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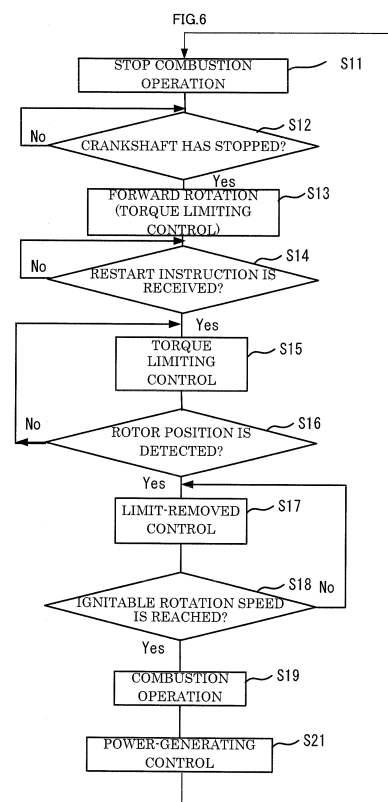
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(54) **ENGINE UNIT AND VEHICLE**

(57) The present invention provides, for example, an engine unit that has a high-load region and a low-load region and that can achieve mountability to vehicle and shortening of the length of time required for restarting after a combustion stop instruction. The engine unit includes a four-stroke engine body, a three-phase brushless motor, an inverter, and a control device. After a combustion operation of the four-stroke engine body and forward rotation of a crankshaft are stopped, the control device controls a voltage applied from a battery to the three-phase brushless motor by controlling a plurality of switching parts of the inverter under a state where a start instruction is not received while the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped, to drive the crankshaft in forward rotation from a stopped position to a compression stroke included in four strokes. Upon receiving the start instruction, the control device drives the crankshaft in forward rotation from a position where the crankshaft is located at a time point when the start instruction is received.



Description

Technical Field

[0001] The present invention relates to an engine unit including a four-stroke engine body in which a high-load region and a low-load region occur during four strokes, and also relates to a vehicle equipped with the engine unit.

Background Art

[0002] Types of engines mounted to vehicles include a four-stroke engine (for example, a single-cylinder engine) having, during four strokes, a high-load region in which a high load is put on rotation of a crankshaft of the engine and a low-load region in which a low load is put on rotation of the crankshaft. Such a four-stroke engine requires that a starter motor generate a high output torque for enabling the rotating crankshaft to overcome the high-load region at a time of engine start. To obtain a high output torque from the starter motor, however, the size of the starter motor has to be increased. This leads to deterioration in mountability of the engine unit to a vehicle. Improvement in mountability of the engine unit to a vehicle has been demanded.

[0003] Patent Literature 1 (PTL1) discloses an engine starter that starts an engine by driving a crankshaft once in reverse rotation, then stopping the crankshaft, and then driving the crankshaft in forward rotation. The engine, which is started by the engine starter as shown in the Patent Literature 1, stops combustion if a combustion stop instruction is received during its operation. After the combustion is stopped, the crankshaft makes freewheeling rotation four to eight times. If the crankshaft can no longer overcome the peak of a load caused by a reaction force of compression in the compression stroke, the crankshaft turns into reverse rotation due to the reaction force of compression, and then stops.

[0004] The engine starter of the Patent Literature 1 is configured to, after rotation of the crankshaft is stopped, drive the crankshaft in reverse rotation up to a position at which a load increase occurs, that is, up to an expansion stroke, and then stops the crankshaft. Subsequently, the engine starter causes motoring of a motor in a forward rotation direction, to drive the crankshaft in forward rotation. Since the engine starter has driven the crankshaft in reverse rotation up to the expansion stroke, the forward rotation of the crankshaft is made substantially over the entire low-load region ranging from the expansion stroke to the compression stroke before the crankshaft reaches the high-load region for the first time. This enables the engine starter to increase the rotation speed of the crankshaft before the crankshaft reaches the high-load region for the first time. Thus, both a high inertial force generated by such a high rotation speed and an output torque of the starter motor can be used to overcome the high-load region encountered for the first time. As a result, the mo-

tor is permitted to have a suppressed output torque, and therefore downsizing of the starter motor is permitted. Accordingly, the engine starter can achieve improved mountability to vehicle. As thus far described, the engine starter disclosed in the Patent Literature 1 aims to achieve improved mountability to vehicle by using both the inertial force generated by the high rotation speed and the output torque of the motor to overcome the high-load region encountered for the first time.

Citation List

Patent Literature

- [0005]** PTL1: Japanese Patent Application Laid-Open No. 2003-343404

Summary of Invention

Technical Problem

[0006] The engine starter of the Patent Literature 1 drives the crankshaft in reverse rotation up to the expansion stroke after combustion of the engine is stopped and coasting rotation of the crankshaft is stopped. Then, the engine starter starts the engine. Therefore, the engine starter of the Patent Literature 1 involves a problem that a prolonged time is required for restarting after a combustion stop instruction is received.

[0007] An engine unit including a four-stroke engine body in which a high-load region and a low-load region occur during four strokes has been desired to achieve mountability to vehicle and shortening of the length of time required for restarting after a combustion stop instruction.

[0008] An object of the present invention is to provide: an engine unit including a four-stroke engine body in which a high-load region and a low-load region occur during four strokes, the engine unit achieving mountability to vehicle and shortening of the length of time required for restarting after a combustion stop instruction; and a vehicle equipped with such an engine unit.

Solution to Problem

[0009] To solve the problems described above, the present invention adopts the following configurations.

(1) An engine unit mounted to a vehicle, the engine unit including:

a four-stroke engine body in which a high-load region and a low-load region occur during four strokes, the high-load region having a high load on rotation of a crankshaft, the low-load region having a load on rotation of the crankshaft lower than that of the high-load region;
a three-phase brushless motor that starts the

four-stroke engine body by driving the crankshaft in forward rotation in response to reception of a start instruction, the three-phase brushless motor being driven by a battery provided in the vehicle;

an inverter including a plurality of switching parts by which a voltage applied from the battery to the three-phase brushless motor is controlled; and

a control device including a starter motor controller and a combustion controller, the starter motor controller controlling the voltage applied from the battery to the three-phase brushless motor by controlling the plurality of switching parts included in the inverter, the combustion controller controlling a combustion operation of the four-stroke engine body, the control device performing such an operation that:

after the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped, the control device controls the voltage applied from the battery to the three-phase brushless motor by controlling the plurality of switching parts of the inverter under a state where the start instruction is not received while the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped, to drive the crankshaft in forward rotation from a stopped position to a compression stroke included in the four strokes and then stop the crankshaft in the compression stroke; and

upon receiving the start instruction after the forward rotation of the crankshaft caused under control of the voltage applied to the three-phase brushless motor is stopped in the compression stroke, the control device controls the voltage applied from the battery to the three-phase brushless motor, to drive the crankshaft in forward rotation from a position where the crankshaft is located at a time point when the start instruction is received.

In the engine unit of (1), after the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped, the control device controls the voltage applied from the battery to the three-phase brushless motor by controlling the plurality of switching parts of the inverter, to drive the crankshaft in forward rotation up to the compression stroke included in the four strokes during which the high-load region and the low-load region occur and then stop the crankshaft in the compression stroke. Subsequently, upon receiving the start instruction af-

ter the forward rotation of the crankshaft caused under control of the voltage applied to the three-phase brushless motor is stopped in the compression stroke, the control device controls the voltage applied from the battery to the three-phase brushless motor, to drive the crankshaft in forward rotation from the position where the crankshaft is located at the time point when the start instruction is received. Accordingly, the forward rotation of the crankshaft is started from the compression stroke in response to reception of the start instruction. This enables the forward rotation of the crankshaft to be started at a position that allows the four-stroke engine body to be readily started even when an output torque of the motor is low. To be specific, the crankshaft, which has started rotation in response to reception of the start instruction, gradually increases the speed from the stopped state. After the crankshaft starts forward rotation from the compression stroke, the crankshaft passes through the compression stroke at a low speed. Since the crankshaft passes through the compression stroke at a low speed, the crankshaft is less likely to be affected by a reaction force of gas compression in the combustion chamber. This enables the crankshaft to promptly overcome a load of the high-load region in the compression stroke. After passing through the compression stroke, the crankshaft is driven in forward rotation over the low-load region which is a wide region ranging from the expansion stroke to the compression stroke, until reaching the high-load region for the second time. That is, a long run-up zone is ensured for acceleration. Therefore, the three-phase brushless motor is able to increase the rotation speed of the crankshaft before the crankshaft reaches the high-load region for the second time. Thus, both a high inertial force generated by the high rotation speed and an output torque of the three-phase brushless motor can be used to overcome the high-load region encountered for the second time. This makes it easy to start the four-stroke engine body, even when the output torque of the motor is low. Accordingly, suppression of the output torque of the motor is permitted, and therefore downsizing of the three-phase brushless motor is permitted.

After the combustion operation of the four-stroke engine body is stopped, the forward rotation of the crankshaft is likely to stop in the compression stroke or near the compression stroke. In the engine unit of (1), after the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped, the plurality of switching parts of the inverter are controlled so that the voltage applied from the battery to the three-phase brushless motor is controlled, to drive the crankshaft in forward rotation up to the compression stroke included in the four strokes during which the high-load region and the low-load region occur. Accordingly, in the engine

unit of (1), as compared with driving the crankshaft in reverse rotation up to the expansion stroke, a shorter time is taken to move the crankshaft to a position that allows the four-stroke engine body to be readily started with a low output torque.

In the configuration of (1), after the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped, the plurality of switching parts of the inverter are controlled so that the voltage applied from the battery to the three-phase brushless motor is controlled, to drive the crankshaft in forward rotation up to the compression stroke included in the four strokes during which the high-load region and the low-load region occur. Driving the crankshaft in forward rotation by controlling the voltage applied to the three-phase brushless motor makes it easier to control a movement of the crankshaft to a target position as compared with, for example, driving the crankshaft in forward rotation by using an inertial force given from the combustion operation of the four-stroke engine body. The crankshaft can therefore be moved in a short time to a position that allows the four-stroke engine body to be readily started with a low output torque.

Accordingly, the engine unit of (1) including the four-stroke engine body in which the high-load region and the low-load region occur during the four strokes can achieve mountability to vehicle and shortening of the length of time required for restarting after a combustion stop instruction.

(2) The engine unit according to (1), wherein the four-stroke engine body includes a combustion chamber and a decompression device that relieves pressure in the combustion chamber during the compression stroke, the decompression device is activated during at least part of a time period in which the control device drives the crankshaft in forward rotation by controlling the voltage applied from the battery to the three-phase brushless motor.

In the configuration of (2), the decompression device is activated during at least part of the time period in which the control device drives the crankshaft in forward rotation by controlling the voltage applied from the battery to the three-phase brushless motor. Since the decompression device relieves pressure in the combustion chamber during the compression stroke, a load on rotation of the crankshaft is reduced. Therefore, even if the output torque of the three-phase brushless motor is further lower, the load of the high-load region can be overcome promptly. Accordingly, the engine unit of (2) including the four-stroke engine body in which the high-load region and the low-load region occur during the four strokes can achieve improved mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction.

(3) The engine unit according to (1) or (2), wherein

the three-phase brushless motor includes a stator and a rotor, the stator including a plurality of teeth arranged in a circumferential direction and windings each wound on each of the plurality of teeth, the rotor being arranged opposed to the stator, the rotor being rotated along with the crankshaft, the rotor including magnetic pole faces, the number of the magnetic pole faces being more than 2/3 of the number of the plurality of teeth,

the control device controls the voltage applied from the battery to each of the plurality of windings of the three-phase brushless motor by controlling the plurality of switching parts of the inverter, to drive the crankshaft in forward rotation.

The control device of (3) controls the voltage applied from the battery to the winding of the three-phase brushless motor by controlling the plurality of switching parts of the inverter, to drive the crankshaft in forward rotation. The number of the magnetic pole faces included in the rotor of three-phase brushless motor is more than 2/3 of the number of the teeth. The more the number of the magnetic pole faces is, the more frequently the voltage varies that is applied to each of the windings of the three-phase brushless motor under control of the switching parts by the control device. For example, assuming that a voltage having a pulsed waveform is applied to each of the windings of the three-phase brushless motor, the pulse frequency is high. Since the voltage applied to each of the windings has a high frequency, a torque that the three-phase brushless motor applies when driving the crankshaft in forward rotation has a high-frequency pulsation. The crankshaft subjected to the torque having such a high-frequency pulsation is able to easily overcome the load of the high-load region. Accordingly, the engine unit of (3) including the four-stroke engine body in which the high-load region and the low-load region occur during the four strokes can achieve improved mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction.

(4) The engine unit according to any one of (1) to (3), wherein

in at least part of a range up to the end of the compression stroke, the control device controls the plurality of switching parts of the inverter so as to cause forward rotation of the three-phase brushless motor with a torque lower than a maximum torque obtainable from the battery.

In the configuration of (4), the torque of the three-phase brushless motor is limited, which leads to a decrease in the speed of the forward rotation of the crankshaft. This suppresses a reaction force of gas compression that occurs in the combustion chamber of the four-stroke engine body along with the forward rotation of the crankshaft. Since a resistance to rotation of the crankshaft, which is caused by the reaction force of compression, is suppressed, the

crankshaft can be moved in a shorter time. In the configuration of (4), therefore, the length of time required for restarting after the combustion stop instruction can be further shortened.

Accordingly, in the engine unit of (4) including the four-stroke engine body in which the high-load region and the low-load region occur during the four strokes, mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction can be achieved at a higher level.

(5) The engine unit according to any one of (1) to (4), wherein

in at least part of a range up to the end of the compression stroke, the control device drives the crankshaft in forward rotation while controlling the plurality of switching parts of the inverter so as to set the voltage applied from the battery to the three-phase brushless motor to be lower than a voltage of the battery.

In the configuration of (5), the voltage applied to the three-phase brushless motor is set lower than the voltage of the battery. As a result, the torque of the three-phase brushless motor is limited, which leads to a decrease in the speed of the forward rotation of the crankshaft. This suppresses a reaction force of gas compression that occurs in the combustion chamber of the four-stroke engine body along with the forward rotation of the crankshaft. Since a resistance to rotation of the crankshaft, which is caused by the reaction force of compression, is suppressed, the crankshaft can be moved in a shorter time. In the configuration of (5), therefore, the length of time required for restarting after the combustion stop instruction can be further shortened.

Accordingly, in the engine unit of (5) including the four-stroke engine body in which the high-load region and the low-load region occur during the four strokes, mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction can be achieved at a higher level.

(6) The engine unit according to any one of (1) to (5), wherein

upon receiving the start instruction in the middle of driving the crankshaft in forward rotation up to the compression stroke while controlling the voltage applied to the three-phase brushless motor by controlling the plurality of switching parts of the inverter under the state where the start instruction is not received while the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped, the control device continues the forward rotation of the crankshaft beyond the compression stroke without stopping the forward rotation in the compression stroke, to start the four-stroke engine body.

In the configuration of (6), an inertial force generated by the crankshaft that is moving in forward rotation up to the compression stroke under the state where

the start instruction is not received is used to rotate the crankshaft for restarting the engine body. This can further shorten the length of time required for restarting.

(7) The engine unit according to any one of (1) to (5), wherein

if the forward rotation of the crankshaft having been continued since the stop of the combustion operation of the four-stroke engine body is stopped in the compression stroke, the control device skips the driving of the crankshaft in forward rotation under the state where the start instruction is not received.

A situation where the forward rotation of the crankshaft having been continued since the stop of the combustion operation of the four-stroke engine body is stopped in the compression stroke, means a situation where the crankshaft is at a position that allows the four-stroke engine body to be readily started even when the output torque of the motor is low. The configuration of (7) skips the step of driving the crankshaft in forward rotation under the state where the start instruction is not received, because the forward rotation of the crankshaft is stopped in the compression stroke. This can shorten the length of time required for starting rotation of the crankshaft in response to reception of the start instruction. Accordingly, in the configuration of (7), mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction can be achieved at a higher level.

(8) The engine unit according to any one of (1) to (5), wherein

the control device switches driving of the crankshaft between forward rotation and reverse rotation under the state where the start instruction is not received, the switching being performed in accordance with a position where the forward rotation of the crankshaft having been continued since the stop of the combustion operation of the four-stroke engine body is stopped.

In some cases, driving the crankshaft in reverse rotation under the state where the start instruction is not received takes a shorter time to move the crankshaft to a position that allows the four-stroke engine body to be readily started than driving the crankshaft in forward rotation does. In the configuration of (8), driving the crankshaft is switched between forward rotation and reverse rotation under the state where the start instruction is not received, in accordance with the position where the forward rotation of the crankshaft having been continued since the stop of the combustion operation is stopped. Accordingly, mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction can be achieved at a higher level.

(9) The engine unit according to (8), wherein

if the position where the forward rotation of the crankshaft having been continued since the stop of the

combustion operation of the four-stroke engine body is stopped is in a first range included in the four strokes, the control device drives the crankshaft in forward rotation up to the compression stroke under the state where the start instruction is not received, and if the position where the forward rotation of the crankshaft having been continued since the stop of the combustion operation of the four-stroke engine body is stopped is in a second range included in the four strokes, the control device drives the crankshaft in reverse rotation under the state where the start instruction is not received, the first range extending from a starting point to an ending point in a forward rotation direction, the starting point being located within a range ranging from a compression top dead center to an exhaust top dead center in the forward rotation direction, the ending point being located within the compression stroke, the second range extending from the compression top dead center to the starting point of the first range in the forward rotation direction.

In the configuration of (9), the second range is closer to the compression top dead center than the first range is with respect to a reverse rotation direction. In the configuration of (9), if the position where the forward rotation of the crankshaft having been continued since the stop of the combustion operation of the four-stroke engine body is stopped is in the second range, the crankshaft is driven in reverse rotation under the state where the start instruction is not received. This reverse rotation is able to move the crankshaft, faster than the forward rotation is, to a position that allows the four-stroke engine body to be readily started. Accordingly, mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction can be achieved at a higher level.

(10) The engine unit according to any one of (1) to (9), wherein

for a predefined time period after starting the combustion operation of the four-stroke engine body by driving the crankshaft in forward rotation in response to reception of the start instruction, the control device controls the voltage applied from the battery to the three-phase brushless motor by controlling the plurality of switching parts of the inverter, to accelerate the forward rotation of the crankshaft.

In the configuration of (10), the three-phase brushless motor accelerates forward rotation of the crankshaft during combustion of the four-stroke engine body. Therefore, forward rotation of the crankshaft rotated by the combustion of the four-stroke engine body can be stabilized. In addition, the forward rotation of the crankshaft rotated by the combustion of the four-stroke engine body can be accelerated more rapidly, for accelerating the vehicle.

(11) The engine unit according to any one of (1) to (10), wherein

after the four-stroke engine body is started, the three-phase brushless motor is rotated along with rotation of the crankshaft, to function as a generator that generates a current for charging the battery.

In the configuration of (11), the three-phase brushless motor functions as a generator to charge the battery. In a case of a three-phase brushless motor serving also as a generator, its stator windings are under structural restrictions because the three-phase brushless motor has to charge a battery. For example, the need to avoid an excessive charging current leads to restricting the performance that would be exerted as a function of the three-phase brushless motor. In the configuration of (11), however, the three-phase brushless motor reaches a highest-load position at a low rotation speed obtained from a limited output torque, and is accelerated through a sufficiently long zone before reaching the highest-load position for the second time. This enables a load of the highest-load position encountered for the second time to be overcome even when the performance is restricted. Accordingly, serving as both the three-phase brushless motor and the generator contributes to achievement of a simple configuration, while mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction can be achieved at a higher level.

(12) A vehicle including the engine unit according to any one of (1) to (11).

[0010] The vehicle of (12) can achieve mountability of the engine unit and shortening of the length of time required for restarting after the combustion stop instruction.

