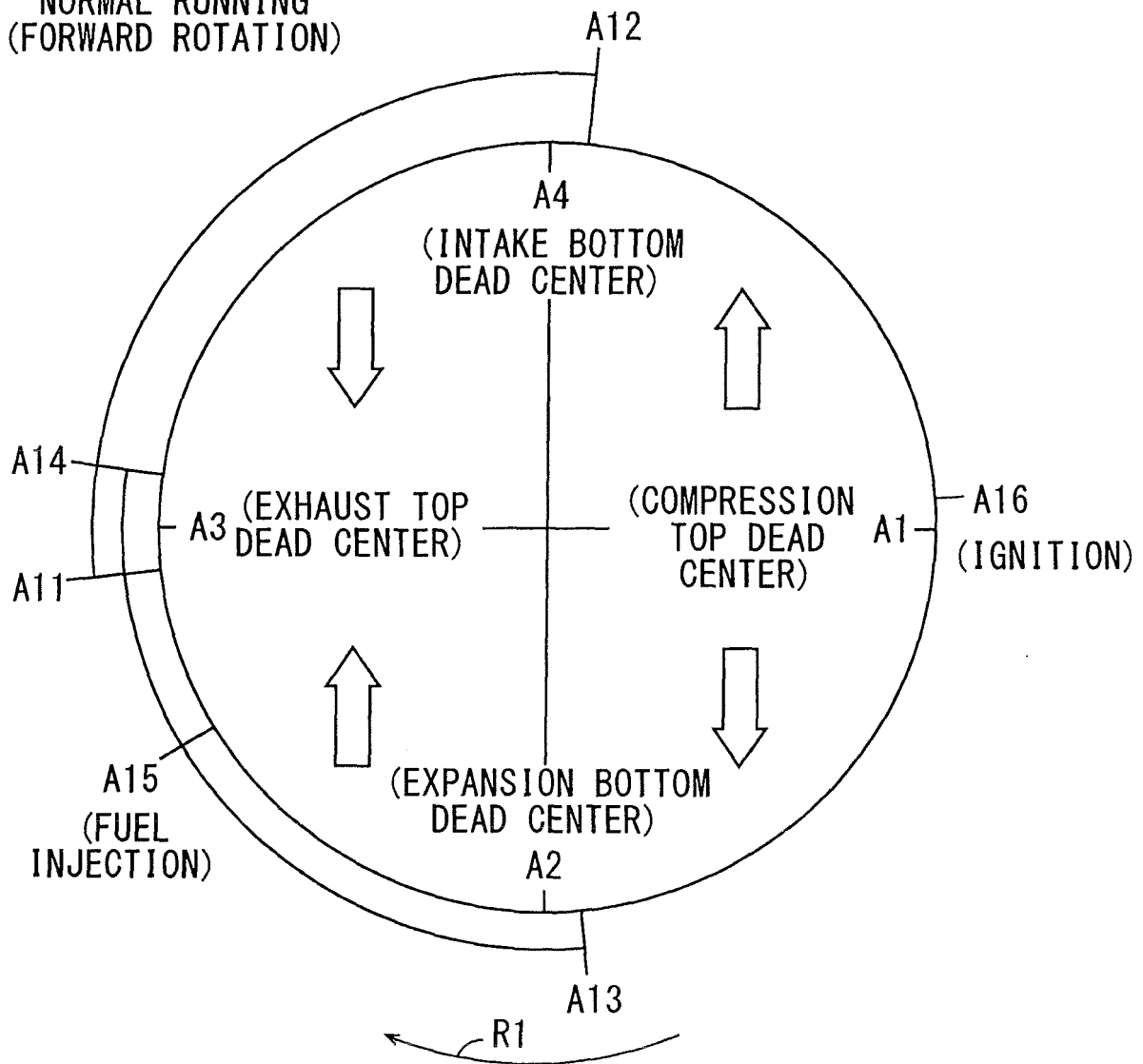


FIG. 27

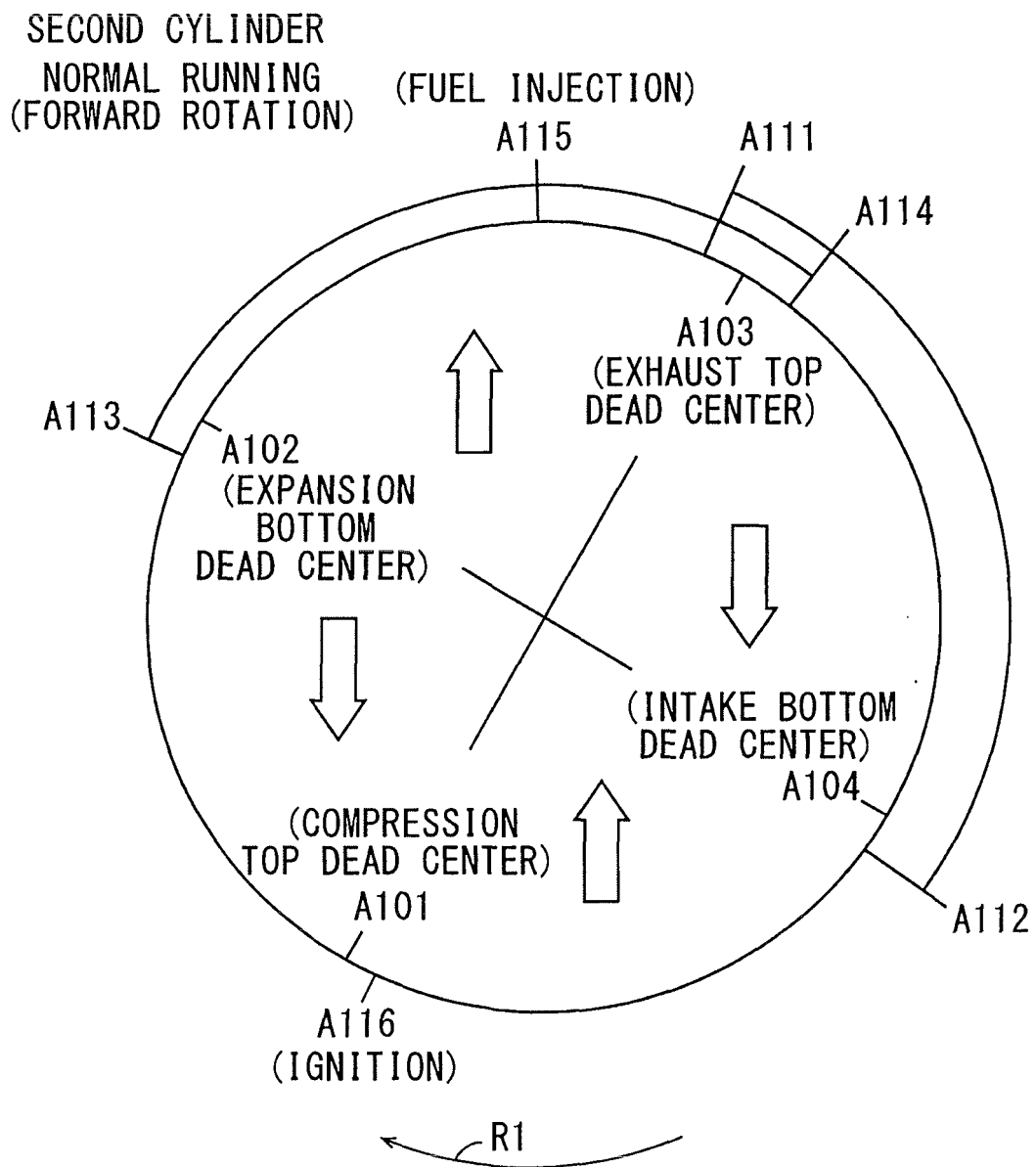


FIG. 28

THIRD CYLINDER
NORMAL RUNNING
(FORWARD ROTATION)