Advantageous Effects of Invention

[0011] The present invention can provide: an engine unit including a four-stroke engine body in which a high-load region and a low-load region occur during four strokes, the engine unit achieving mountability to vehicle and shortening of the length of time required for restarting after a combustion stop instruction; and a vehicle equipped with such an engine unit.

Brief Description of Drawings

[0012]

[Fig. 1] Fig. 1 is a cross-sectional view schematically showing an outline configuration of part of an engine unit according to an embodiment of the present invention.

[Fig. 2] Fig. 2 is an illustrative diagram schematically showing the relationship between a crank angle position and a required torque at a time of engine start.

[Fig. 3] Fig. 3 is a cross-sectional view showing, on an enlarged scale, a three-phase brushless motor

shown in Fig. 1 and therearound.

[Fig. 4] Fig. 4 is a cross-sectional view showing a cross-section of the three-phase brushless motor shown in Fig. 3, as taken along a plane perpendicular to its rotation axis J.

[Fig. 5] Fig. 5 is a block diagram showing a basic electrical configuration of the engine unit shown in Fig. 1.

[Fig. 6] Fig. 6 is a flowchart illustrating an operation of the engine unit shown in Fig. 1.

[Fig. 7] Fig. 7(a) illustrates a movement of a crankshaft of the engine unit shown in Fig. 1; and Fig. 7(b) shows a comparative example illustrating a movement of the crankshaft in reverse rotation.

[Fig. 8] Fig. 8 is an illustrative diagram schematically showing the relationship between the crank angle position and the required torque.

[Fig. 9] Fig. 9 is an illustrative diagram schematically showing the relationship between the crank angle position and the required torque in an engine unit according to a second embodiment of the present invention.

[Fig. 10] Fig. 10 is a flowchart illustrating an operation of an engine unit according to a third embodiment.

[Fig. 11] Fig. 11 illustrates a movement of a crankshaft of the engine unit according to the third embodiment.

[Fig. 12] Fig. 12 is a flowchart illustrating an operation of an engine unit according to a fourth embodiment.

[Fig. 13] Fig. 13 is a block diagram showing a basic electrical configuration of an engine unit according to a fifth embodiment.

[Fig. 14] Fig. 14 is a diagram showing an external appearance of a vehicle to which the engine unit is mounted.

Description of Embodiments

[0013] A description will be given of studies that the present inventors have conducted about rotating a crankshaft under a state where no start instruction is received while a combustion operation of a four-stroke engine body and forward rotation of the crankshaft are stopped.

[0014] For example, as shown in the Patent Literature 1, it takes time to drive the crankshaft in reverse rotation under a state where no start instruction is received while the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped. That is, a prolonged time is required for restarting after a combustion stop instruction is received.

[0015] Assisting rotation of the crankshaft by using a motor in a time period after the combustion operation of the four-stroke engine body is stopped and before the forward rotation of the crankshaft is stopped makes it difficult to ensure that the crankshaft stops in a target region in which a shortened time is required for starting. This is because the crankshaft whose rotation is assisted by the motor after the combustion operation is stopped

is rotated not only by a force given from the motor but also by an inertial force given from the final combustion operation. It is not easy for the motor to assist the rotation of the crankshaft, which is rotated also by the inertial force given from the final combustion operation, so as to ensure that the crankshaft is placed in the target region. For example, a high load caused by a reaction force of compression is often used to stop the crankshaft rotated by the inertial force given from the final combustion operation. In such a case, the crankshaft once makes reverse rotation and then stops without overcoming the peak of the load. Since a stop position of the crankshaft depends on the degree (distance) of the reverse rotation which is made without overcoming of the peak of the load, there is a large variation in the stop position of the crankshaft. That is, there is a large variation in the position from which the crankshaft will start rotation in response to reception of a start instruction. Thus, there is a large variation in the length of time required for restarting after the combustion stop instruction is received. In some case, therefore, a long time is required for restarting.

[0016] On the other hand, driving the crankshaft in forward rotation until reaching a compression stroke by controlling a voltage applied from a battery to a three-phase brushless motor under a state where forward rotation of the crankshaft is stopped, makes it easier to control a movement of the crankshaft to the target position as compared with driving the crankshaft in forward rotation by using the inertial force given from the combustion operation of the four-stroke engine body. The crankshaft can therefore be moved in a short time to a position that allows the four-stroke engine body to be readily started. Accordingly, both shortening of the length of time required for restarting and downsizing of the three-phase brushless motor are achieved at a higher level.

[0017] Hereunder, the present invention will be described based on preferred embodiments with reference to the drawings.

[First Embodiment]

[0018] Fig. 1 is a cross-sectional view schematically showing an outline configuration of part of an engine unit EU according to a first embodiment of the present invention. The engine unit EU of this embodiment is a four-stroke engine unit for use in vehicle.

[0019] The engine unit EU is installed in a motorcycle (see Fig. 14) that is an example of a vehicle. The engine unit EU includes a four-stroke engine body E and a three-phase brushless motor SG. The four-stroke engine body E is a four-stroke engine having a single cylinder. In the four-stroke engine body E, the relationship shown in Fig. 2 is established between a crank angle position and a required torque.

[0020] Fig. 2 is an illustrative diagram schematically showing the relationship between a crank angle position and a required torque at a time of engine start.

[0021] The four-stroke engine body E includes, during four strokes, a high-load region TH in which a high load is put on rotation of a crankshaft 5 and a low-load region TL in which a load put on rotation of the crankshaft 5 is lower than that of the high-load region TH. From the viewpoint of the rotation angle of the crankshaft 5, the low-load region TL is equal to or wider than the high-load region TH. To be specific, the low-load region TL is wider than the high-load region TH. In other words, a rotation angle region corresponding to the low-load region TL is wider than a rotation angle region corresponding to the high-load region TH. In more detail, during rotation, the four-stroke engine body E repeats four strokes, namely, an intake stroke, a compression stroke, an expansion stroke, and an exhaust stroke. The compression stroke is included in the high-load region TH, and not included in the low-load region TL. In the four-stroke engine body E of this embodiment, the high-load region TH is a region that substantially overlaps the compression stroke, and the low-load region TL is a region that substantially overlaps the intake stroke, the expansion stroke, and the exhaust stroke. It is not necessary that the boundary of the high-load region TH and the boundary of the low-load region TL are coincident with the boundaries of the corresponding strokes.

[0022] As shown in Fig. 1, the engine unit EU includes the three-phase brushless motor SG. The three-phase brushless motor SG is a starter motor. At a time of engine start, the three-phase brushless motor SG drives the crankshaft 5 in forward rotation to start the four-stroke engine body E. During at least part of a time period following the start of the four-stroke engine body E, the three-phase brushless motor SG is driven in forward rotation by the crankshaft 5, to function as a generator. Although the three-phase brushless motor SG functions as a generator, it is not indispensable that the three-phase brushless motor SG functions as a generator all the time after combustion of the engine is started. In an acceptable example, the three-phase brushless motor SG does not function as a generator immediately after combustion of the engine is started, and the three-phase brushless motor SG functions as a generator upon satisfaction of a predetermined condition. Examples of the predetermined condition include a condition that the rotation speed of the engine reaches a predetermined speed or a condition that a predetermined time period elapses after combustion of the engine is started. It may be acceptable that a period in which the three-phase brushless motor SG functions as a generator and a period in which the three-phase brushless motor SG functions as a motor (for example, as a vehicle-driving motor) are present after combustion of the engine is started.

[0023] The three-phase brushless motor SG is attached to the crankshaft 5 of the four-stroke engine body E. In this embodiment, the three-phase brushless motor SG is attached to the crankshaft 5 without interposition of a power transmission mechanism (such as a belt, a chain, a gear, a speed reducer, or a speed increaser). In

the present invention, however, it suffices that the three-phase brushless motor SG is configured such that the crankshaft 5 is driven in forward rotation by forward rotation of the three-phase brushless motor SG. Therefore, the three-phase brushless motor SG may be attached to the crankshaft 5 with interposition of a power transmission mechanism. In the present invention, it is preferable that the rotation axis of the three-phase brushless motor SG is substantially coincident with the rotation axis of the crankshaft 5. It is also preferable that the three-phase brushless motor SG is attached to the crankshaft 5 without interposition of a power transmission mechanism, as illustrated in this embodiment.

[0024] The four-stroke engine body E includes a crank case 1 (engine case 1), a cylinder 2, a piston 3, a connecting rod 4, and a crankshaft 5. The cylinder 2 is arranged to protrude from the crank case 1 in a predetermined direction (for example, obliquely upward). The piston 3 is arranged in the cylinder 2 such that the piston 3 is freely movable to and fro. The crankshaft 5 is rotatably arranged in the crank case 1. One end portion (for example, an upper end portion) of the connecting rod 4 is coupled to the piston 3. The other end portion (for example, a lower end portion) of the connecting rod 4 is coupled to the crankshaft 5. A cylinder head 6 is attached to an end portion (for example, an upper end portion) of the cylinder 2. The crankshaft 5 is supported on the crank case 1 via a pair of bearings 7 in a freely rotatable manner. One end portion 5a (for example, a right end portion) of the crankshaft 5 protrudes out of the crank case 1. The three-phase brushless motor SG is attached to the one end portion 5a of the crankshaft 5.

[0025] The other end portion 5b (for example, a left end portion) of the crankshaft 5 protrudes out of the crank case 1. A primary pulley 20 of a continuously variable transmission CVT is attached to the other end portion 5b of the crankshaft 5. The primary pulley 20 includes a fixed sheave 21 and a movable sheave 22. The fixed sheave 21 is fixed to a distal end portion of the other end portion 5b of the crankshaft 5 in such a manner that the fixed sheave 21 rotates together with the crankshaft 5. The movable sheave 22 is splined to the other end portion 5b of the crankshaft 5. Thus, the movable sheave 22 is movable in an axial direction X. The movable sheave 22 is configured to rotate together with the crankshaft 5 with the interval between the movable sheave 22 and the fixed sheave 21 varying. A belt B is wrapped on the primary pulley 20 and a secondary pulley (not shown). A rotation force of the crankshaft 5 is transmitted to a drive wheel of a motorcycle (see Fig. 8).

[0026] Fig. 3 is a cross-sectional view showing, on an enlarged scale, the three-phase brushless motor SG shown in Fig. 1 and therearound. Fig. 4 is a cross-sectional view showing a cross-section of the three-phase brushless motor SG, as taken along a plane perpendicular to its rotation axis J shown in Fig. 3.

[0027] The three-phase brushless motor SG includes an outer rotor 30 and an inner stator 40. The outer rotor

30 includes an outer rotor main body part 31. The outer rotor main body part 31 is made of, for example, a ferromagnetic material. The outer rotor main body part 31 is in the shape of a cylinder with a bottom. The outer rotor main body part 31 includes a cylindrical boss portion 32, a disk-shaped bottom wall portion 33, and a back yoke portion 34 having a cylindrical shape. The cylindrical boss portion 32 is fixed to the crankshaft 5 under a state where the one end portion 5a of the crankshaft 5 is received in the cylindrical boss portion 32. The bottom wall portion 33, which is fixed to the cylindrical boss portion 32, has a disk-like shape that extends in a radial direction Y of the crankshaft 5. The back yoke portion 34 has a cylindrical shape that extends from an outer circumferential edge of the bottom wall portion 33 in the axial direction X of the crankshaft 5. The back yoke portion 34 extends toward the crank case 1.

[0028] The bottom wall portion 33 and the back yoke portion 34 are integrally formed of, for example, a metal plate being stamped. In the present invention, however, it is acceptable that the bottom wall portion 33 and the back yoke portion 34 are formed as separate parts. More specifically, in the outer rotor main body part 31, the back yoke portion 34 may be formed integrally with another part of the outer rotor main body part 31, or may be formed as a part separate from another part of the outer rotor main body part 31. In a case where the back yoke portion 34 and another part are formed as separate parts, an essential feature is that the back yoke portion 34 is made of a ferromagnetic material, and another part may be made of a material different from the ferromagnetic material.

[0029] The cylindrical boss portion 32 has a tapered reception hole 32a for receiving the one end portion 5a of the crankshaft 5. The tapered reception hole 32a extends in the axial direction X of the crankshaft 5. The tapered reception hole 32a has a taper angle that corresponds to an outer circumferential surface of the one end portion 5a of the crankshaft 5. When the one end portion 5a of the crankshaft 5 enters the reception hole 32a, the outer circumferential surface of the one end portion 5a comes into contact with an inner circumferential surface of the reception hole 32a, and the crankshaft 5 is fixed to the reception hole 32a. As a result, the position of the boss portion 32 is settled with respect to the axial direction X of the crankshaft 5. In this condition, a nut 35 is screwed onto a male thread portion 5c formed in a distal end portion of the one end portion 5a of the crankshaft 5. In this manner, the cylindrical boss portion 32 is fixed to the crankshaft 5.

[0030] The cylindrical boss portion 32 has a large-diameter portion 32b that is provided in a proximal end portion (in Fig. 3, at the right side) of the cylindrical boss portion 32. The cylindrical boss portion 32 has a flange portion 32c that is formed on an outer circumferential surface of the large-diameter portion 32b. The flange portion 32c extends radially outward. The large-diameter portion 32b of the cylindrical boss portion 32 is received

in a hole 33a that is formed in a central region of the bottom wall portion 33 of the outer rotor main body part 31. In this condition, the flange portion 32c is in contact with an outer peripheral surface (a right-hand surface in Fig. 3) of the bottom wall portion 33. The flange portion 32c of the cylindrical boss portion 32 and the bottom wall portion 33 of the outer rotor main body part 31 are fixed together by rivets 36 at a plurality of locations with respect to a circumferential direction of the outer rotor main body part 31. The rivets 36 penetrate through the flange portion 32c and the bottom wall portion 33.

[0031] The three-phase brushless motor SG is a permanent-magnet motor. The back yoke portion 34 of the outer rotor main body part 31 has a plurality of permanent magnet parts 37 that are provided on an inner circumferential surface of the back yoke portion 34. Each of the permanent magnet parts 37 is provided such that S pole and N pole are arranged side by side with respect to a radial direction of the three-phase brushless motor SG.

[0032] The plurality of permanent magnet parts 37 are arranged in such a manner that N pole and S pole alternately appear with respect to a circumferential direction of the three-phase brushless motor SG. In this embodiment, the number of magnetic poles of the outer rotor 30 opposed to the inner stator 40 is twenty-four. The number of magnetic poles of the outer rotor 30 means the number of magnetic poles opposed to the inner stator 40. The number of magnetic pole faces of the permanent magnet parts 37 that are opposed to teeth 43 of a stator core ST is equivalent to the number of magnetic poles of the outer rotor 30. A magnetic pole face included in each magnetic pole of the outer rotor 30 corresponds to a magnetic pole face of the permanent magnet part 37 that is opposed to the inner stator 40. The magnetic pole face of the permanent magnet part 37 is covered with a non-magnetic material (not shown) that is arranged between the permanent magnet part 37 and the inner stator 40. No magnetic material is arranged between the permanent magnet part 37 and the inner stator 40. No particular limitation is put on the non-magnetic material, and examples thereof include a stainless steel material. In this embodiment, the permanent magnet part 37 is a ferrite magnet. In the present invention, conventionally known magnets including a neodymium bonded magnet, a samarium-cobalt magnet, a neodymium magnet, and the like, are adoptable for the permanent magnet part. The shape of the permanent magnet part 37 is not particularly limited. It may be acceptable that the outer rotor 30 is of interior permanent magnet type (IPM type) having the permanent magnet parts 37 embedded in a magnetic material, but preferably the outer rotor 30 is of surface permanent magnet type (SPM type) having the permanent magnet parts 37 exposed from a magnetic material, as illustrated in this embodiment.

[0033] As described above, the outer rotor 30, which is attached to the crankshaft 5 such that it is rotatable together with the crankshaft 5, is a rotating element for increasing the inertia of the crankshaft 5. A cooling fan

F including a plurality of blade portions Fa is provided to the outer peripheral surface (at the right side in Figs. 1 and 3) of the bottom wall portion 33 of the outer rotor 30. The cooling fan F is fixed to the outer peripheral surface of the bottom wall portion 33 by means of a fixture (a plurality of bolts Fb).

[0034] The inner stator 40 includes a stator core ST and multi-phase stator windings W. The stator core ST is obtained by, for example, thin silicon steel plates being stacked in the axial direction. The stator core ST has, in its central region, a hole 41 whose inner diameter is larger than the outer diameter of the cylindrical boss portion 32 of the outer rotor 30. The stator core ST includes a plurality of teeth 43 that integrally extend radially outward (see Fig. 4). In this embodiment, eighteen teeth 43 in total are arranged at intervals with respect to the circumferential direction. In other words, the stator core ST has eighteen slots SL in total that are arranged at intervals with respect to the circumferential direction (see Fig. 4). The teeth 43 are arranged at substantially equal intervals with respect to the circumferential direction.

[0035] Each of the stator windings W is wound on each of the teeth 43. That is, the multi-phase stator windings W are arranged through the slots SL. Each of the multi-phase stator windings W belongs to any of U-phase, V-phase, and W-phase. The stator windings W are arranged in the order of U-phase, V-phase, and W-phase, for example.

[0036] The stator winding W corresponds to an example of the winding of the present invention. The inner stator 40 corresponds to an example of the stator of the present invention. The outer rotor 30 corresponds to an example of the rotor of the present invention.

[0037] As shown in Fig. 3, the inner stator 40 has the hole 41 formed in a central region of the inner stator 40 with respect to the radial direction of the three-phase brushless motor SG. The crankshaft 5 and the cylindrical boss portion 32 of the outer rotor 30 are arranged in the hole 41 with a gap ensured between them and a wall surface (of the inner stator 40) defining the hole 41. The inner stator 40 under this condition is attached to the crank case 1 of the four-stroke engine body E. The teeth 43 of the inner stator 40 are arranged such that end portions (distal surfaces) of the teeth 43 are at an interval from the magnetic pole faces (inner circumferential surfaces) of the permanent magnet parts 37 of the outer rotor 30. In this state, the outer rotor 30 is rotated along with rotation of the crankshaft 5. The outer rotor 30 rotates integrally with the crankshaft 5. That is, the speed of rotation of the outer rotor 30 is equal to the speed of rotation of the crankshaft 5.

[0038] A further description of the outer rotor 30 will be given with reference to Fig. 4. The permanent magnet parts 37 are provided outside the inner stator 40 with respect to the radial direction of the three-phase brushless motor SG. The back yoke portion 34 is provided outside the permanent magnet parts 37 with respect to the radial direction. The permanent magnet parts 37 in-

clude, in their surfaces opposed to the inner stator 40, a plurality of magnetic pole faces 37a. The magnetic pole faces 37a are arranged in the circumferential direction of the three-phase brushless motor SG. Each of the magnetic pole faces 37a has N pole or S pole. The N pole and S pole are arranged alternately with respect to the circumferential direction of the three-phase brushless motor SG. The magnetic pole faces 37a of the permanent magnet parts 37 face the inner stator 40. In this embodiment, a plurality of magnets are arranged in the circumferential direction of the three-phase brushless motor SG, and each of the plurality of magnets is arranged with its S pole and N pole arranged side by side in the radial direction of the three-phase brushless motor SG. A single S pole and a single N pole adjacent to each other with respect to the circumferential direction constitute a magnetic pole face pair 37p. The number of the magnetic pole face pairs 37p is one-half of the number of the magnetic pole faces 37a. In this embodiment, the outer rotor 30 is provided with twenty-four magnetic pole faces 37a that are opposed to the inner stator 40, and the number of the magnetic pole face pairs 37p included in the outer rotor 30 is twelve. Twelve magnetic pole face pairs 37p corresponding to twelve magnet pairs are shown in Fig. 4. For clarity of the drawing, the reference sign 37p is given to only one of the pairs. The number of the magnetic pole faces 37a included in the three-phase brushless motor SG is more than 2/3 of the number of the teeth 43. The number of the magnetic pole faces 37a included in the three-phase brushless motor SG is equal or more than 4/3 of the number of the teeth 43.