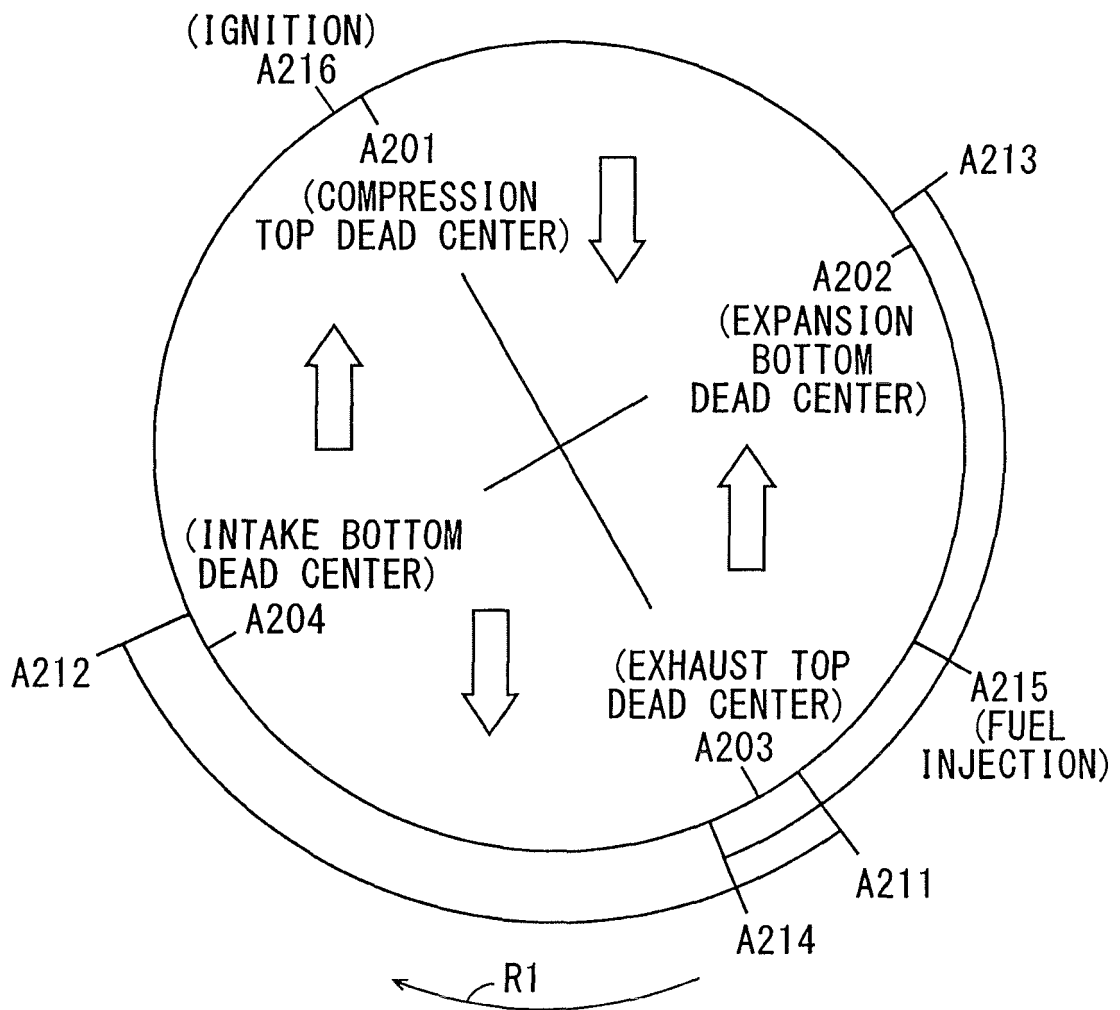


FIG. 29

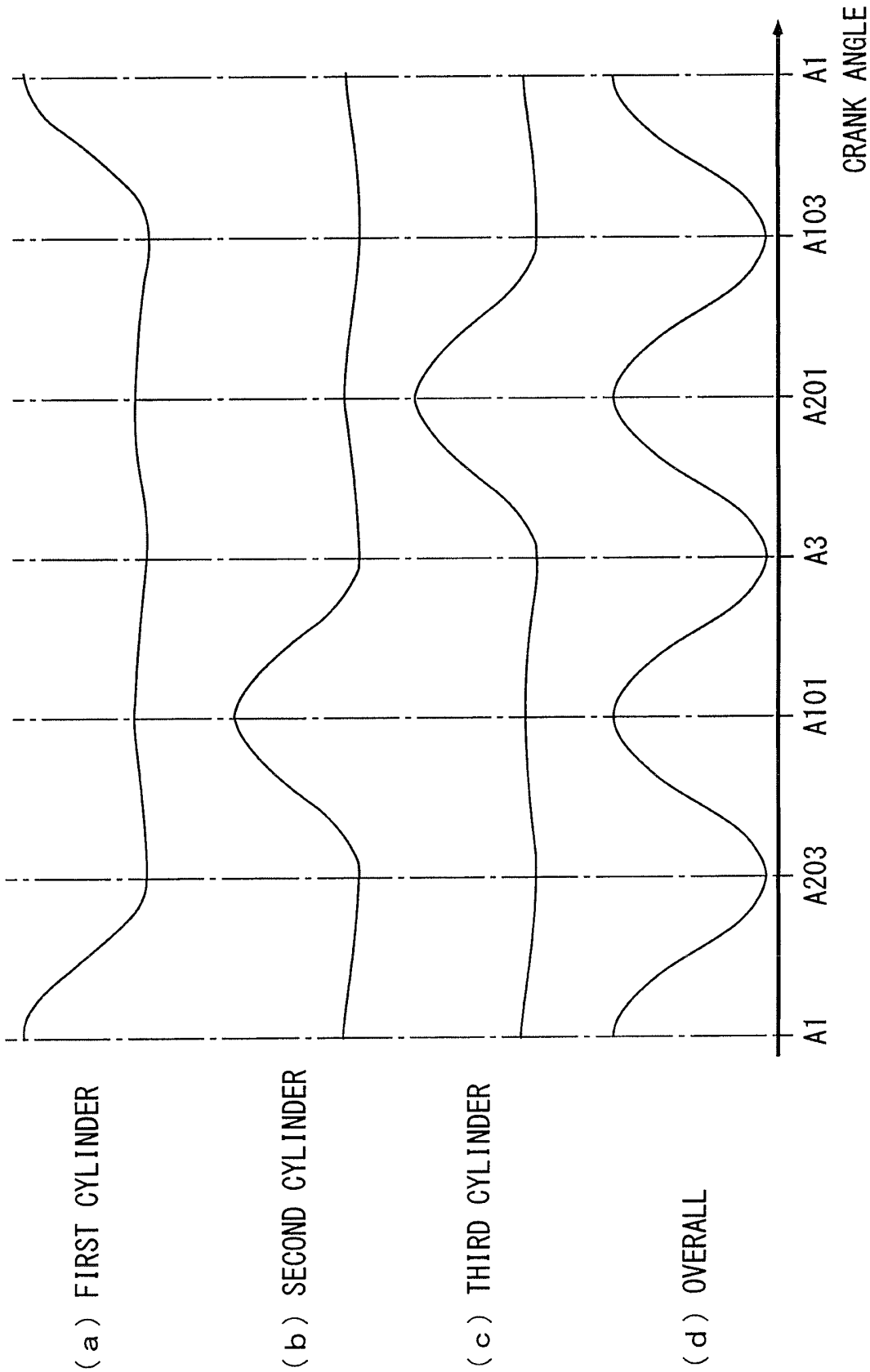


FIG. 30

FIRST CYLINDER
FORWARD ROTATION
POSITIONING OPERATION