[0039] The outer rotor 30 includes, on its outer surface, a plurality of detection object parts 38 for detection of the rotation position of the outer rotor 30. Magnetic effects are used to detect the plurality of detection object parts 38. The plurality of detection object parts 38 arranged at intervals with respect to the circumferential direction are provided on the outer surface of the outer rotor 30. In this embodiment, the plurality of detection object parts 38 arranged at intervals with respect to the circumferential direction are provided on an outer circumferential surface of the outer rotor 30. The plurality of detection object parts 38 are arranged on an outer circumferential surface of the back yoke portion 34 having a cylindrical shape. Each of the plurality of detection object parts 38 protrudes from the outer circumferential surface of the back yoke portion 34 toward the outside with respect to the radial direction Y of the three-phase brushless motor SG. The bottom wall portion 33, the back yoke portion 34, and the detection object parts 38 are integrally formed of, for example, a metal plate such as an iron plate being stamped. That is, the detection object parts 38 are made of a ferromagnetic material. Details of arrangement of the detection object parts 38 will be described later.

[0040] A rotor position detection device 50 is a device that detects the position of the outer rotor 30. The rotor position detection device 50 is provided at a position allowed to be opposed to the plurality of detection object

parts 38. To be more specific, the rotor position detection device 50 is arranged at a position that allows the plurality of detection object parts 38 to come into opposition to the rotor position detection device 50 one after another. The rotor position detection device 50 is opposed to a path through which the detection object parts 38 move along with rotation of the outer rotor 30. The rotor position detection device 50 is arranged at a position distant from the inner stator 40. In this embodiment, the rotor position detection device 50 is arranged such that the back yoke portion 34 and the permanent magnet parts 37 of the outer rotor 30 are located between the rotor position detection device 50 and the inner stator 40 having the stator windings W with respect to the radial direction of the crankshaft 5. The rotor position detection device 50 is arranged outside the outer rotor 30 with respect to the radial direction of the three-phase brushless motor SG. The rotor position detection device 50 faces the outer circumferential surface of the outer rotor 30.

[0041] The rotor position detection device 50 includes a detection-purpose winding 51, a detection-purpose magnet 52, and a core 53. The detection-purpose winding 51 functions as a pick-up coil for detecting the detection object parts 38. The core 53 is a rod-like member made of, for example, iron. The detection-purpose winding 51 magnetically detects the detection object parts 38. Upon start of rotation of the crankshaft 5, the rotor position detection device 50 starts detection of the rotation position of the outer rotor 30. Instead of the above-described configuration in which a voltage caused by an electromotive force varies along with passing of the detection object parts 38, other configurations are also adoptable for the rotor position detection device 50. Examples of such other configurations adoptable for the rotor position detection device 50 include a configuration in which the detection-purpose winding 51 is constantly rendered conducting and a conducting current varies depending on a variation in inductance caused along with passing of the detection object parts 38. No particular limitation is put on the rotor position detection device 50, and it may include a Hall element or an MR element. The engine unit EU of this embodiment (see Fig. 1) may include a Hall element or an MR element.

[0042] Referring to Fig. 4, a description will be given of arrangement of the detection object parts 38 of the outer rotor 30. In this embodiment, the plurality of detection object parts 38 are provided on the outer surface of the outer rotor 30. The plurality of detection object parts 38 have the same positional relationship relative to the corresponding magnetic pole face pairs 37p. The rotor position detection device 50 is provided at a position allowed to be opposed to the plurality of detection object parts 38. The rotor position detection device 50 is provided at a position allowed to be opposed to each of the plurality of detection object parts 38 during rotation of the outer rotor 30. The number of the detection object parts 38 to which the rotor position detection device 50 is simultaneously (at one time) opposed is one, and not more

than one. In Fig. 4, the dashed and dotted lines indicate specified positions with respect to the circumferential direction, which are defined in advance. Each of the specified positions is a position in the magnetic pole pair 37p including two magnetic poles (S pole and N pole) adjacent to each other with respect to the circumferential direction. In this embodiment, the outer rotor 30 is provided with eleven detection object parts 38, the number of which is one less than the number of the specified positions. The eleven detection object parts 38 are arranged at eleven of the twelve specified positions, respectively. The plurality of detection object parts 38 may be, for example, formed as parts separate from the back yoke portion 34. The plurality of detection object parts 38 may be, for example, formed as a single part including a plurality of sections that are magnetized alternately with opposite poles with respect to the circumferential direction.

[Electrical Configuration]

[0043] Fig. 5 is a block diagram showing a basic electrical configuration of the engine unit EU shown in Fig. 1.

[0044] The engine unit EU includes the four-stroke engine body E, the three-phase brushless motor SG, and a control device CT. The three-phase brushless motor SG, a spark plug 29, and a battery 14 are connected to the control device CT.

[0045] The control device CT in combination with the rotor position detection device 50 and the plurality of detection object parts 38 corresponds to an example of the control device of the present invention.

[0046] The control device CT is connected to the multi-phase stator windings W, and supplies a current from the battery 14 provided in a vehicle to the multi-phase stator windings W. The control device CT includes a starter motor controller 62, a combustion controller 63, and a plurality of switching parts 611 to 616. In this embodiment, the control device CT includes six switching parts 611 to 616. The switching parts 611 to 616 constitute an inverter 61. The inverter 61 is a three-phase bridge inverter. The switching parts 611 to 616 of the inverter 61 are provided between the battery 14 and the three-phase brushless motor SG. The switching parts 611 to 616 control a voltage applied from the battery 14 to the three-phase brushless motor SG. The plurality of switching parts 611 to 616, each of which is connected to each phase of the multi-phase stator windings W, selectively apply or do not apply the voltage from the battery 14 to the multi-phase stator windings W. In this manner, the plurality of switching parts 611 to 616 selectively allow or block the passing of a current between the multi-phase stator windings W and the battery 14. More specifically, when the three-phase brushless motor SG functions as a starter motor, switching between causing conduction of the multi-phase stator windings W and stopping the conduction is implemented by on/off-operation of the switching parts 611 to 616. When the three-phase brushless motor SG functions as a generator, switching be-

tween allowing and blocking the passing of a current between each of the stator windings W and the battery 14 is implemented by on/off-operation of each of the switching parts 611 to 616. By switching on/off the switching parts 611 to 616 one after another, a control of a voltage and a rectification of a three-phase AC outputted from the three-phase brushless motor SG are performed.

[0047] Each of the switching parts 611 to 616 includes a switching element. The switching element is, for example, a transistor and in more detail, a FET (Field Effect Transistor). Instead of FETs, for example, thyristors or IGBTs (Insulated Gate Bipolar Transistors) are also adoptable for the switching parts 611 to 616.

[0048] The starter motor controller 62 controls the plurality of switching parts 611 to 616. The starter motor controller 62 controls a voltage applied from the battery 14 to the three-phase brushless motor SG by controlling each of the six switching parts 611 to 616 corresponding to the three phases. The starter motor controller 62 controls the operation of the three-phase brushless motor SG by controlling on/off-operation of each of the switching parts 611 to 616. The starter motor controller 62 is able to drive the three-phase brushless motor SG in either forward or reverse rotation by controlling on/off-operation of each of the switching parts 611 to 616. The starter motor controller 62 includes a cranking control unit 621, a torque limiting unit 622, an on/off-operation storage unit 623, and an initial operation unit 624. The combustion controller 63 and the starter motor controller 62 including the cranking control unit 621 and the torque limiting unit 622 are implemented by a computer (not shown) and control software executable by the computer. Here, it may be also acceptable that the combustion controller 63 and the starter motor controller 62 including the cranking control unit 621 and the torque limiting unit 622 are partially or entirely implemented by a wired logic which is an electronic circuit. For example, the starter motor controller 62 and the combustion controller 63 may be configured as separate devices arranged at a distance from each other, or alternatively they may be configured as an integrated device.

[0049] The on/off-operation storage unit 623 is formed of a memory, for example. The on/off-operation storage unit 623 stores data relating to on/off-operation of the plurality of switching parts 611 to 616. More specifically, the on/off-operation storage unit 623 stores a map of information used for the control device CT to control the three-phase brushless motor SG and the four-stroke engine body E, and software describing the information. The initial operation unit 624 is formed of an electronic circuit. The initial operation unit 624 generates an electrical signal for performing on/off-operation of the plurality of switching parts 611 to 616 when the crankshaft 5 is in a stopped state. The control device CT may concurrently operate both the on/off-operation storage unit 623 and the initial operation unit 624, or may operate one of the on/off-operation storage unit 623 and the initial operation unit 624.

[0050] The combustion controller 63 causes the spark plug 29 to perform an ignition operation, thus controlling a combustion operation of the four-stroke engine body E. In a case where the four-stroke engine body E includes a fuel injector that injects a fuel for generation of a mixed gas, the combustion controller 63 also controls injection of the fuel injector, to control the combustion operation of the four-stroke engine body E.

[0051] A starter switch 16 for starting the four-stroke engine body E is connected to the starter motor controller 62. In response to a rider operating the starter switch 16 to start the four-stroke engine body E, a start instruction is inputted from the starter switch 16 to the control device CT. The control device CT controls the three-phase brushless motor SG by operating the inverter 61, the starter motor controller 62, and the combustion controller 63.

[Operation for Starting Engine Unit]

[0052] Fig. 6 is a flowchart illustrating an operation of the engine unit EU shown in Fig. 1.

[0053] Fig. 7(a) illustrates a movement of the crankshaft 5 of the engine unit EU shown in Fig. 1. Fig. 7(b) shows a comparative example illustrating a movement of the crankshaft in reverse rotation.

[0054] With reference to Figs. 6 and 7(a), the operation of the engine unit EU will be described beginning with the stage of a combustion stop.

[0055] Upon receiving a combustion stop instruction, the control device CT stops the combustion operation of the four-stroke engine body E (S11). To be more specific, upon receiving a combustion stop instruction, the combustion controller 63 stops the combustion operation of the four-stroke engine body E. The combustion stop instruction is inputted from a main switch 17 to the control device CT when, for example, the main switch 17 is switched off. In a case where the engine unit EU has an idling stop function, the control device CT itself executes the combustion stop instruction by determining an engine stop condition which relates to the state of running of the vehicle and the state of rotation of the crankshaft 5. Typically, for example, if a predetermined time period has elapsed since the vehicle stopped, it is determined that the vehicle has stopped and thus the engine is stopped.

[0056] The combustion stop instruction may be an internal instruction generated when the control device CT determines that the vehicle has stopped. Alternatively, the combustion stop instruction may be an external instruction inputted by the rider.

[0057] After the combustion operation of the four-stroke engine body E is stopped, an inertial force makes the crankshaft 5 continue rotating. The crankshaft 5 rotates with the speed decreasing, and then stops. The inertial force is decreased by, for example, a frictional force. The decrease in the inertial force involves a relative increase in the frictional force.

[0058] Fig. 7(a) shows a state where the crankshaft

stops at a stop position P1 after the combustion operation of the four-stroke engine body E is stopped. After the combustion operation of the four-stroke engine body E is stopped, the forward rotation of the crankshaft 5 is likely to stop in the compression stroke or near the compression stroke. That is, the stop position of the crankshaft 5 is, though not particularly limited, likely to locate in the compression stroke or near the compression stroke. The location near the compression stroke is, for example, a position in the intake stroke. The location near the compression stroke is, for example, a position in the intake stroke closer to the compression stroke than to the exhaust stroke. In the example shown in Fig. 7(a), the stop position P1 at which the crankshaft stops locates in the intake stroke.

[0059] The outer rotor 30 of the three-phase brushless motor SG is rotated along with rotation of the crankshaft 5. The plurality of detection object parts 38 provided on the outer rotor 30 (see Fig. 4) are detected by the rotor position detection device 50. The control device CT detects the position (angle) of the crankshaft 5 based on the detection of the plurality of detection object parts 38 by the rotor position detection device 50. The control device CT also detects rotation of the crankshaft 5 based on the detection of the plurality of detection object parts 38 by the rotor position detection device 50. The control device CT also detects stop of rotation of the crankshaft 5 based on the detection of the plurality of detection object parts 38 by the rotor position detection device 50. In more detail, if the rotor position detection device 50 does not detect the plurality of detection object parts 38, the control device CT determines that rotation of the crankshaft 5 has stopped.

[0060] The rotor position detection device 50 detects the plurality of detection object parts 38 moving at a location distant from the rotor position detection device 50. The rotor position detection device 50 detects the plurality of detection object parts 38 based on an electrical signal that varies depending on a variation in the magnetic condition caused by movement of the plurality of detection object parts 38. Therefore, when the rotation speed of the crankshaft 5 is low enough to disable the detection of the plurality of detection object parts 38 by the rotor position detection device 50, the control device CT determines that the crankshaft 5 has stopped. The rotation speed of the crankshaft 5 at this time may not necessarily be zero, and instead the crankshaft 5 may be rotating at a low speed. After determining that the crankshaft 5 has stopped, the control device CT performs a control so as to rotate the crankshaft 5 under a state where no start instruction is received, for example. The state where the rotation of the crankshaft 5 is stopped means the state where the rotation speed of the crankshaft 5 is zero or substantially zero. The state where the rotation speed of the crankshaft 5 is substantially zero is, for example, the state where the crankshaft 5 is rotating at a speed that does not allow the rotation of the crankshaft 5 to be detected by a detection device (for

example, the rotor position detection device 50) configured to detect rotation of the crankshaft 5. The state where the rotation speed of the crankshaft 5 is substantially zero is, for example, the state where the crankshaft 5 is rotating at a speed lower than the highest rotation speed of the crankshaft 5 that is obtained during the forward rotation in step S13 of Fig. 6. The highest rotation speed of the crankshaft 5 obtained in S13 of Fig. 6 is the highest rotation speed obtained when the control device CT rotates the crankshaft 5 under the state where no start instruction is received after the combustion operation of the four-stroke engine body is stopped.

[0061] After the combustion operation of the four-stroke engine body E and the forward rotation of the crankshaft 5 are stopped (S11, S12: Yes), the control device CT drives the crankshaft 5 in forward rotation from the stop position P1 shown in Fig. 7(a) up to the compression stroke among the four strokes (S13). The control device CT drives the crankshaft 5 in forward rotation (S13) under the state where no start instruction is received while the combustion operation of the four-stroke engine body E and the forward rotation of the crankshaft 5 are stopped. More specifically, after the combustion controller 63 stops the combustion operation of the four-stroke engine body E (S11) and then the forward rotation of the crankshaft 5 stops (S12: Yes), the starter motor controller 62 drives the crankshaft 5 in forward rotation from the stop position P1 up to the compression stroke among the four strokes (S13). The control device CT makes the crankshaft 5 stop in the compression stroke. Fig. 7(a) shows that the crankshaft 5 moves in forward rotation from the stop position P1 to a position P2 that is located in the compression stroke. In this embodiment, the control device CT controls the crankshaft 5 without causing reverse rotation in a time period after the combustion operation of the four-stroke engine body E and the forward rotation of the crankshaft 5 are stopped and before a start instruction is received. The control device CT controls the crankshaft 5 without causing reverse rotation until performing a combustion operation.

[0062] In at least part of a range from the position where the forward rotation of the crankshaft 5 is stopped to the end of the compression stroke (to the compression top dead center), the control device CT controls the plurality of switching parts 611 to 616 of the inverter 61 so as to cause the three-phase brushless motor SG to rotate with a torque lower than a maximum torque obtainable from the battery 14. In step S13 mentioned above, the control device CT drives the crankshaft 5 in forward rotation while controlling the voltage applied from the battery 14 to the three-phase brushless motor SG by controlling the plurality of switching parts 611 to 616 of the inverter 61. More specifically, the starter motor controller 62 (control device CT) performs on/off-operation of the plurality of switching parts 611 to 616 at predefined timings. As a result, the voltage is applied to the multi-phase stator windings W of the three-phase brushless motor SG, so that the outer rotor 30 of the three-phase brushless motor

SG is rotated. The crankshaft 5 is rotated along with the rotation of the outer rotor 30.

[0063] In step S13, the control device CT causes the three-phase brushless motor SG to rotate with a torque lower than the maximum torque obtainable from the battery 14. The control device CT drives the crankshaft 5 in forward rotation up to the compression stroke while causing the three-phase brushless motor SG to rotate with a torque lower than the maximum torque which could be obtained when the crankshaft 5 is driven in forward rotation in response to reception of a start instruction (S17). More specifically, the torque limiting unit 622 of the starter motor controller 62 performs on/off-operation of the plurality of switching parts 611 to 616 at predefined timings. The starter motor controller 62 performs an open-loop control for the on/off-operation of the switching parts 611 to 616. That is, the starter motor controller 62 renders the multi-phase stator windings W conducting one after another at predefined timings instead of adopting a feedback control based on the position of the outer rotor 30. If, for example, the multi-phase stator windings W are rendered conducting one after another at most appropriate timings in accordance with the position of the outer rotor 30, the three-phase brushless motor SG exerts the maximum torque obtainable from the battery 14. In a torque limiting control in step S13 of this embodiment, the torque limiting unit 622 of the starter motor controller 62 (control device CT) performs on/off-operation of the switching parts 611 to 616 at predefined timings based on a feed-forward control, instead of the most appropriate timings in accordance with the position of the outer rotor 30. As a result, the three-phase brushless motor SG rotates with a torque lower than the maximum torque obtainable from the battery 14.

[0064] Performing on/off-operation of the switching parts 611 to 616 at predefined timings means performing on/off-operation of the switching parts 611 to 616 without using position information of the outer rotor 30.

[0065] For example, performing on/off-operation of the switching parts 611 to 616 at predefined timings means performing on/off-operation of the switching parts 611 to 616 not based on a signal supplied from the rotor position detection device 50. Performing on/off-operation of the switching parts 611 to 616 at predefined timings means, for example, performing on/off-operation of the switching parts 611 to 616 without using a magnetic sensor having a semiconductor element provided therein.

[0066] The predefined timings may be changed based on information other than the position information of the outer rotor 30, such as the temperature or the voltage of the battery 14.

[0067] In a later step in which the control device CT drives the crankshaft 5 in forward rotation in response to reception of a start instruction (S17), the multi-phase stator windings W are rendered conducting one after another in accordance with the position of the outer rotor 30 detected by the rotor position detection device 50. That is, when driving the crankshaft 5 in forward rotation in

response to reception of a start instruction, the control device CT renders the multi-phase stator windings W conducting one after another with a feedback control based on the position of the outer rotor 30 which more specifically is the position of the magnetic pole faces 37a relative to the stator windings W. The feedback control based on the position of the outer rotor 30 enables the maximum torque obtainable from the battery 14 to be exerted. In the torque limiting control in step S13 of this embodiment, the torque limiting unit 622 of the starter motor controller 62 (control device CT) performs on/off-operation of the plurality of switching parts 611 to 616 at the predefined timings that are independent of the position of the magnetic pole faces 37a relative to the stator windings W. This allows the control device CT to rotate the crankshaft 5 with a torque lower than the maximum torque which is obtained when the crankshaft 5 is driven in forward rotation in response to reception of a start instruction.

[0068] In step S13, the control device CT performs on/off-operation of the plurality of switching parts 611 to 616, to drive the crankshaft 5 in forward rotation up to the compression stroke. The control device CT is able to drive the crankshaft 5 in forward rotation up to the compression stroke by performing on/off-operation of the plurality of switching parts 611 to 616 a predefined number of times. In the example shown in Fig. 7(a), the crankshaft 5 is rotated to the position P2 included in the compression stroke. Here, the number of times the on/off-operation of the plurality of switching parts 611 to 616 is performed can be controlled by the control device CT in accordance with the stop position P1 of the crankshaft 5 at which rotation of the crankshaft 5 has stopped after the combustion operation was stopped (S12: Yes).