(FORWARD ROTATION)

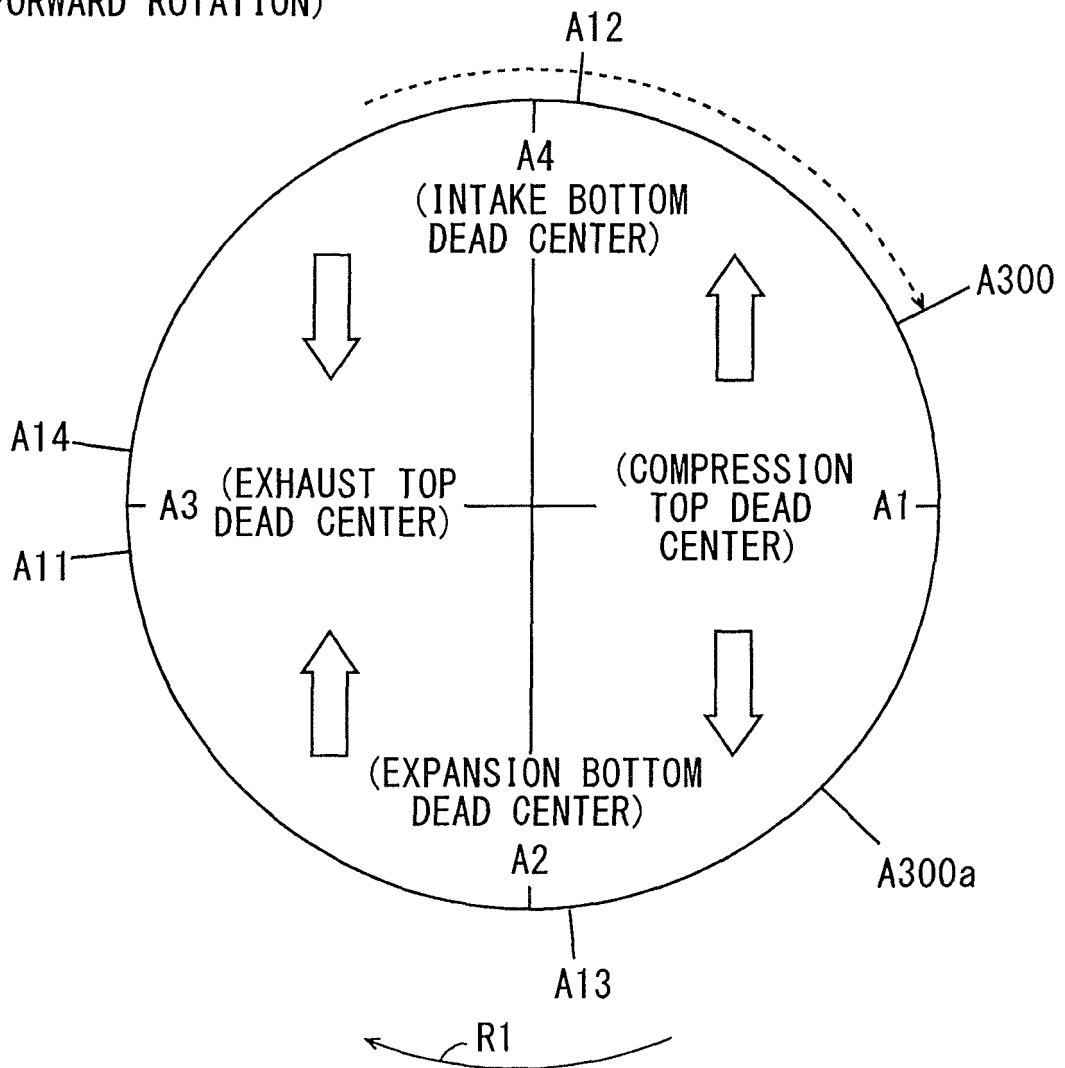


FIG. 31

FIRST CYLINDER
REVERSE ROTATION
START-UP OPERATION
(REVERSE ROTATION)