[0069] If no restart instruction is received (S14: No), the control device CT terminates on/off-operation of the plurality of switching parts 611 to 616. Thus, the control device CT stops the crankshaft 5 in the compression stroke. In the example shown in Fig. 7(a), the crankshaft 5 is stopped at the position P2. Since the crankshaft 5 is stopped in the compression stroke, it can be ensured that rotation of the crankshaft starts from the compression stroke at a time of engine start.

[0070] Upon receiving a start instruction (S14: Yes), the control device CT causes the three-phase brushless motor SG to rotate the crankshaft 5, thus starting the four-stroke engine body E (S15). To be specific, if a start instruction is received (S14: Yes) after the forward rotation of the crankshaft 5 (S13), which is caused under control of the voltage applied to the three-phase brushless motor SG, is stopped in the compression stroke; the control device CT controls the voltage applied from the battery 14 to the three-phase brushless motor SG, to drive the crankshaft in forward rotation (S15). In other words, in response to reception of a start instruction under the state where the forward rotation of the crankshaft 5 is stopped, the control device CT controls the voltage applied from the battery 14 to the three-phase brushless

motor SG, to drive the crankshaft in forward rotation (S15). The control device CT drives the crankshaft 5 in forward rotation from the position where the crankshaft 5 locates at a time point when the start instruction is received (S14: Yes). The control device CT drives the crankshaft 5 in forward rotation from the stop position of the crankshaft 5 where the crankshaft 5 is stopped at the time point when the start instruction is received (S14: Yes).

[0071] The start instruction is inputted from the starter switch 16 to the control device CT when, for example, the starter switch 16 is operated. In a case where the engine unit EU has an idling stop function, the control device CT itself executes the start instruction by determining a predefined engine start condition. Achievement of the predefined engine start condition is included in the input of the start instruction. The predefined engine start condition is, for example, activation of an acceleration operator (not shown).

[0072] If a restart instruction is received during a time period in which on/off-operation of the plurality of switching parts 611 to 616 is performed in step S13, the control device CT starts the four-stroke engine body E (S15 to S21) by continuing the forward rotation of the crankshaft 5 beyond the compression stroke instead of stopping the forward rotation in the compression stroke. More specifically, if the control device CT receives a start instruction in the middle of driving the crankshaft 5 in forward rotation up to the compression stroke under the state where no start instruction is received while the combustion operation of the four-stroke engine body E and the forward rotation of the crankshaft 5 are stopped; the control device CT continues the forward rotation of the crankshaft 5 beyond the compression stroke instead of stopping the forward rotation in the compression stroke. Thereby, the control device CT starts the four-stroke engine body E (S15 to S21).

[0073] If the forward rotation is continued beyond the compression stroke, an inertial force generated by the forward rotation of the crankshaft 5 up to the compression stroke under the state where no start instruction is received is used as a force for rotating the crankshaft 5 to restart the four-stroke engine body E. This can further shorten the length of time required for restarting.

[0074] In step S15, the control device CT drives the crankshaft 5 in forward rotation from the compression stroke while causing the three-phase brushless motor SG to rotate with a torque lower than the maximum torque obtainable from the battery 14. The control device CT continues the control of limiting an output torque of the three-phase brushless motor SG, in at least part of the range from the start point of the forward rotation of the crankshaft 5 to the end of the compression stroke. Specifically, the control device CT firstly performs the torque limiting control (S15). More specifically, the torque limiting unit 622 of the starter motor controller 62 performs on/off-operation of the plurality of switching parts 611 to 616 at the predefined timings. The starter motor controller

62 performs the open-loop control for the on/off-operation of the switching parts 611 to 616. That is, the starter motor controller 62 renders the multi-phase stator windings W conducting one after another at the predefined timings instead of adopting a feedback control based on the position of the outer rotor 30. Performing, by the torque limiting unit 622 of the starter motor controller 62 (control device CT), the on/off-operation of the plurality of switching parts 611 to 616 at the predefined timings allows the crankshaft 5 to rotate with a torque lower than the maximum torque obtainable from the battery 14.

[0075] After the crankshaft 5 starts the forward rotation and then the rotor position detection device 50 detects the position of the outer rotor 30 (S16: Yes), the control device CT performs a limit-removed control (S17). In a case where the position of the outer rotor 30 is detected before the end of the compression stroke, the torque limiting control is performed in part of the range up to the end of the compression stroke. It may be acceptable that the torque limiting control is performed after the compression stroke, too. In the limit-removed control, the control device CT removes the limit put on the output torque of the three-phase brushless motor SG.

[0076] In the limit-removed control (S17) of this embodiment, the control device CT renders the plurality of stator windings W conducting one after another at timings in accordance with the position of the outer rotor 30, in order to remove the limit put on the output torque. In other words, the control device CT renders the multi-phase stator windings W conducting one after another with the feedback control based on the position of the outer rotor 30. As a result, the limit put on the output torque of the three-phase brushless motor SG is removed, and the maximum torque that would be obtained when the crankshaft 5 is driven in forward rotation in response to reception of a start instruction is exerted. At this time, the control device CT preferably causes the three-phase brushless motor SG to rotate with the maximum torque obtainable from the battery 14. By performing the limit-removed control (S17), the control device CT is shifted to a mode of accelerating the rotation of the outer rotor 30.

[0077] Then, if the rotation speed of the crankshaft 5 is higher than a predetermined ignitable rotation speed (S18: Yes), the control device CT starts the combustion operation of the four-stroke engine body E (S19). In more detail, the combustion controller 63 of the control device CT controls the combustion operation of the four-stroke engine body E by controlling the spark plug 29. In a case where the four-stroke engine body E includes a fuel injector that injects a fuel for generation of a mixed gas, the combustion controller 63 also controls injection of the fuel injector to control the combustion operation of the four-stroke engine body E. Starting the combustion operation of the four-stroke engine body E includes evaluating whether or not the combustion operation is successful. Whether or not the combustion operation is successful is determined by, for example, measuring the rotation speed of the crankshaft 5 while the crankshaft 5 is

rotated a plurality of times and evaluating whether or not the measured rotation speed is higher than a value defined as a value that would be obtained on the condition that the combustion operation is successful.

[0078] After the control device CT of this embodiment starts the combustion operation of the four-stroke engine body E by driving the crankshaft 5 in the forward rotation in response to reception of the start instruction, the control device CT still accelerates the forward rotation of the crankshaft 5 (S19). More specifically, after starting the combustion operation of the four-stroke engine body E including evaluation of whether or not the combustion operation is successful, the three-phase brushless motor SG continuously accelerates the rotation of the crankshaft 5. For a predefined time period after starting the combustion operation, the control device CT controls the plurality of switching parts 611 to 616 of the inverter 61 to control the voltage applied from the battery 14 to the three-phase brushless motor SG, thus accelerating the forward rotation of the crankshaft 5. This provides an increased acceleration to the forward rotation of the crankshaft 5, as compared with forward rotation energized only by the combustion operation of the four-stroke engine body E.

[0079] The stability of rotation of the crankshaft 5 may be sometimes poor after the four-stroke engine body E starts the combustion operation. After the combustion of the four-stroke engine body is started, the three-phase brushless motor SG continuously accelerates the forward rotation of the crankshaft 5, so that the forward rotation of the crankshaft 5 rotated by the combustion of the four-stroke engine body is stabilized. Here, the predefined time period is set to be a length of time (time duration) sufficient for stabilizing the rotation of the crankshaft 5. For example, the predefined time period is set to be a length of time sufficient for the rotation speed of the crankshaft 5 to reach an idle rotation speed.

[0080] When, for example, it is required that the vehicle be accelerated after the start of the combustion of the four-stroke engine body E, the acceleration of the forward rotation of the crankshaft 5 assists acceleration of the vehicle. When acceleration is required under a state where the three-phase brushless motor SG is generating power, the control device CT switches from a power-generating control to a motoring control of the three-phase brushless motor SG, thus accelerating the forward rotation of the crankshaft 5.

[0081] As thus far described, the control device CT accelerates the forward rotation of the crankshaft 5 for the predefined time period after the start of the four-stroke engine body E is completed. Therefore, the forward rotation of the crankshaft 5 rotated by the combustion operation of the four-stroke engine body E can be stabilized. In addition, the forward rotation of the crankshaft 5 can be accelerated more rapidly.

[0082] After the four-stroke engine body E is started, the three-phase brushless motor SG is rotated along with rotation of the crankshaft 5, to function as a generator

that generates a current for charging the battery 14. More specifically, upon start of the combustion of the four-stroke engine body E, the three-phase brushless motor SG driven by the four-stroke engine body E functions as a generator (S21). The control device CT performs on/off-operation of the plurality of switching parts 611 to 616, to control the current supplied from the plurality of stator windings W to the battery 14. The control device CT performs the on/off-operation of the plurality of switching parts 611 to 616 based on an electrical signal in the detection-purpose winding 51 of the rotor position detection device 50.

[0083] Fig. 7(b) shows a comparative example of this embodiment, illustrating a movement of the crankshaft in reverse rotation.

[0084] In the example shown in Fig. 7(b), as with this embodiment shown in Fig. 7(a), the crankshaft stops at the stop position P1 after the combustion operation of the four-stroke engine body is stopped. Then, the crankshaft is driven in reverse rotation up to a position P3 located in the expansion stroke. In response to reception of a start instruction, the crankshaft starts forward rotation from the position P3 located in the expansion stroke.

[0085] In this embodiment, as in the example shown in Fig. 7(a), the crankshaft moves through a distance from the stop position P1 at which the crankshaft stops after the combustion operation of the four-stroke engine body is stopped to the position P2 from which the crankshaft will start forward rotation in response to reception of a start instruction. This distance is shorter than the distance from the position P1 to the position P3 shown in Fig. 7(b).

[0086] Fig. 8 is an illustrative diagram schematically showing the relationship between a crank angle position and a required torque.

[0087] In Fig. 8, the solid line indicates a required torque Ta for forward rotation. The high-load region TH is located in the compression stroke and close to the compression top dead center (where the crank angle position is at zero degree). The low-load region TL is included in the intake stroke, the expansion stroke, and the exhaust stroke.

[0088] In Fig. 8, the broken line indicates a required torque Tb for reverse rotation. As indicated by the broken line in Fig. 8, in a case of reverse rotation of the crankshaft, the high-load region is included in the expansion stroke instead of the compression stroke.

[0089] Fig. 8 shows, below the graph, a movement M1 of the crankshaft in forward rotation illustrated in Fig. 7(a), and a movement M2 of the crankshaft in reverse rotation according to the comparative example illustrated in Fig. 7(b).

[0090] The movement M2 of the crankshaft in reverse rotation according to the comparative example will be described.

[0091] The crankshaft, which stops at the stop position P1 located in the compression stroke or near the compression stroke after the combustion operation of the

four-stroke engine body is stopped, is driven in reverse rotation up to the position P3 located in the expansion stroke, and then stops. Subsequently, in response to reception of a start instruction, the crankshaft is driven in forward rotation, so that the rotation speed of the crankshaft is increased before the crankshaft reaches the high-load region.

[0092] In the comparative example, after the combustion operation is stopped and the crankshaft is stopped, the crankshaft is driven in reverse rotation within a zone that leads to the expansion stroke through the intake stroke and the exhaust stroke. In a case of reverse rotation of the crankshaft, the high-load region occurs in the exhaust stroke. If the crankshaft overcame a highest-load position in the high-load region during reverse rotation of the crankshaft, the crankshaft would move to the compression stroke. Such a movement to the compression stroke of the crankshaft driven in reverse rotation makes the reverse rotation no longer advantageous, and, what is even worse, requires power and time for causing a transition from the reverse rotation to the forward rotation. Accordingly, driving the crankshaft in reverse rotation involves the need to avoid a situation where the crankshaft moves to the compression stroke. For this purpose, the crankshaft cannot be brought sufficiently close to the highest-load position located near the compression top dead center (zero degree). Since it is difficult to bring the crankshaft sufficiently close to the highest-load position in the reverse rotation of the crankshaft, a distance L4 is short through which the crankshaft is driven in forward rotation up to the highest-load position from the position P3 where the forward rotation is started in response to reception of a start instruction. This results in a relatively low inertial force obtained from the forward rotation caused in response to reception of the start instruction.

[0093] In this embodiment, on the other hand, after the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft 5 are stopped, the three-phase brushless motor SG drives the crankshaft 5 in forward rotation up to the position P2 located in the compression stroke. Then, in response to reception of a start instruction, the crankshaft 5 starts rotation. At this time, the crankshaft 5 gradually increases the speed from the stopped state. The crankshaft 5, which has started forward rotation from the position P2 located in the compression stroke, passes through the compression stroke at a low speed after the start of rotation. Since the crankshaft 5 passes through the compression stroke at a low speed, the crankshaft 5 is less likely to be affected by a reaction force of gas compression. This enables the crankshaft 5 to promptly overcome a load of the high-load region in the compression stroke. After passing through the compression stroke, the crankshaft is driven in forward rotation over a low-load region which is a wide region ranging from the expansion stroke to the compression stroke, until reaching the high-load region for the second time. That is, a long run-up zone L2 is ensured

for acceleration. Therefore, the three-phase brushless motor SG is able to increase the rotation speed of the crankshaft 5 before the crankshaft 5 reaches the high-load region for the second time. Thus, both a high inertial force generated by the high rotation speed and the output torque of the three-phase brushless motor can be used to overcome the high-load region encountered for the second time. Accordingly, suppression of the output torque of the three-phase brushless motor SG is permitted, and therefore downsizing of the three-phase brushless motor is permitted. The position P2 is a position that allows the four-stroke engine body E to be started with a low output torque. The position P2 is a position located in the compression stroke. The position P2 is, for example, a position located in the compression stroke and close to the compression top dead center.

[0094] A situation where the combustion operation of the four-stroke engine body E is stopped will be described again. After forward rotation of the crankshaft 5 is stopped, the control device CT controls the plurality of switching parts 611 to 616 of the inverter 61, to control the voltage applied from the battery 14 to the three-phase brushless motor SG, thus driving the crankshaft 5 in forward rotation from the stop position P1 to the position P2 located in the compression stroke. A zone L1 through which the crankshaft 5 moves in this forward rotation is shorter than a zone L3 through which the crankshaft 5 moves in reverse rotation. Accordingly, as compared with driving the crankshaft in reverse rotation up to the expansion stroke, a shorter time is taken to move the crankshaft 5 to a position that allows the four-stroke engine body E to be readily started with a low torque.

[0095] When the control of the voltage applied to the three-phase brushless motor SG is adopted in order to drive the crankshaft 5 stopped at the stop position P1 into forward rotation up to the position P2 located in the compression stroke, the movement of the crankshaft to the position P2 can be controlled more easily as compared with, for example, when an inertial force generated by the combustion operation of the four-stroke engine body E is adopted in order to cause the forward rotation. Therefore, the crankshaft can be moved in a short time to the position that allows the four-stroke engine body E to be readily started.

[0096] Accordingly, the engine unit EU of this embodiment including the four-stroke engine body E in which the high-load region and the low-load region occur during the four strokes can achieve both mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction.

[0097] Under the state where no start instruction is received, the control device CT drives the crankshaft 5 in forward rotation up to the compression stroke while causing the three-phase brushless motor SG to rotate with a torque lower than the maximum torque obtainable from the battery 14 (step S13 in Fig. 6).

[0098] During the forward rotation of the crankshaft 5 up to the compression stroke, that is, in at least part of

the range from the stop position P1 of the crankshaft 5 to the end of the compression stroke, the three-phase brushless motor SG rotates with a torque lower than the maximum torque obtainable from the battery 14, so that the speed of the forward rotation of the crankshaft 5 is low. This suppresses a reaction force of gas compression that occurs in a combustion chamber of the four-stroke engine body E along with the forward rotation of the crankshaft 5. Since a resistance to rotation of the crankshaft 5, which is caused by the reaction force of compression, is suppressed, the crankshaft 5 can be moved to the compression stroke in a shorter time. Accordingly, the length of time required for restarting is shortened with an enhanced reliability.

[0099] To start the four-stroke engine body E, the control device CT drives the crankshaft 5 in forward rotation from the compression stroke while causing the three-phase brushless motor SG to rotate with a limited torque lower than the maximum torque obtainable from the battery 14 (step S15 in Fig. 6). In at least part of the range from the start point of the forward rotation of the crankshaft 5 to the end of the compression stroke, the control device CT causes the three-phase brushless motor SG to rotate with a torque lower than the maximum torque obtainable from the battery 14. Therefore, at the time of starting the four-stroke engine body E, the forward rotation of the crankshaft 5 is started from the compression stroke at a lower speed than the speed obtained when, for example, rotation is caused with the maximum torque obtainable from the battery 14. This makes it still easier for the crankshaft 5 to overcome the load of the high-load region in the compression stroke. The reason why such a low speed enables the crankshaft 5 to easily overcome the load is considered to be because it increases the amount of gas leaking out of the combustion chamber of the four-stroke engine body E so that the amount of load caused by a reaction force of compression decreases.

[0100] The crankshaft 5 having passed through, at least, the compression stroke makes forward rotation substantially over the entire low-load region ranging from the expansion stroke to the compression stroke, and then reaches the high-load region for the second time. Here, the crankshaft 5 is able to overcome the second high-load region by using both the high inertial force generated by the high rotation speed and the output torque of the three-phase brushless motor SG.

[0101] The number of the magnetic pole faces 37a included in the rotor 30 of the three-phase brushless motor SG is more than 2/3 of the number of the teeth 43. The more the number of the magnetic pole faces 37a is, the more frequently the voltage varies that is applied to each of the windings W under control of the switching parts 611 to 616 by the control device CT. For example, assuming that a voltage having a pulsed waveform is applied to each of the windings W, the pulse frequency is high. Since the voltage applied to each of the windings W has a high frequency, the torque that the three-phase brushless motor SG applies to drive the crankshaft 5 in

forward rotation has a high-frequency pulsation. The crankshaft 5 subjected to the torque having such a high-frequency pulsation is able to easily overcome the load of the high-load region.

[0102] After the four-stroke engine body E is started, the three-phase brushless motor SG is rotated along with rotation of the crankshaft 5, to function as a generator that generates a current for charging the battery 14. In a case of the three-phase brushless motor SG serving also as a generator, its stator windings W are under structural restrictions because the three-phase brushless motor SG has to charge the battery 14. For example, the need to avoid an excessive charging current leads to restricting the performance that would be exerted as a function of the three-phase brushless motor SG.

[0103] In this embodiment, however, the crankshaft 5 reaches the highest-load position at a low rotation speed produced from an output torque lower than the maximum torque, and is accelerated through a sufficiently long zone before reaching the highest-load position for the second time. This enables a load of the highest-load position encountered for the second time to be overcome even when the performance of the three-phase brushless motor SG is restricted. Accordingly, downsizing of the three-phase brushless motor SG is permitted with achievement of a simple configuration in which the three-phase brushless motor SG serves as both a starter motor and a generator.

[Second Embodiment]

[0104] Next, a second embodiment of the present invention will be described. In the description of the second embodiment below, elements corresponding to the elements of the first embodiment are given the same reference signs, and differences from the above-described first embodiment will be mainly described.

[0105] The four-stroke engine body E provided in the engine unit EU of this embodiment includes a decompression device (decompressor). Fig. 1 briefly shows a decompression device D. The decompression device D opens a valve provided in the four-stroke engine body E during part of the compression stroke, to discharge some of a gas existing in the combustion chamber. In other words, the decompression device D relieves pressure in the combustion chamber during part of the compression stroke. As a result, the crankshaft 5 is affected by a less reaction force of gas compression. That is, a load on rotation of the crankshaft 5 in the high-load region is reduced.

[0106] If the decompression device D is not activated, the valve is kept closed in the compression stroke, so that a high load occurs in the high-load region.

[0107] The decompression device D is activated when the rotation speed of the crankshaft 5 is less than a pre-defined threshold value. The threshold value is less than the rotation speed that enables the combustion operation of the four-stroke engine body E. Therefore, the decom-

pression device D is activated during part of the time period in which the control device CT drives the crankshaft 5 in forward rotation by controlling the voltage applied from the battery 14 to the three-phase brushless motor SG.