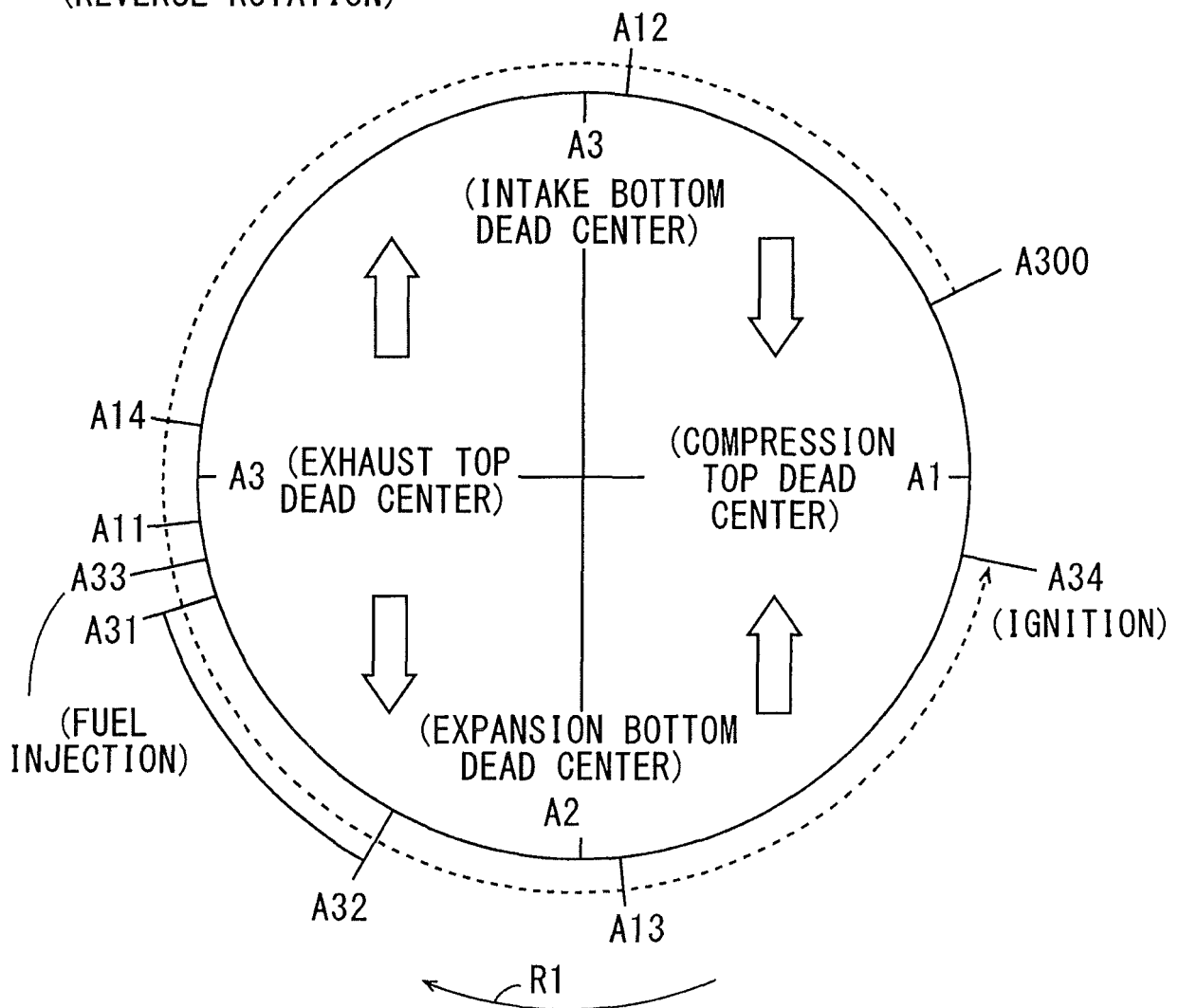


FIG. 32

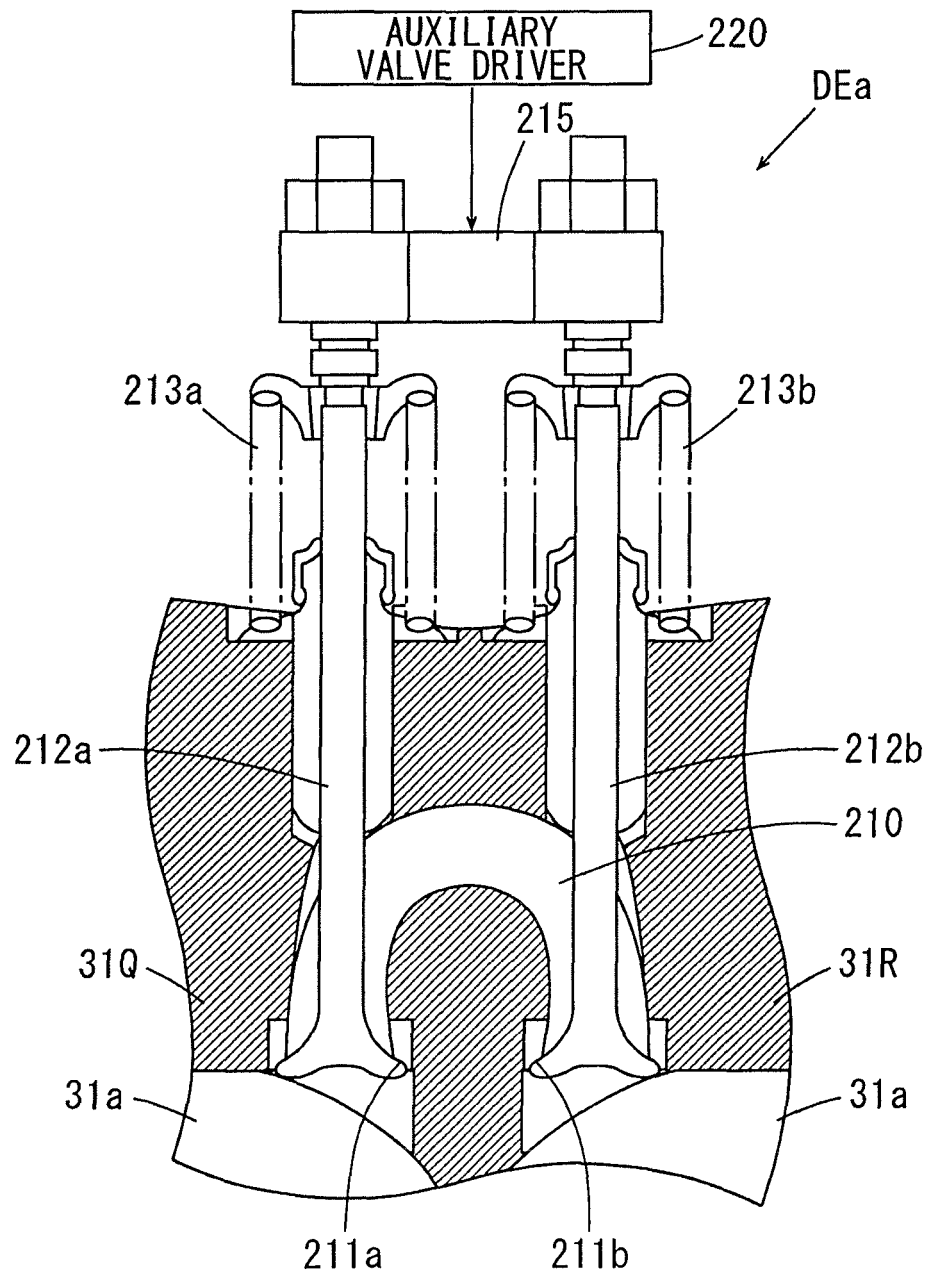


FIG. 33