[0108] Fig. 9 is an illustrative diagram schematically showing the relationship between the crank angle position and the required torque in the engine unit EU according to the second embodiment of the present invention.

[0109] In the engine unit EU of this embodiment, after the combustion operation of the four-stroke engine body E and the forward rotation of the crankshaft 5 are stopped, the control device CT drives the crankshaft 5 in forward rotation from the stop position to the compression stroke among the four strokes under the state where no start instruction is received while the combustion operation of the four-stroke engine body E and the forward rotation of the crankshaft 5 are stopped.

[0110] When the control device CT drives the crankshaft 5 in forward rotation from the stop position to the compression stroke under the state where no start instruction is received, the decompression device D is activated. As a result, a required torque, which means a load, exhibits a plurality of local maximums (peaks) Q1, Q2, as shown in Fig. 9. The load is reduced in a region between the plurality of local maximums Q1, Q2.

[0111] The control device CT drives the crankshaft 5 in forward rotation up to a position that is located between, among the plurality of local maximums Q1, Q2 of the load coming before the compression top dead center during the forward rotation of the crankshaft 5, the local maximum Q2 of the load closest to the compression top dead center and the local maximum Q1 of the load adjacent to the local maximum Q2 of the load closest to the compression top dead center. The control device CT causes the crankshaft 5 to stop at the position located between the local maximum Q2 and the local maximum Q1.

[0112] If a start instruction is received after the forward rotation of the crankshaft 5 is stopped in the compression stroke, the control device CT drives the crankshaft 5 in forward rotation from the position where the crankshaft 5 is located at the time of reception of the start instruction. To be more specific, the control device CT controls the voltage applied from the battery 14 to the three-phase brushless motor SG, to drive the crankshaft 5 in forward rotation from the position located between the local maximum Q2 and the local maximum Q1.

[0113] Since the pressure in the combustion chamber is relieved by the decompression device D, the load on rotation of the crankshaft 5 is reduced. Therefore, even if the output torque of the three-phase brushless motor SG is further lower, the load of the high-load region can be overcome promptly. Accordingly, the length of time required for restarting the four-stroke engine body E is shortened. In addition, the four-stroke engine body E can be promptly restarted even when the output torque of the

three-phase brushless motor SG is lowered. Accordingly, this embodiment can achieve improved mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction.

[0114] It may be acceptable that the decompression device D is activated in both a time period in which the control device CT drives the crankshaft 5 in forward rotation under the state where no start instruction is received and a time period in which the control device CT drives the crankshaft 5 in forward rotation in response to reception of a start instruction. Alternatively, the decompression device D may be activated in either one of these time periods. Alternatively, the decompression device D may be activated during part of each of these time periods.

[0115] In this embodiment, if no start instruction is received, the control device CT drives the crankshaft 5 in forward rotation up to the compression stroke, and if a start instruction is received, the control device CT drives the crankshaft in forward rotation from the position where the crankshaft 5 is located at the time of reception of the start instruction. That is, the control device CT causes rotation of the crankshaft 5 to stop in the compression stroke, and starts rotation of the crankshaft 5 from the compression stroke. The crankshaft 5 passes through the compression stroke at a low rotation speed. The decompression device D relieves the pressure in the combustion chamber by opening the valve during part of the compression stroke.

[0116] While the decompression device D relieves the pressure in the combustion chamber by opening the valve during part of the compression stroke, the crankshaft 5 is rotating through the compression stroke at a low rotation speed. Therefore, a sufficient time is ensured for the relief of the pressure in the combustion chamber. As a result, a large pressure drop in the combustion chamber is obtained. Accordingly, the load on rotation of the crankshaft 5 is reduced.

[0117] In a case of the comparative example shown in Fig. 7(b) in which the crankshaft is driven in reverse rotation up to the position P3 located in the expansion stroke, the crankshaft starts forward rotation from the position P3 located in the expansion stroke in response to reception of a start instruction. The crankshaft passes through the compression stroke at a high rotation speed. This fails to ensure a sufficient time for the relief of the pressure in the combustion chamber. Therefore, a sufficient pressure drop in the combustion chamber is not obtained. As a result, the load on rotation of the crankshaft is not reduced well.

[0118] In this embodiment, on the other hand, a sufficient time is ensured for the relief of the pressure in the combustion chamber by the decompression device D. Thus, a high effect is obtained from the decompression device D reducing the load on rotation. Therefore, even when the output torque of the three-phase brushless motor SG is low, the load of the high-load region can be overcome promptly. This embodiment can achieve im-

proved mountability to vehicle and shortening of the length of time required for restarting after the combustion stop instruction.

[0119] In this embodiment, activation of a decompression mechanism reduces the load in at least part of the high-load region. Therefore, a load necessary for rotating the crankshaft in response to reception of the start instruction is reduced. Accordingly, suppression of the output torque of the three-phase brushless motor SG is permitted, so that downsizing of the three-phase brushless motor is permitted.

[Third Embodiment]

[0120] Next, a third embodiment of the present invention will be described. In the description of the third embodiment below, elements corresponding to top elements of the first embodiment are given the same reference signs, and differences from the above-described first embodiment will be mainly described.

[0121] Fig. 10 is a flowchart illustrating an operation of the engine unit EU according to the third embodiment. Fig. 11 illustrates a movement of the crankshaft 5 of the engine unit EU according to the third embodiment.

[0122] In the engine unit EU of this embodiment, the control device CT switches the driving of the crankshaft 5 between forward rotation and reverse rotation under the state where no start instruction is received (S301), in accordance with the position where the rotation of the crankshaft 5 having been continued since the stop of the combustion operation of the four-stroke engine body E is stopped (S12 in Fig. 10).

[0123] If, for example, the position where the forward rotation of the crankshaft 5 having been continued since the stop of the combustion operation of the four-stroke engine body E is stopped is in a first range R1 in the four strokes (see Fig. 11), the control device CT drives the crankshaft 5 in forward rotation up to the compression stroke under the state where no start instruction is received (S302). If the position where the forward rotation of the crankshaft 5 having been continued since the stop of the combustion operation of the four-stroke engine body E is stopped is in a second range R2 in the four strokes, the control device CT drives the crankshaft in reverse rotation under the state where no start instruction is received (S303). The control device CT detects the position of the crankshaft 5 based on detection of the plurality of detection object parts 38 by the rotor position detection device 50 (see Fig. 4).

[0124] In the engine unit EU according to this embodiment, the operations in steps S301 to S303 described above are different from the first embodiment. The other operations are the same as those of the first embodiment.

[0125] Fig. 11 shows an example case where the crankshaft is driven in forward rotation under the state where no start instruction is received as well as an example case where the crankshaft is driven in reverse rotation under the state where no start instruction is re-

ceived. Fig. 11 also shows examples of the first range R1 and the second range R2 mentioned above.

[0126] The first range R1 extends from a starting point Ra to an ending point Rb in a forward rotation direction. The starting point Ra of the first range R1 is set within a region ranging from the compression top dead center (zero degree) to the exhaust top dead center (360 degrees) in the forward rotation direction. The ending point Rb of the first range R1 is set within the compression stroke.

[0127] The second range R2 extends from the compression top dead center (zero degree) to the starting point Ra of the first range R1 in the forward rotation direction. The second range R2 is closer to the compression top dead center than the first range R1 is with respect to a reverse rotation direction.

[0128] In this embodiment, the driving of the crankshaft 5 is switched between forward rotation and reverse rotation under the state where no start instruction is received, the switching being performed in accordance with the position where the forward rotation of the crankshaft 5 having been continued since the stop of the combustion operation is stopped.

[0129] If, for example, the position where the forward rotation of the crankshaft 5 having been continued since the stop of the combustion operation of the four-stroke engine body E is stopped is in the first range R1 as indicated by P1 in Fig. 11, the control device CT drives the crankshaft 5 in forward rotation up to, for example, the position P2 located in the compression stroke as shown in Fig. 11 under the state where no start instruction is received. An operation for this forward rotation is the same as that of the first embodiment.

[0130] If, for example, the position where the forward rotation of the crankshaft 5 having been continued since the stop of the combustion operation of the four-stroke engine body E is stopped is in the second range R2 as indicated by P5 in Fig. 11, the control device CT drives the crankshaft 5 in reverse rotation under the state where no start instruction is received. The reverse rotation brings the crankshaft 5 close to the compression top dead center. The control device CT drives the crankshaft 5 in reverse rotation up to, for example, a position P6 located in the expansion stroke as shown in Fig. 11. If a start instruction is received after the reverse rotation is stopped, the crankshaft 5 starts forward rotation from the position where the reverse rotation was stopped as described above. The crankshaft 5 starts forward rotation from, for example, the position P6 located in the expansion stroke. Driving the crankshaft 5 in reverse rotation under the state where no start instruction is received contributes to ensuring a long run-up zone before the crankshaft 5 driven in forward rotation in response to reception of a start instruction reaches the high-load region next time. In this embodiment, even if the forward rotation of the crankshaft 5 having been continued since the stop of the combustion operation of the four-stroke engine body E is stopped in the second range R2, the crankshaft

5 is driven in reverse rotation under the state where no start instruction is received, so that the crankshaft can be moved to a position that allows the four-stroke engine body to be readily started. Accordingly, this embodiment can achieve further shortening of the length of time required for restarting after the combustion stop instruction.

[Fourth Embodiment]

[0131] Next, a fourth embodiment of the present invention will be described. In the description of the fourth embodiment below, elements corresponding to the elements of the first embodiment are given the same reference signs, and differences from the above-described first embodiment will be mainly described.

[0132] Fig. 12 is a flowchart illustrating an operation of the engine unit EU according to the fourth embodiment.

[0133] In the engine unit EU of this embodiment, if the forward rotation of the crankshaft 5 having been continued since the stop of the combustion operation of the four-stroke engine body E is stopped in the compression stroke (S401: "COMPRESSION STROKE"), the control device CT skips the step of driving the crankshaft 5 in forward rotation under the state where no start instruction is received (S13). If the forward rotation of the crankshaft 5 having been continued since the stop of the combustion operation of the four-stroke engine body E is stopped before the compression stroke (S401: "BEFORE COMPRESSION STROKE"), the control device CT drives the crankshaft 5 in forward rotation under the state where no start instruction is received (S13).

[0134] Except for step S401 described above, the operations of the engine unit EU according to this embodiment are the same as those according to the first embodiment.

[0135] A situation where the forward rotation of the crankshaft 5 having been continued since the stop of the combustion operation of the four-stroke engine body E is stopped in the compression stroke, means a situation where the crankshaft 5 is at a position that allows the four-stroke engine body E to be readily started even when the output torque of the three-phase brushless motor SG is low. In this embodiment, the step of driving the crankshaft in forward rotation under the state where no start instruction is received is skipped if forward rotation of the crankshaft 5 is stopped at the position that allows the four-stroke engine body E to be readily started. This can shorten a time taken to start rotation of the crankshaft in response to reception of a start instruction. Accordingly, the length of time required for restarting after the combustion stop instruction can be further shortened.

[Fifth Embodiment]

[0136] Next, a fifth embodiment of the present invention will be described. In the description of the fifth embodiment below, elements corresponding to the elements of the first embodiment are given the same refer-

ence signs, and differences from the above-described first embodiment will be mainly described.

[0137] Fig. 13 is a block diagram showing a basic electrical configuration of the engine unit EU according to the fifth embodiment.

[0138] In the engine unit EU shown in Fig. 13, a rotor position detection device 850 includes a Hall IC. The rotor position detection device 850 detects the magnetic pole faces 37a provided on the outer rotor 30. The control device CT determines the position of the outer rotor 30 based on a variation in an electrical signal outputted from the rotor position detection device 850. The control device CT controls the plurality of switching parts 611 to 616 of the inverter 61 based on the position of the outer rotor 30. Thus, the control device CT controls rotation of the three-phase brushless motor SG. The control device CT of this embodiment performs on/off-operation of the plurality of switching parts 611 to 616 not at predefined timings but in accordance with the position of the outer rotor 30 detected by the rotor position detection device 850. That is, the control device CT of this embodiment adopts a feedback control based on the position of the outer rotor 30 when performing on/off-operation of the plurality of switching parts 611 to 616.

[0139] The control device CT of this embodiment controls a voltage (voltage value) applied from the battery 14 to the three-phase brushless motor SG by controlling the plurality of switching parts 611 to 616 of the inverter 61. In more detail, each of a cranking control unit 8621 and a torque limiting unit 8622 of a starter motor controller 862 controls the plurality of switching parts 611 to 616 of the inverter 61, thus controlling the voltage (voltage value) applied from the battery 14 to the three-phase brushless motor SG. In this embodiment, the control includes not only selectively allowing or blocking conduction of the stator windings W but also controlling the voltage value.

[0140] More specifically, the control device CT performs a pulse width modulation (PWM) control on the plurality of switching parts 611 to 616 of the inverter 61. The control device CT uses a pulse-width-modulated signal to perform on-operation of the plurality of switching parts 611 to 616 of the inverter 61. For example, the control device CT repeats a conduction period and a non-conduction period in each of the three phases. The conduction period is a time period corresponding to 120 degrees in electrical angle. The non-conduction period is a time period following the conduction period and corresponding to 60 degrees in electrical angle. By using a pulse-width-modulated signal, the control device CT performs on-operation of, among the switching parts of the three phases, the switching part whose phase corresponds to the conduction period. A pulse cycle is shorter than a repetition cycle of the conduction and non-conduction periods. In this embodiment, the control device CT and the inverter 61 control the duty cycle of the pulse-width-modulated signal, to control an average voltage (voltage value) applied to the stator windings W of the

three-phase brushless motor SG. The average voltage value is, for example, a time-average value of the voltage averaged per unit time. The unit time is, for example, a time period corresponding to the conduction period. The control device CT not only selectively allows or blocks conduction of the stator windings W but also controls the voltage value applied to the stator windings W in the conduction period.

[0141] The control device CT of this embodiment drives the crankshaft 5 in forward rotation under the state where a combustion operation of the four-stroke engine body E and forward rotation of the crankshaft 5 are stopped. At this time, in at least part of a range from the position where the forward rotation of the crankshaft 5 is stopped to the end of the compression stroke, the control device CT controls the plurality of switching parts 611 to 616 of the inverter 61 so as to cause the three-phase brushless motor SG to rotate with a torque lower than the maximum torque obtainable from the battery 14. In at least part of a range up to the end of the compression stroke, the control device CT of this embodiment controls the plurality of switching parts 611 to 616 of the inverter 61 such that the voltage applied from the battery 14 to the three-phase brushless motor SG is set lower than the voltage of the battery 14. Here, during at least part of a period in which the crankshaft 5 is driven in forward rotation up to the compression stroke under the state where no start instruction is received, the control device CT of this embodiment controls the plurality of switching parts 611 to 616 of the inverter 61 such that the voltage applied to the three-phase brushless motor SG is set lower than the voltage of the battery 14. That is, during at least part of the period in which the crankshaft 5 is driven in forward rotation up to the compression stroke under the state where no start instruction is received, the control device CT controls the plurality of switching parts 611 to 616 of the inverter 61 so as to cause the three-phase brushless motor SG to rotate with a torque lower than the maximum torque obtainable from the battery 14.

[0142] More specifically, in the forward rotation in step S13 shown in Fig. 6, the control device CT sets the voltage applied to the three-phase brushless motor SG to be lower than the voltage that is applied to the three-phase brushless motor SG when the crankshaft 5 is driven in forward rotation in response to reception of a start instruction (S17). On the condition that a signal for controlling the switching parts 611 to 616 has a duty cycle of 100%, the voltage applied to the three-phase brushless motor SG is equal to the voltage of the battery 14. In such a condition, the three-phase brushless motor SG exerts the maximum torque obtainable from the battery 14. The control device CT of this embodiment sets the voltage applied to the three-phase brushless motor SG to be lower than the voltage of the battery 14, by setting the duty cycle of the signal for controlling the switching parts 611 to 616 to be less than 100%. This causes the three-phase brushless motor SG to rotate with a torque lower than the maximum torque obtainable from the bat-

tery 14.

[0143] In the above-described manner, the control device CT drives the crankshaft 5 in forward rotation up to the compression stroke while causing the three-phase brushless motor SG to rotate with a limited torque lower than the maximum torque obtainable from the battery 14. In this embodiment, therefore, the crankshaft 5 passes through the compression stroke at a low speed, so that the crankshaft 5 is less likely to be affected by a reaction force of gas compression. Thus, in this embodiment, similarly to the first embodiment, a resistance that the reaction force of compression applies to the rotation of the crankshaft 5 is suppressed, which enables the crankshaft 5 to be moved to the compression stroke in a shorter time. Accordingly, the length of time required for restarting is shortened with an enhanced reliability.

[0144] The control device CT of this embodiment sets the voltage applied from the battery 14 to the three-phase brushless motor SG to be lower than the voltage of the battery 14, during at least part of a period from when a start instruction is received under the state where the combustion operation of the four-stroke engine body E and the forward rotation of the crankshaft 5 are stopped to when the crankshaft 5 driven in forward rotation is moved to the compression stroke. The control device CT controls the plurality of switching parts 611 to 616 of the inverter 61 so as to drive the crankshaft 5 in forward rotation with setting the voltage applied from the battery 14 to the three-phase brushless motor SG to be lower than the voltage of the battery 14.

[0145] More specifically, in the torque limiting control in step S15 shown in Fig. 6, the control device CT sets the voltage applied to the three-phase brushless motor SG to be lower than the voltage of the battery 14, by setting the duty cycle of the signal for controlling the plurality of switching parts 611 to 616 to be less than 100%. As a result, similarly to the first embodiment, the torque of the three-phase brushless motor SG is limited during at least part of the period from when a start instruction is received to when the crankshaft 5 driven in forward rotation is moved to the compression stroke. Since the torque of the three-phase brushless motor SG is limited, the speed of the forward rotation of the crankshaft is decreased. This suppresses a resistance that the reaction force of compression applies to the rotation of the crankshaft. Consequently, to start the four-stroke engine body in response to reception of a start instruction, the crankshaft can be moved to the compression stroke in a shorter time. Accordingly, as in the first embodiment, the length of time required for restarting after the combustion stop instruction can be further shortened.

[Motorcycle]

[0146] Fig. 14 is a diagram showing an external appearance of a vehicle to which the engine unit according to any of the first to fifth embodiments is mounted.

[0147] A vehicle A shown in Fig. 14 includes an engine

unit EU, a vehicle body 101, wheels 102 and 103, and a battery 14. The engine unit EU may be any of the engine units EU according to the first to fifth embodiments. The engine unit EU mounted to the vehicle A drives the wheel 103, which is a drive wheel, so that the wheel 103 is rotated to cause the vehicle A to travel.

[0148] The vehicle A shown in Fig. 14 is equipped with the four-stroke engine unit for use in vehicle. The four-stroke engine unit, in which the capability of early start is ensured, has a heat resistance and also has a simple structure with improved mountability to vehicle. Accordingly, the vehicle A can be made compact in its entirety.

[0149] The vehicle A shown in Fig. 14 is a motorcycle. The vehicle of the present invention is not limited to motorcycles. Examples of the vehicle of the present invention include a scooter type motorcycle, a moped type motorcycle, an off-road type motorcycle, and an on-road type motorcycle. Straddled vehicles other than motorcycles are also acceptable. For example, an ATV (All-Terrain Vehicle) is acceptable. The vehicle of the present invention is not limited to straddled vehicles, and may be a four-wheeled vehicle including a passenger compartment, for example.

[0150] The control device CT may use a detector different from the rotor position detection device 50 in order to detect rotation and stop of rotation of the crankshaft 5. In an acceptable example, the engine unit includes a Hall IC or a rotary encoder, and the control device detects rotation and stop of rotation of the crankshaft 5 based on detection of a signal outputted from the Hall IC or the rotary encoder.

[0151] In this embodiment, the control device CT configured to decrease the rate of limiting the output torque if the crankshaft 5 reaches the highest-load position, is illustrated as an example of the control device. The control device of the present invention, however, is not limited thereto. For example, the control device may be configured to, after the crankshaft reaches the highest-load position, continue the rotation with a torque lower than the maximum torque obtainable from the battery 14 until the engine is ignited.

[0152] In this embodiment, the control device CT configured to cause the three-phase brushless motor SG to rotate with a torque lower than the maximum torque obtainable from the battery 14 during the period in which the crankshaft 5 is driven in forward rotation up to the compression stroke under the state where no start instruction is received, is illustrated as an example of the control device. The control device of the present invention, however, is not limited thereto. For example, the control device may be configured to cause the three-phase brushless motor SG to rotate with a torque lower than the maximum torque obtainable from the battery 14 during part of the period in which the crankshaft 5 is driven in forward rotation up to the compression stroke under the state where no start instruction is received.

[0153] In this embodiment, the control device CT configured to set the voltage applied to the three-phase

brushless motor SG to be lower than the voltage of the battery 14 during the period in which the crankshaft 5 is driven in forward rotation up to the compression stroke under the state where no start instruction is received, is illustrated as an example of the control device. The control device of the present invention, however, is not limited thereto. For example, the control device may be configured to set the voltage applied to the three-phase brushless motor SG to be lower than the voltage of the battery 14 during part of the period in which the crankshaft 5 is driven in forward rotation up to the compression stroke under the state where no start instruction is received.

[0154] In this embodiment, the control device CT configured to set the voltage applied to the three-phase brushless motor SG to be lower than the voltage of the battery 14 in a period from when a start instruction is received to when the crankshaft moves past the compression stroke, is illustrated as an example of the control device. The control device of the present invention, however, is not limited thereto. For example, the control device may be configured to set the voltage applied to the three-phase brushless motor SG to be lower than the voltage of the battery 14 during part of the period from when a start instruction is received to when the crankshaft moves past the compression stroke.

[0155] In this embodiment, the control device CT configured to set the duty cycle of the signal for controlling the switching parts 611 to 616 to be less than 100%, is illustrated as an example of the control device that sets the voltage applied to the three-phase brushless motor to be lower than the voltage of the battery. The control device of the present invention, however, is not limited thereto. In a possible example, the control device includes a voltage limiting circuit arranged between the switching part and the battery, and the voltage limiting circuit sets the voltage applied to the switching part to be lower than the voltage of the battery.

[0156] The embodiment illustrates the case where the four-stroke engine body E is a single-cylinder engine. The engine of the present invention, however, is not particularly limited as long as the engine has a high-load region and a low-load region. Thus, a multi-cylinder engine is also adoptable. Examples of the engine other than the engine illustrated in this embodiment include a straight single-cylinder engine, a parallel double-cylinder engine, a straight double-cylinder engine, a V-type double-cylinder engine, and a horizontal opposed double-cylinder engine. The number of cylinders included in the multi-cylinder engine is not particularly limited. The multi-cylinder engine may be, for example, a four-cylinder engine. Here, some of four-cylinder engines have no low-load region. For example, a four-cylinder engine configured such that compression strokes of cylinders occur at equal intervals (a four-cylinder engine configured such that explosion occurs at equal intervals) may be mentioned. Such an engine having no low-load region does not conform to the definition of the engine of the present invention.

Reference Signs List

[0157]

A	vehicle	5
CT	control device	
E	four-stroke engine body	
EU	engine unit	
SG	three-phase brushless motor	
5	crankshaft	10
29	spark plug	
62, 862	starter motor controller	
63	combustion controller	
61	inverter	
611-616	switching part	15

Claims

1. An engine unit mounted to a vehicle, the engine unit comprising:

a four-stroke engine body in which a high-load region and a low-load region occur during four strokes, the high-load region having a high load on rotation of a crankshaft, the low-load region having a load on rotation of the crankshaft lower than that of the high-load region;

a three-phase brushless motor that starts the four-stroke engine body by driving the crankshaft in forward rotation in response to reception of a start instruction, the three-phase brushless motor being driven by a battery provided in the vehicle;

an inverter including a plurality of switching parts by which a voltage applied from the battery to the three-phase brushless motor is controlled; and

a control device including a starter motor controller and a combustion controller, the starter motor controller controlling the voltage applied from the battery to the three-phase brushless motor by controlling the plurality of switching parts included in the inverter, the combustion controller controlling a combustion operation of the four-stroke engine body, the control device performing such an operation that:

after the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped, the control device controls the voltage applied from the battery to the three-phase brushless motor by controlling the plurality of switching parts of the inverter under a state where the start instruction is not received while the combustion operation of the four-stroke engine body and the forward rotation of the crank-

shaft are stopped, to drive the crankshaft in forward rotation from a stopped position to a compression stroke included in the four strokes and then stop the crankshaft in the compression stroke; and
upon receiving the start instruction after the forward rotation of the crankshaft caused under control of the voltage applied to the three-phase brushless motor is stopped in the compression stroke, the control device controls the voltage applied from the battery to the three-phase brushless motor, to drive the crankshaft in forward rotation from a position where the crankshaft is located at a time point when the start instruction is received.

2. The engine unit according to claim 1, wherein the four-stroke engine body includes a combustion chamber and a decompression device that relieves pressure in the combustion chamber during the compression stroke, the decompression device is activated during at least part of a time period in which the control device drives the crankshaft in forward rotation by controlling the voltage applied from the battery to the three-phase brushless motor.
3. The engine unit according to claim 1 or 2, wherein the three-phase brushless motor includes a stator and a rotor, the stator including a plurality of teeth arranged in a circumferential direction and windings each wound on each of the plurality of teeth, the rotor being arranged opposed to the stator, the rotor being rotated along with the crankshaft, the rotor including magnetic pole faces, the number of the magnetic pole faces being more than 2/3 of the number of the plurality of teeth, the control device controls the voltage applied from the battery to each of the plurality of windings of the three-phase brushless motor by controlling the plurality of switching parts of the inverter, to drive the crankshaft in forward rotation.
4. The engine unit according to any one of claims 1 to 3, wherein in at least part of a range up to the end of the compression stroke, the control device controls the plurality of switching parts of the inverter so as to cause forward rotation of the three-phase brushless motor with a torque lower than a maximum torque obtainable from the battery.
5. The engine unit according to any one of claims 1 to 4, wherein in at least part of a range up to the end of the compression stroke, the control device drives the crankshaft in forward rotation while controlling the plurality

of switching parts of the inverter so as to set the voltage applied from the battery to the three-phase brushless motor to be lower than a voltage of the battery.

6. The engine unit according to any one of claims 1 to 5, wherein

upon receiving the start instruction in the middle of driving the crankshaft in forward rotation up to the compression stroke while controlling the voltage applied to the three-phase brushless motor by controlling the plurality of switching parts of the inverter under the state where the start instruction is not received while the combustion operation of the four-stroke engine body and the forward rotation of the crankshaft are stopped, the control device continues the forward rotation of the crankshaft beyond the compression stroke without stopping the forward rotation in the compression stroke, to start the four-stroke engine body.

7. The engine unit according to any one of claims 1 to 5, wherein

if the forward rotation of the crankshaft having been continued since the stop of the combustion operation of the four-stroke engine body is stopped in the compression stroke, the control device skips the driving of the crankshaft in forward rotation under the state where the start instruction is not received.

8. The engine unit according to any one of claims 1 to 5, wherein

the control device switches driving of the crankshaft between forward rotation and reverse rotation under the state where the start instruction is not received, the switching being performed in accordance with a position where the forward rotation of the crankshaft having been continued since the stop of the combustion operation of the four-stroke engine body is stopped.

9. The engine unit according to claim 8, wherein

if the position where the forward rotation of the crankshaft having been continued since the stop of the combustion operation of the four-stroke engine body is stopped is in a first range included in the four strokes, the control device drives the crankshaft in forward rotation up to the compression stroke under the state where the start instruction is not received, and if the position where the forward rotation of the crankshaft having been continued since the stop of the combustion operation of the four-stroke engine body is stopped is in a second range included in the four strokes, the control device drives the crankshaft in reverse rotation under the state where the start instruction is not received, the first range extending from a starting point to an ending point in a forward rotation direction, the starting point being located

within a range ranging from a compression top dead center to an exhaust top dead center in the forward rotation direction, the ending point being located within the compression stroke, the second range extending from the compression top dead center to the starting point of the first range in the forward rotation direction.

10. The engine unit according to any one of claims 1 to 9, wherein

for a predefined time period after starting the combustion operation of the four-stroke engine body by driving the crankshaft in forward rotation in response to reception of the start instruction, the control device controls the voltage applied from the battery to the three-phase brushless motor by controlling the plurality of switching parts of the inverter, to accelerate the forward rotation of the crankshaft.

11. The engine unit according to any one of claims 1 to 10, wherein

after the four-stroke engine body is started, the three-phase brushless motor is rotated along with rotation of the crankshaft, to function as a generator that generates a current for charging the battery.