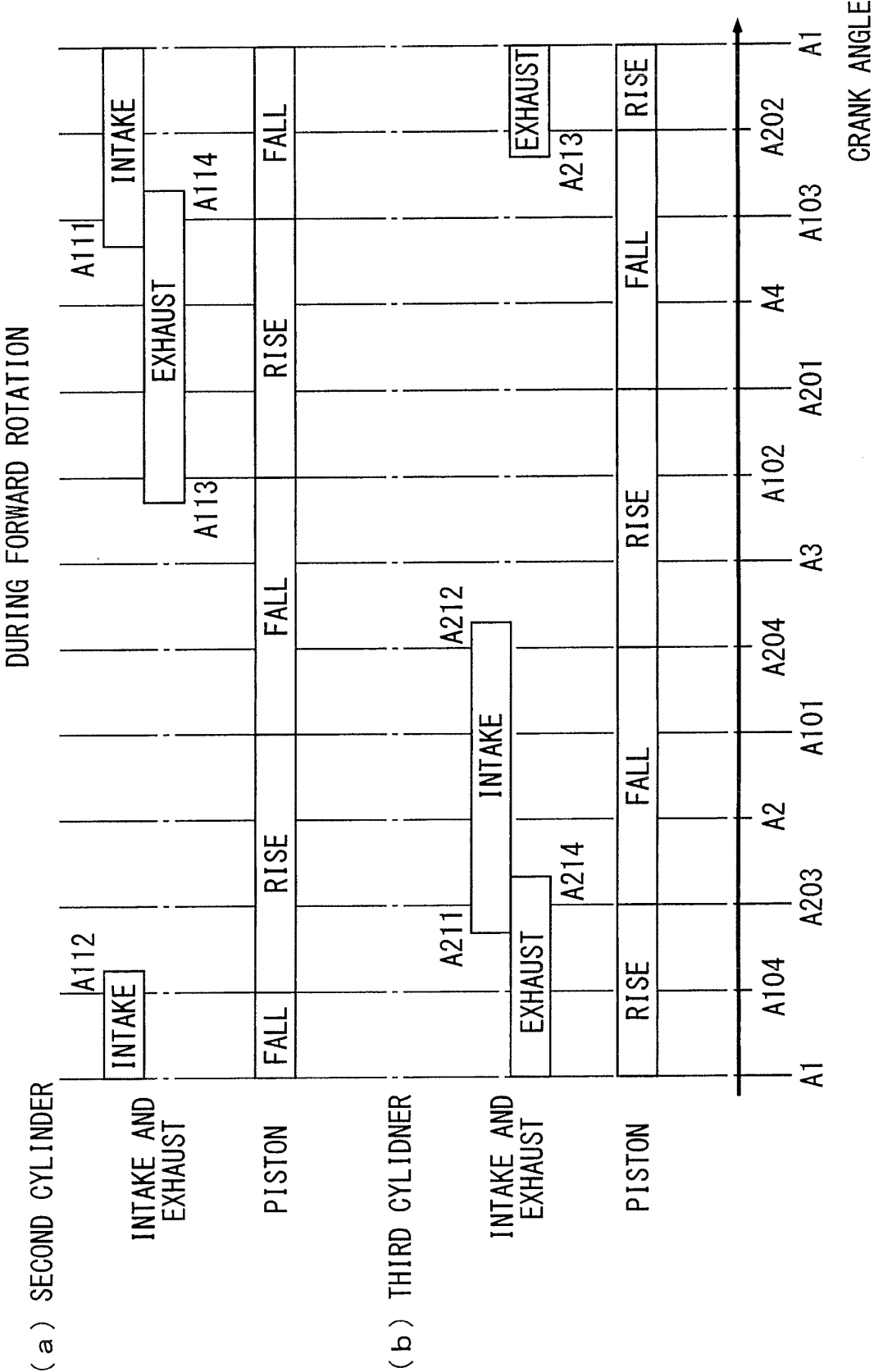
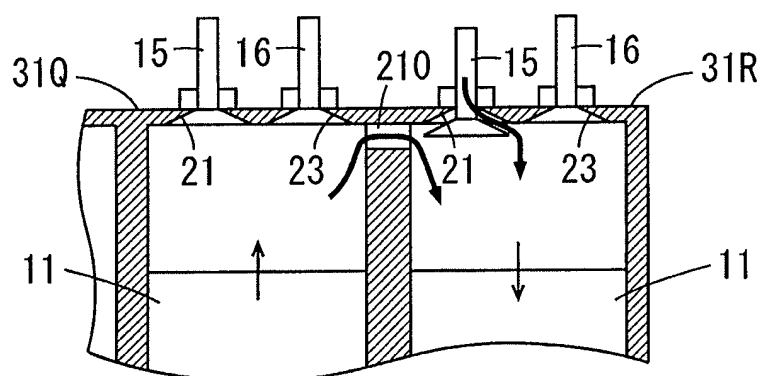
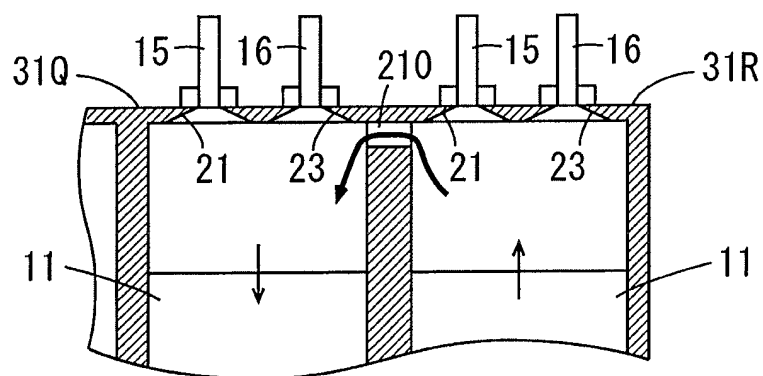


FIG. 34

(a) ANGLE A214→ANGLE A101



(b) ANGLE A212→ANGLE A113



(c) ANGLE A102→ANGLE A201

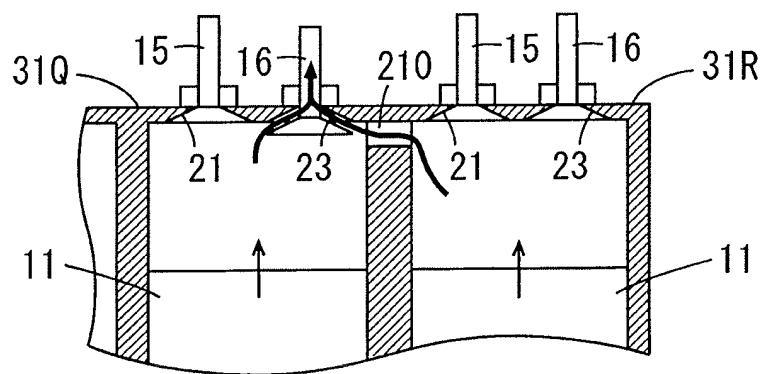


FIG. 35

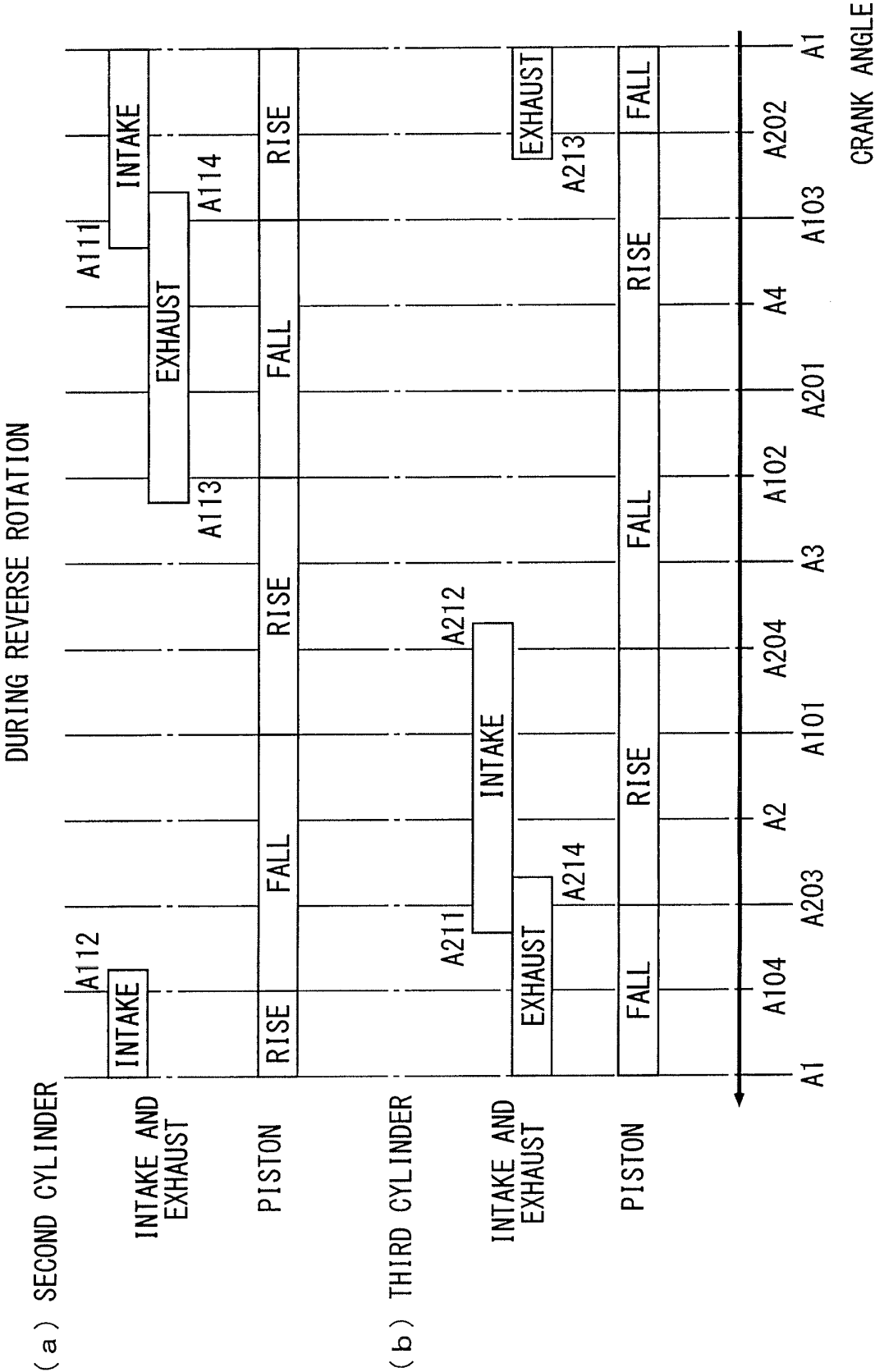
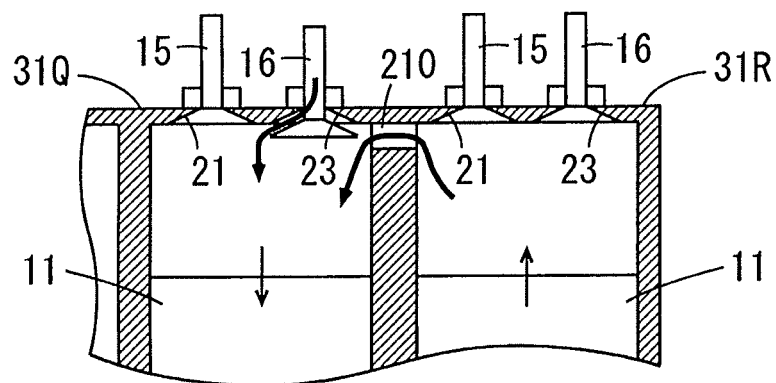
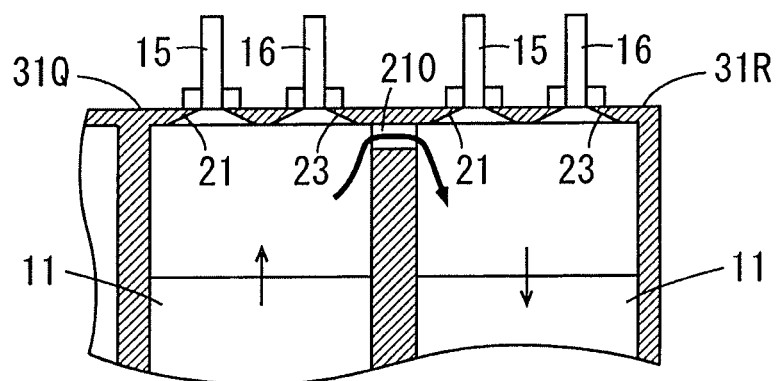