12. A vehicle comprising the engine unit according to any one of claims 1 to 11.

FIG.1

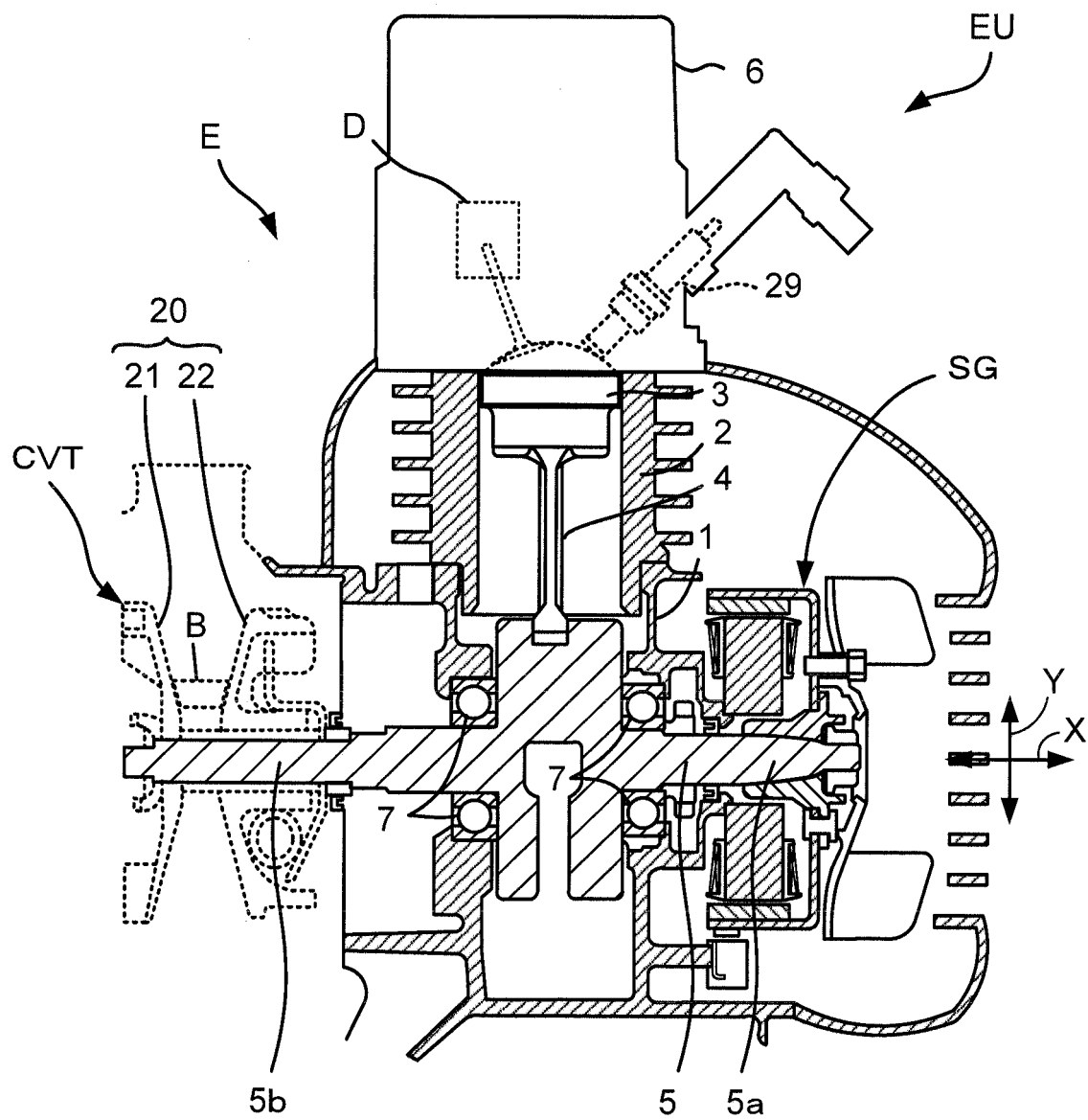


FIG.2

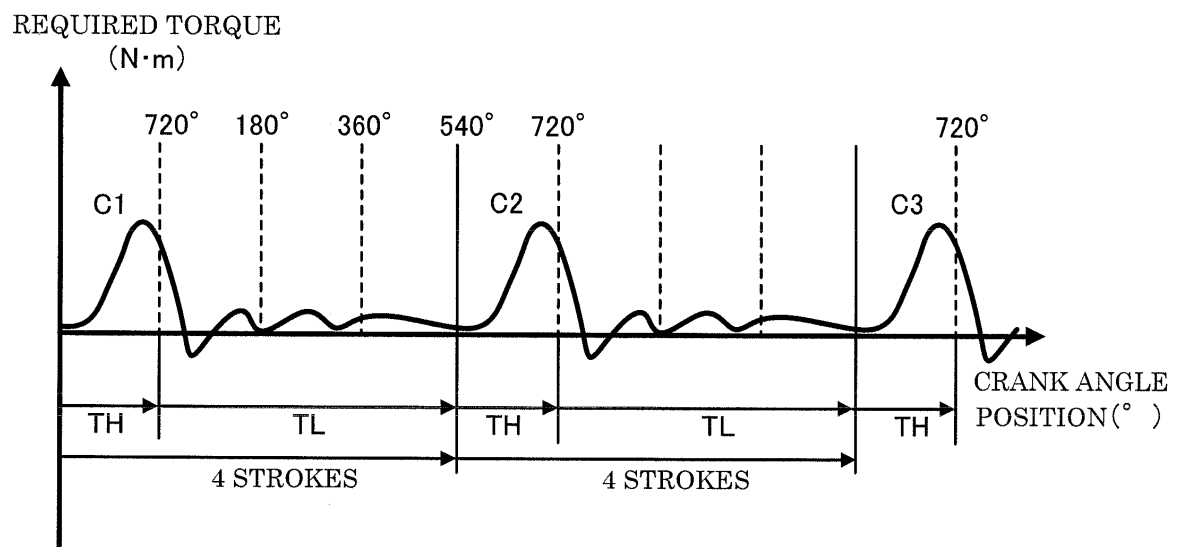


FIG.3

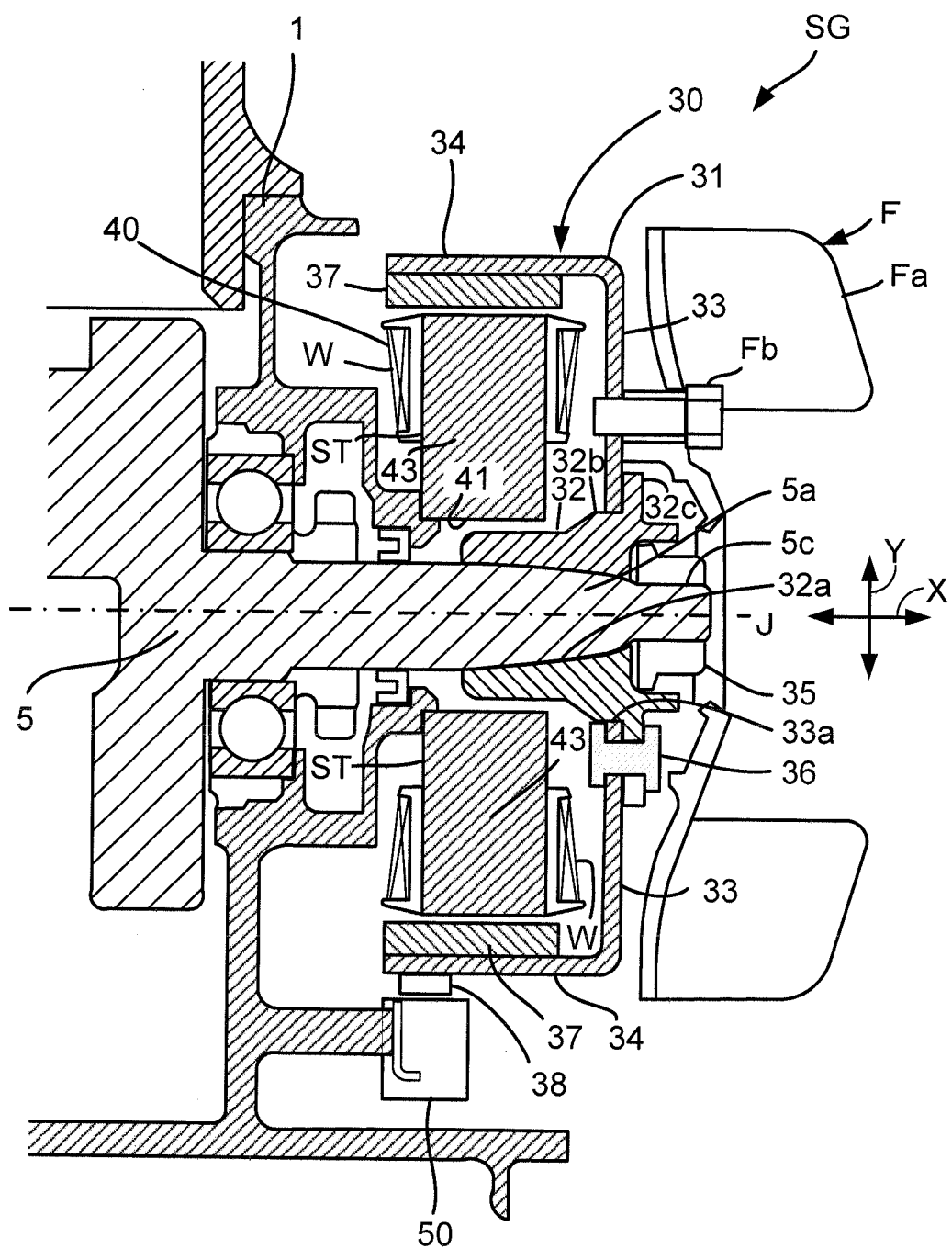


FIG.4

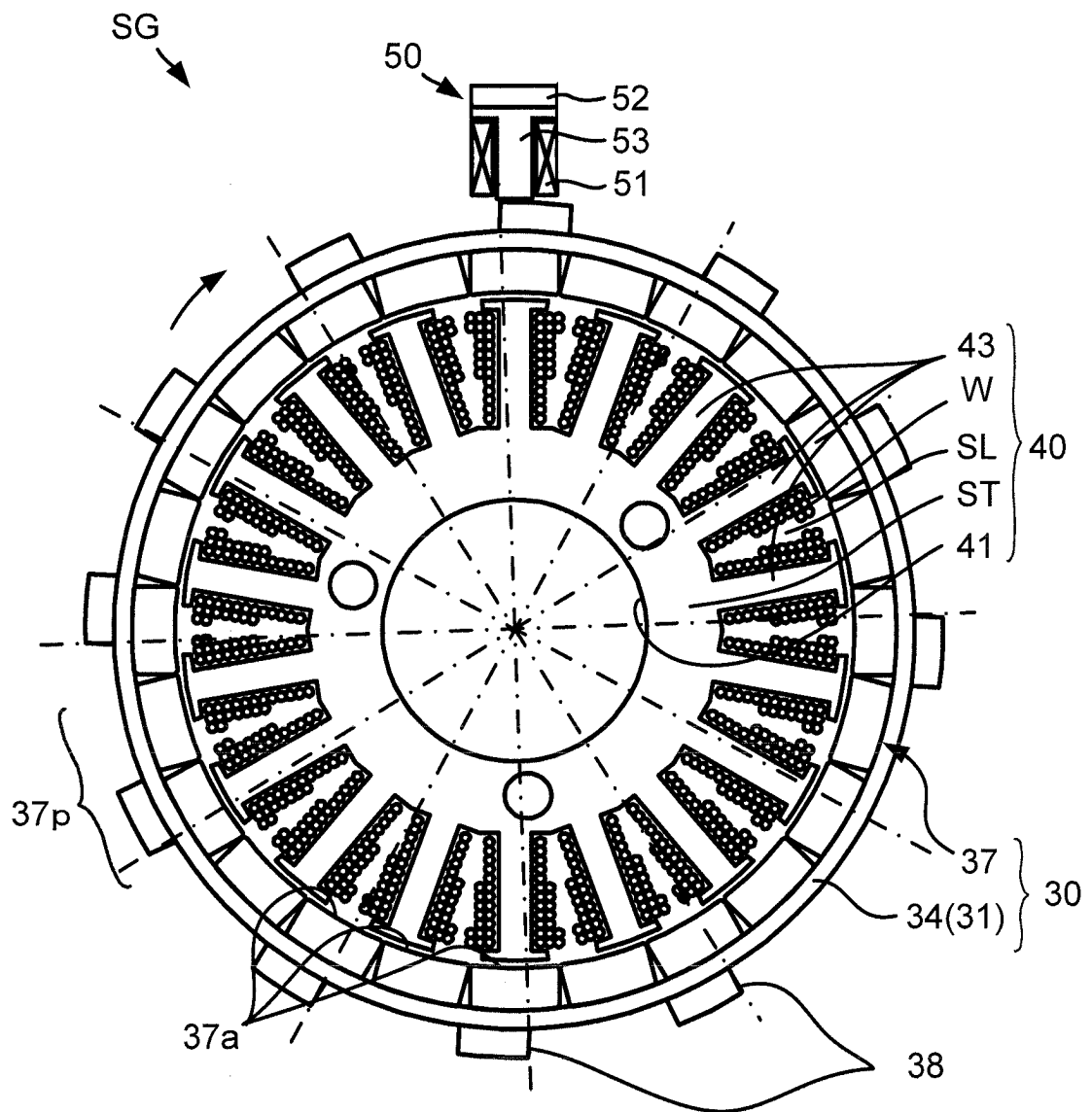


FIG.5

EU

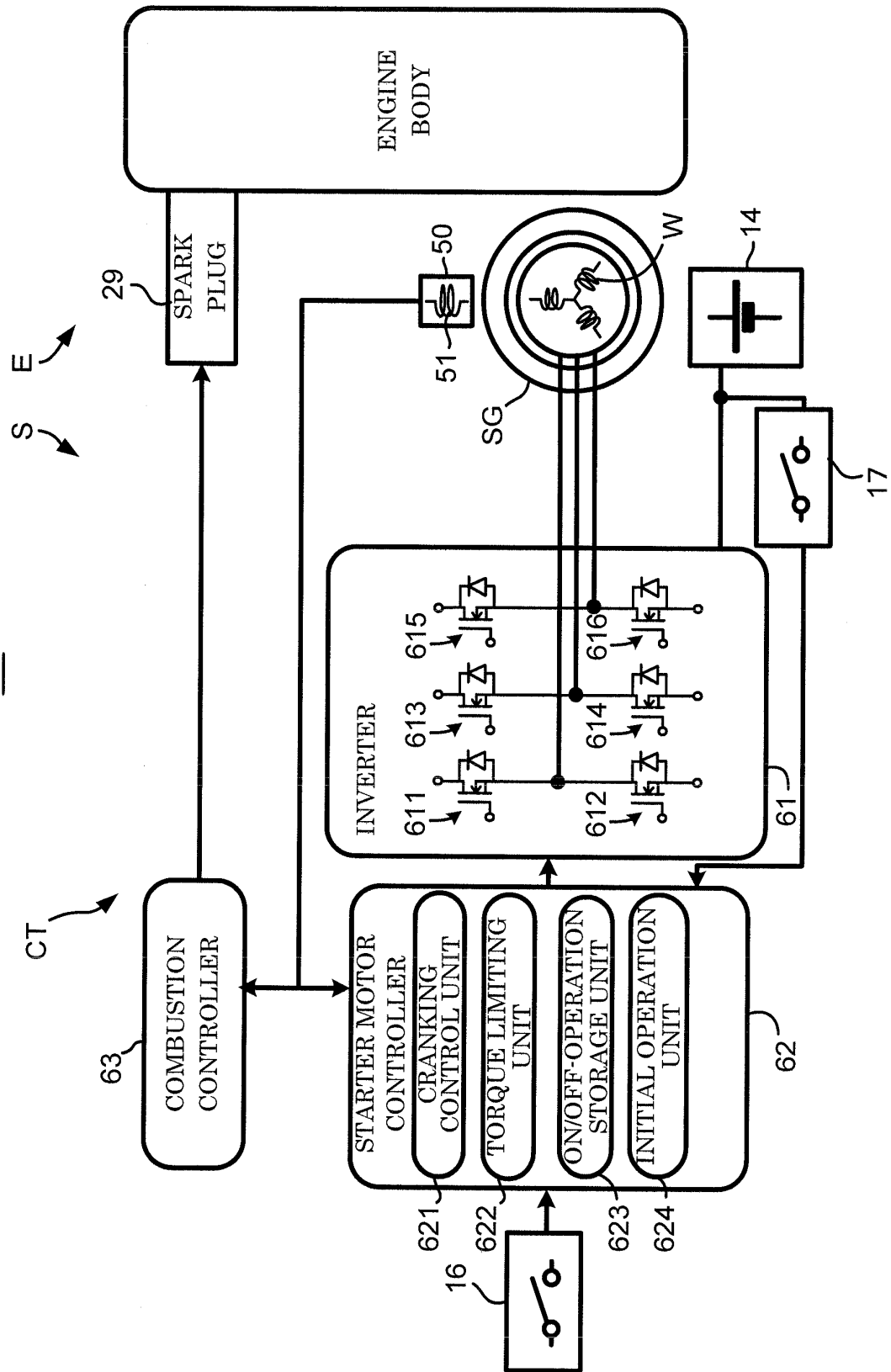


FIG.6

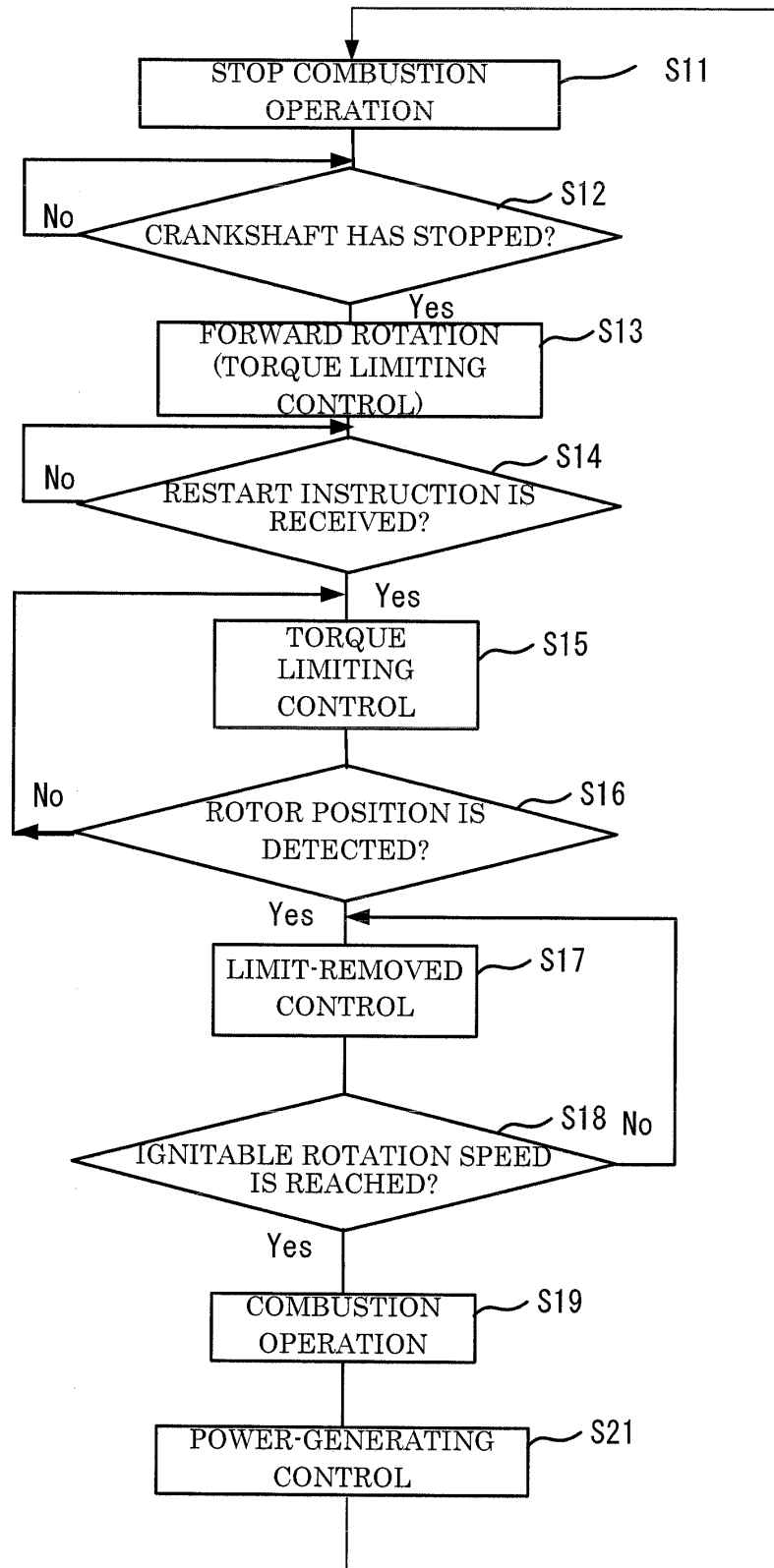


FIG.7
0(720) [deg.]

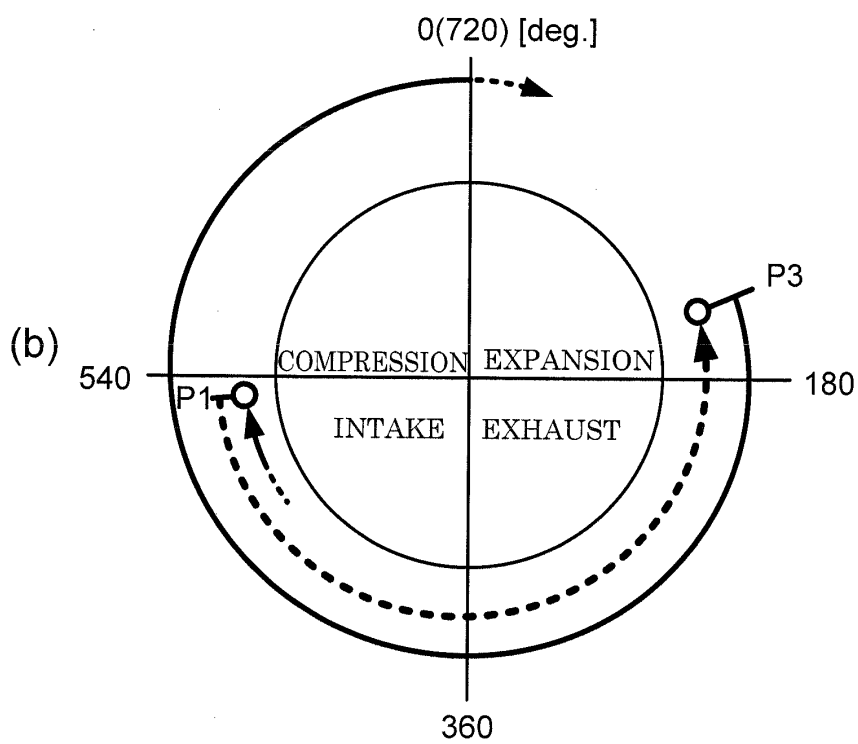
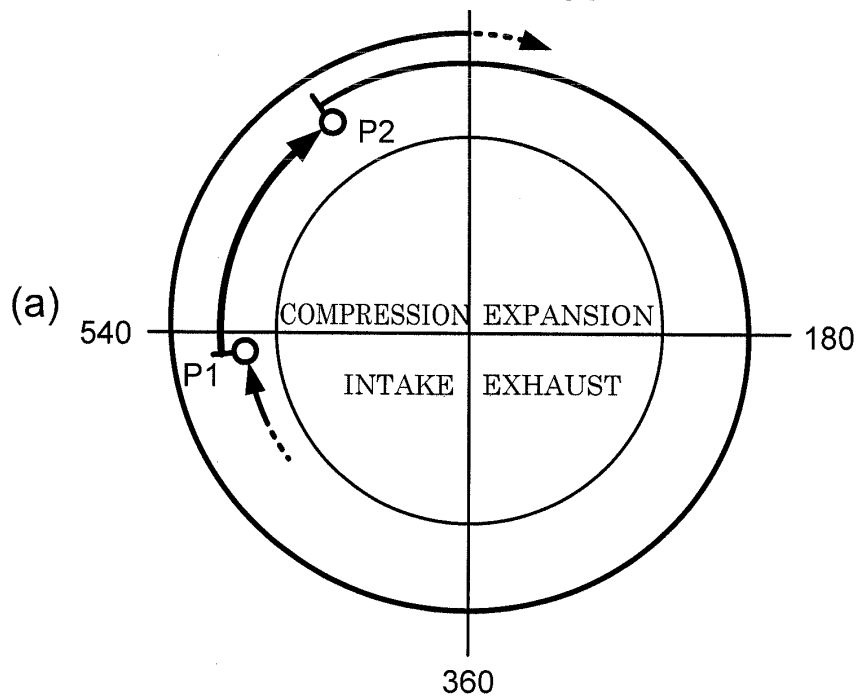


FIG.8

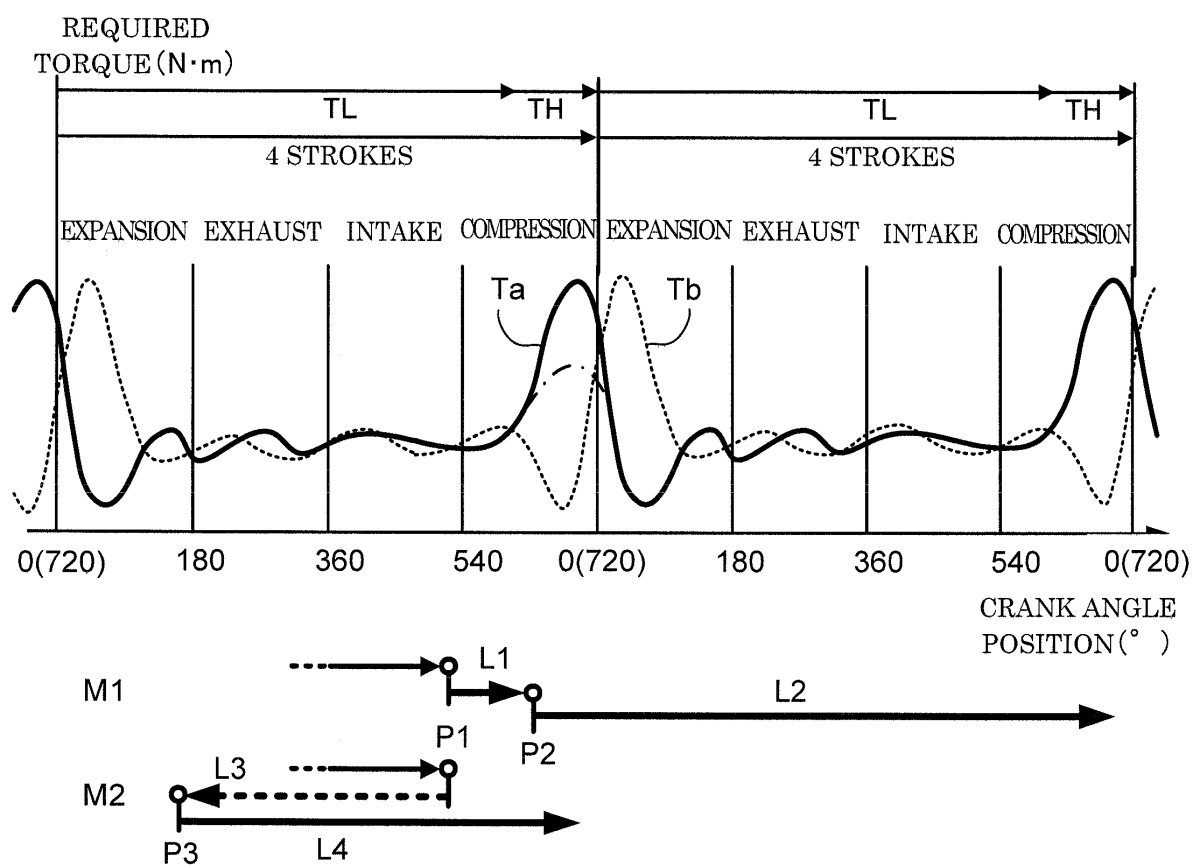
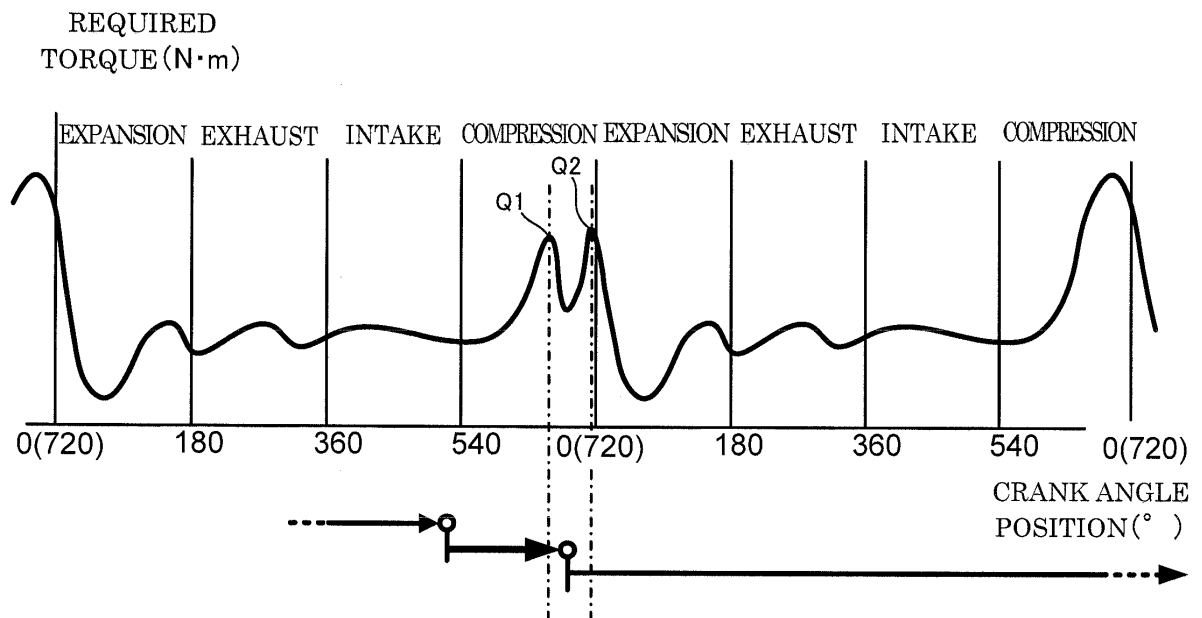