FIG. 36

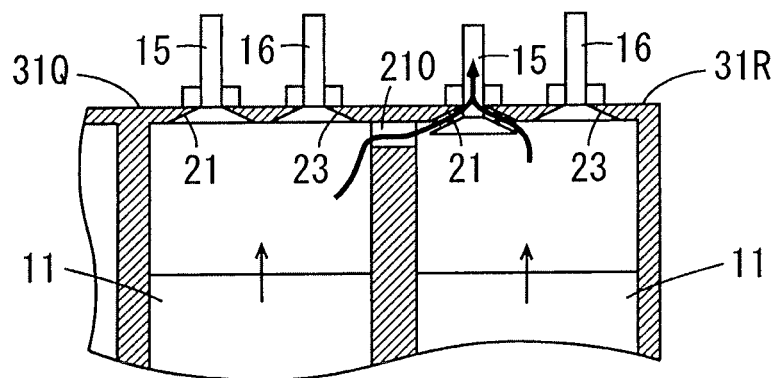
(a) ANGLE A111→ANGLE A201



(b) ANGLE A113→ANGLE A212



(c) ANGLE A204→ANGLE A101



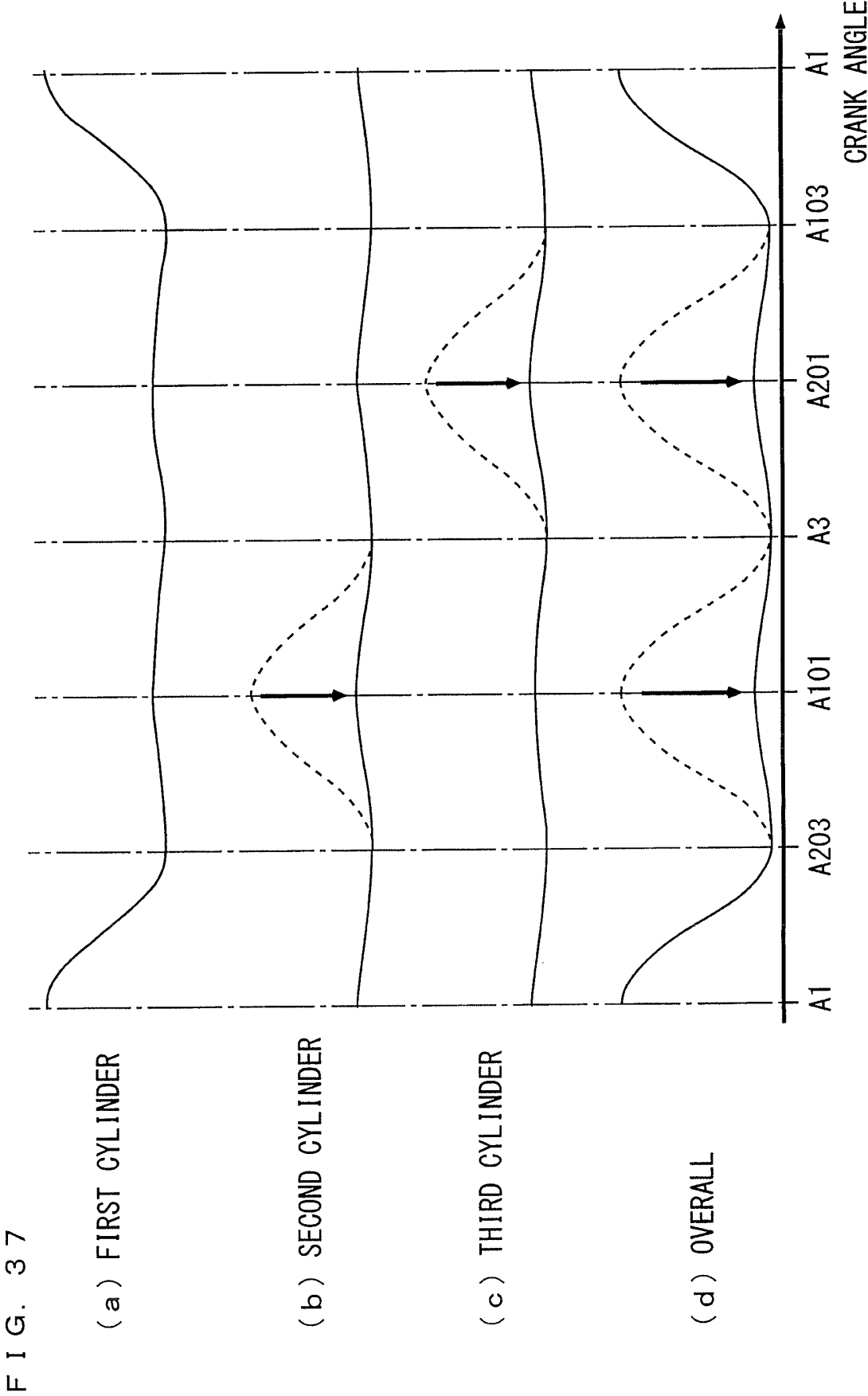


FIG. 38

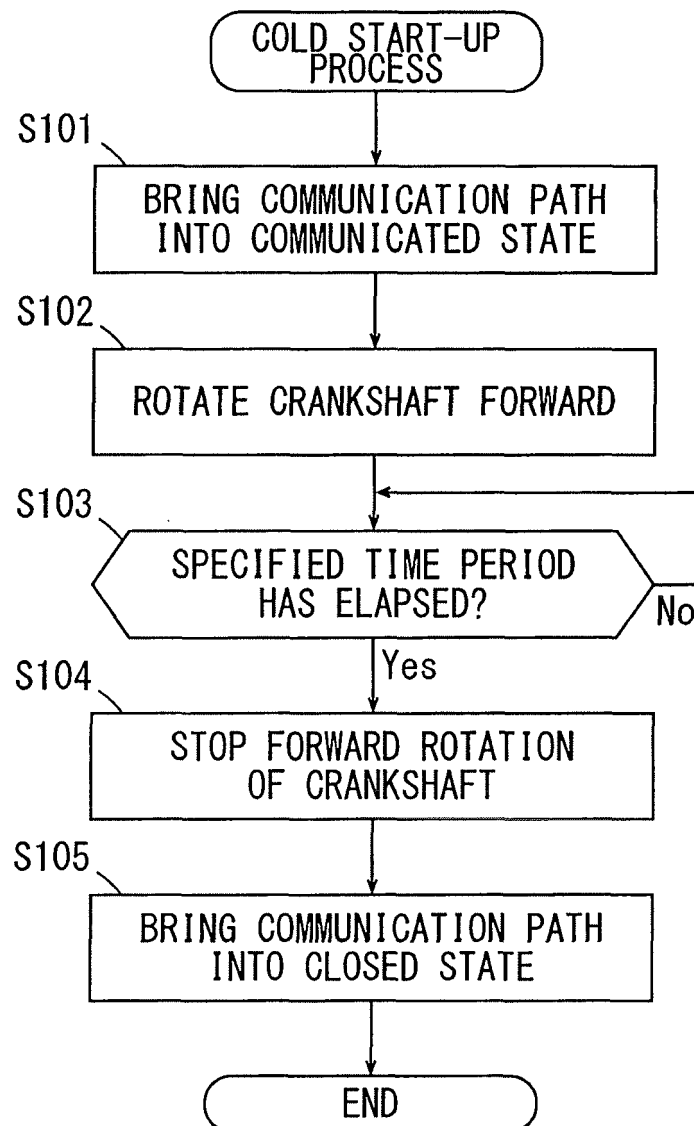


FIG. 39

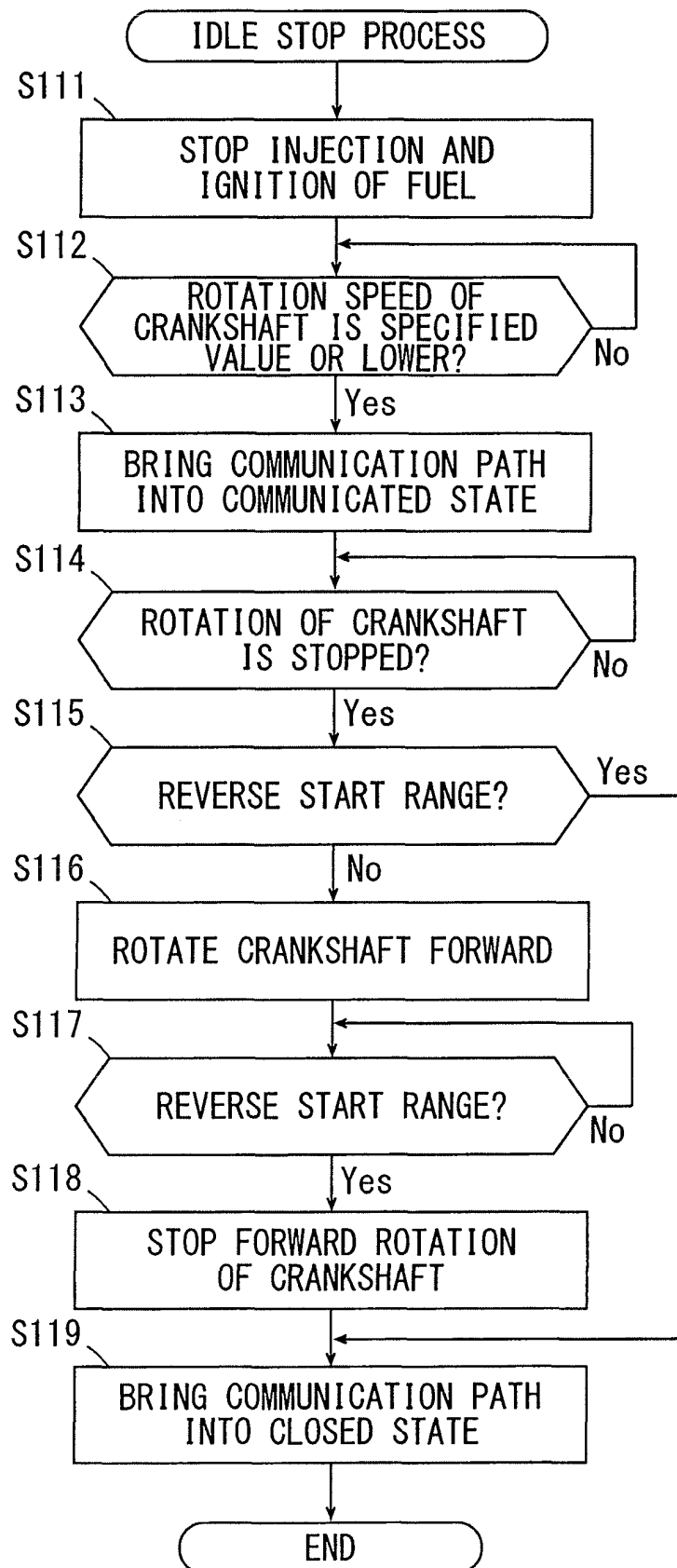
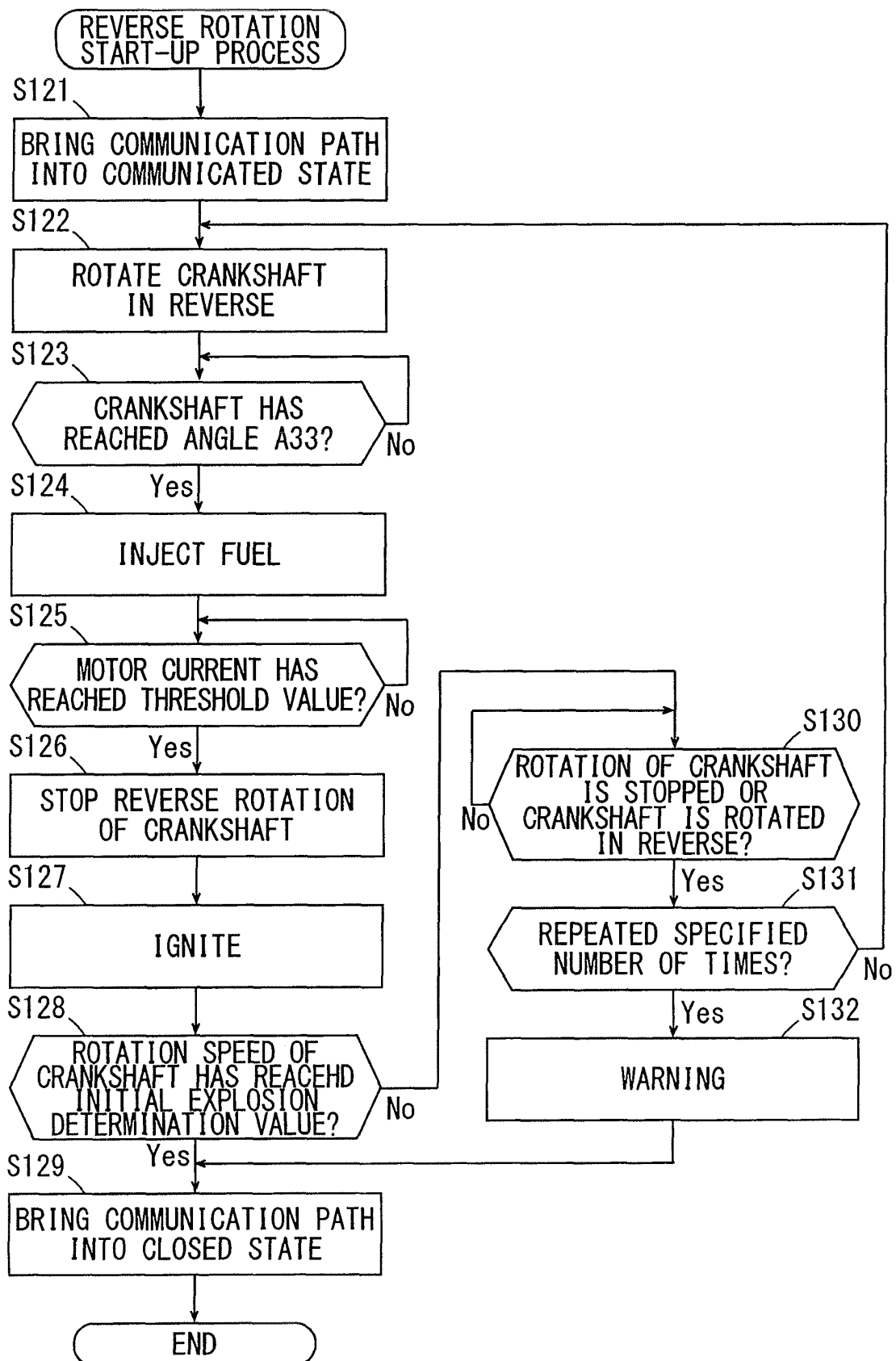


FIG. 40



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/003330

A. CLASSIFICATION OF SUBJECT MATTER

F02D15/00(2006.01)i, F01L13/08(2006.01)i, F02D29/02(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)

F02D15/00, F01L13/08, F02D29/02, F02D45/00, 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 1996-2015
Kokai Jitsuyo Shinan Koho 1971-2015 Toroku Jitsuyo Shinan Koho 1994-2015

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.
X A	JP 2008-202557 A (Kokusan Denki Co., Ltd.), 04 September 2008 (04.09.2008), paragraphs [0024], [0031], [0064] to [0067] (Family: none)	1-2, 12, 16 3-11, 13-15
A	JP 2005-180380 A (Toyota Motor Corp.), 07 July 2005 (07.07.2005), paragraphs [0006] to [0007] (Family: none)	1-16
A	JP 2002-332938 A (Honda Motor Co., Ltd.), 22 November 2002 (22.11.2002), claims 1, 4; paragraphs [0040] to [0046] & CN 1384281 A	1-16

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search
28 August 2015 (28.08.15)

Date of mailing of the international search report
08 September 2015 (08.09.15)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2005180380 A [0003]