FIG.9



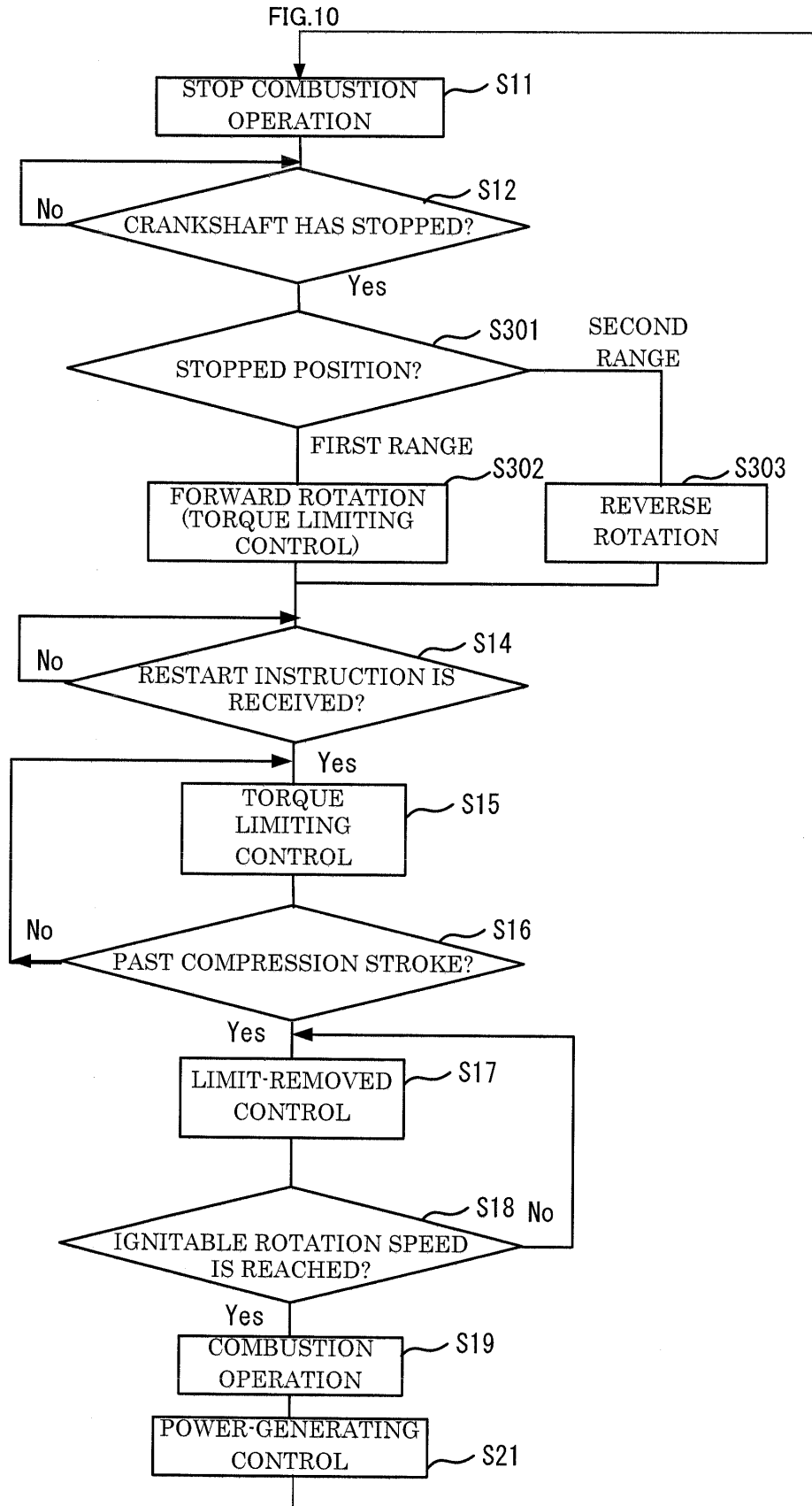
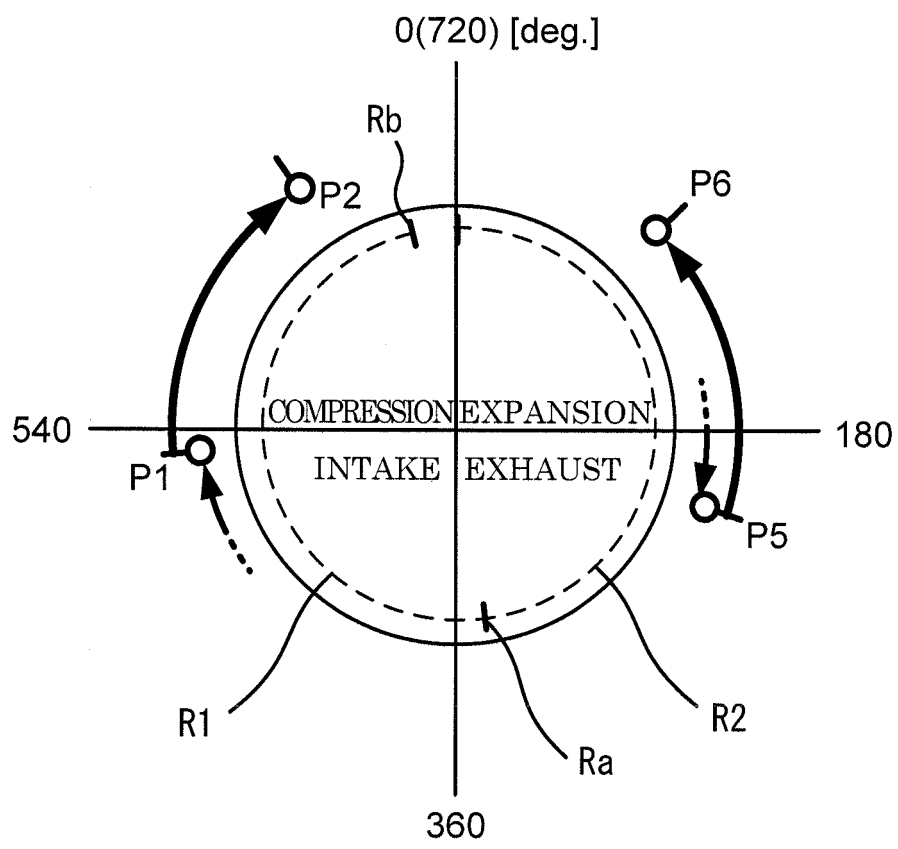


FIG.11



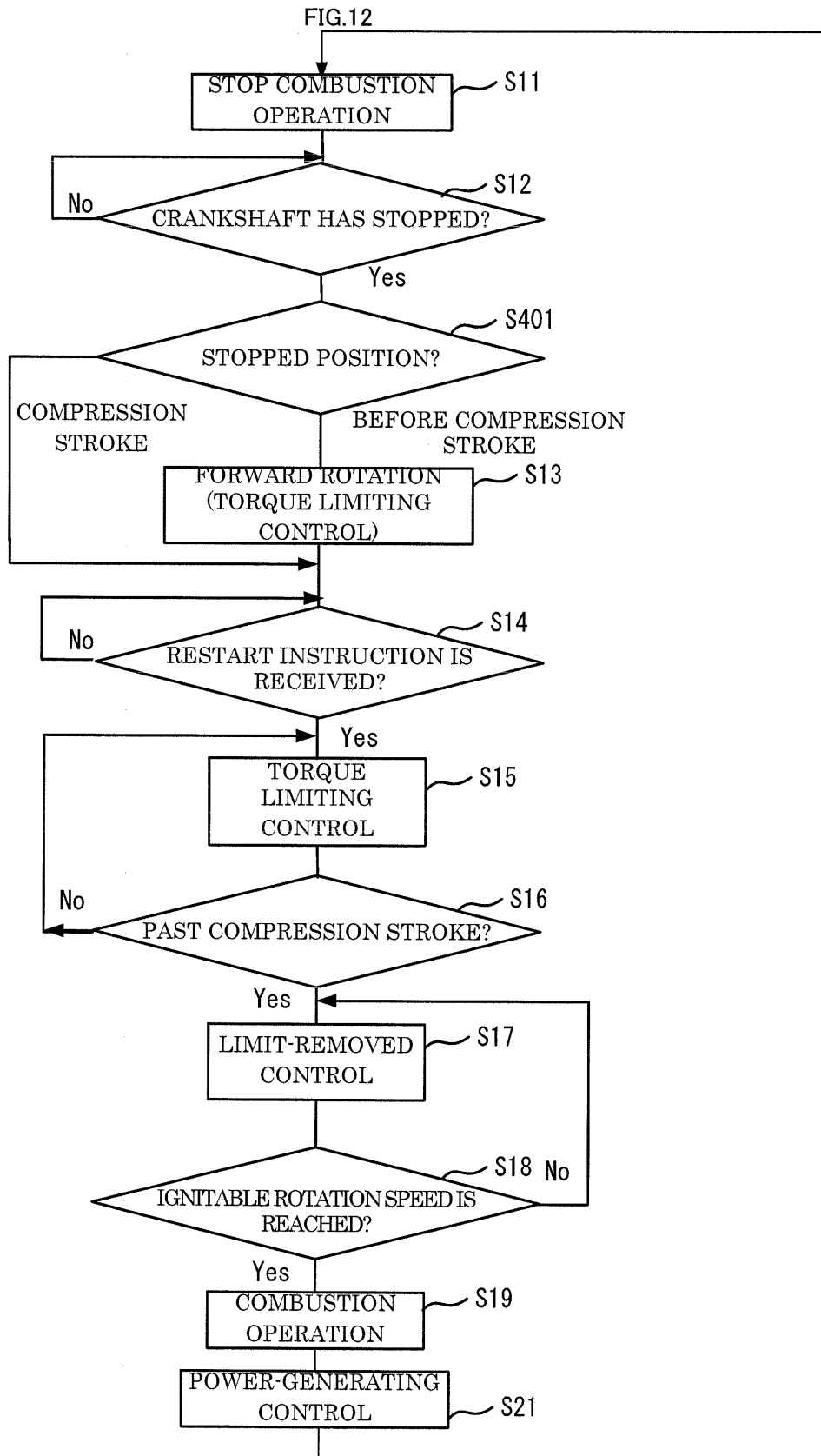


FIG. 13

리

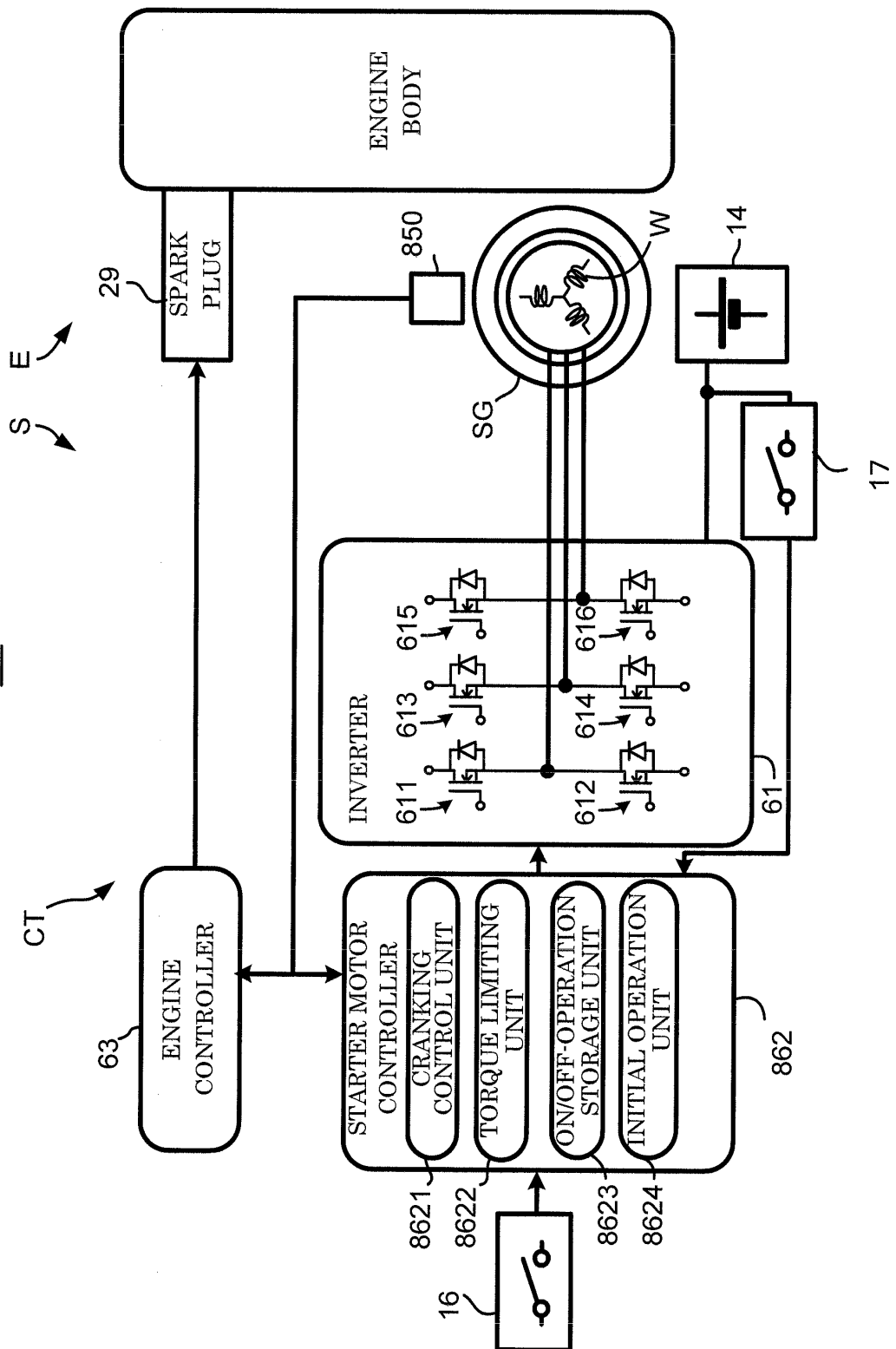
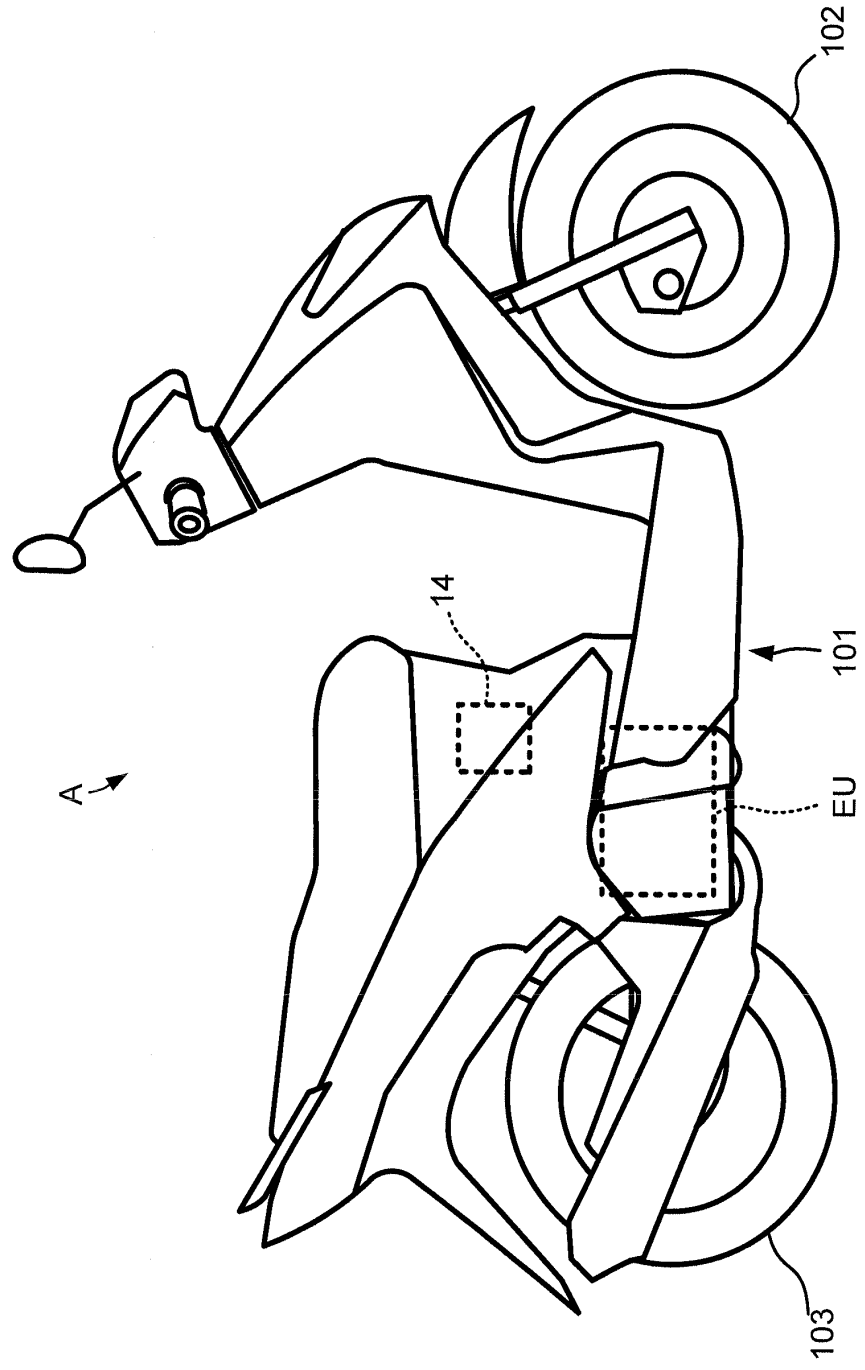


FIG.14



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/083592

A. CLASSIFICATION OF SUBJECT MATTER

F02N11/08(2006.01)i, F02D29/02(2006.01)i, F02N11/04(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)

F02N11/08, F02D29/02, F02N11/04

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.
Y A	JP 2-41689 A (Mazda Motor Corp.), 09 February 1990 (09.02.1990), column 24, line 4 to column 28, line 2; fig. 13 (Family: none)	1-8, 10-12 9
Y	JP 2004-68632 A (Toyota Motor Corp.), 04 March 2004 (04.03.2004), paragraphs [0040] to [0052], [0058] to [0061]; fig. 1 to 5 (Family: none)	1-8, 10-12
Y	JP 2003-106124 A (Hino Motors, Ltd.), 09 April 2003 (09.04.2003), paragraph [0002] (Family: none)	2-8, 10-12

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

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

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document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"

document member of the same patent family

Date of the actual completion of the international search
16 February 2015 (16.02.15)Date of mailing of the international search report
03 March 2015 (03.03.15)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/083592

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 3-64667 A (Toyoda Automatic Loom Works, Ltd., Toyota Motor Corp.), 20 March 1991 (20.03.1991), page 3, upper left column, line 12 to upper right column, line 10; fig. 7 (Family: none)	2-8, 10-12
Y	JP 63-297769 A (Kubota Tekko Kabushiki Kaisha), 05 December 1988 (05.12.1988), specification, page 2, upper right column, lines 1 to 18; fig. 3 (Family: none)	2-8, 10-12
Y	JP 2002-315250 A (Moric Co., Ltd.), 25 October 2002 (25.10.2002), paragraphs [0018], [0027]; fig. 2, 7 & US 2002/0145354 A1 & EP 1249920 A2 & TW 575998 B & CN 1380733 A	3-8, 10-12
Y	JP 2001-221138 A (Mitsubishi Motors Corp.), 17 August 2001 (17.08.2001), paragraphs [0012] to [0019]; fig. 2 (Family: none)	6-7, 10-12
Y	JP 2004-36428 A (Toyota Motor Corp.), 05 February 2004 (05.02.2004), paragraph [0029] (Family: none)	8, 10-12

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2003343404 A [0005]