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(54) **STRADDLED VEHICLE**

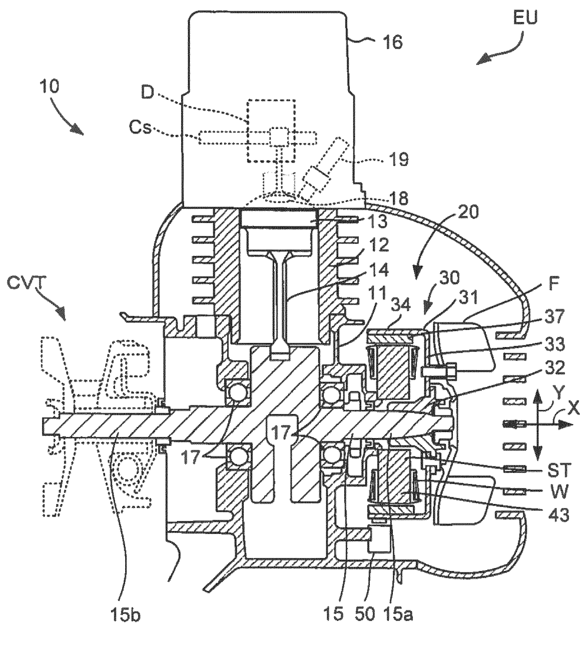
(57) [PROBLEM]

To provide a straddled vehicle that is able to shorten a time period until completion of engine start after an engine start instruction.

[SOLUTION]

An engine unit includes a single-cylinder engine, a compression release mechanism, a drive wheel, a permanent magnet type motor, a battery, an inverter including a plurality of switching parts, and a control device. The control device controls the switching parts in such a manner that, upon reception of a start instruction for starting the single-cylinder engine, the permanent magnet type motor moves a piston so as to operate the compression release mechanism in a compression stroke of a first combustion cycle, and then the permanent magnet type motor applies a force to the piston via a crankshaft such that the rotation speed of the crankshaft in a second combustion cycle exceeds the pressure-reduction upper limit speed for the compression release mechanism, so that the piston is moved without operating the compression release mechanism in a compression stroke of the second combustion cycle, thus assisting compression of the mixed gas.

FIG.2



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Description

[TECHNICAL FIELD]

[0001] The present teaching relates to a straddled vehicle.

[BACKGROUND ART]

[0002] For example, Patent Document 1 shows a control device for controlling a starter generator of an engine that is mounted to a motorcycle. In the motorcycle of Patent Document 1, the starter generator is used as an electric motor. Upon a request for starting the engine, the control device directs the starter generator to rotate a crankshaft of the engine.

[0003] The control device of Patent Document 1 performs what is called "swing-back", for the purpose of ensuring a rotation speed of the crankshaft before reaching a compression stroke. The swing-back means a process in which the crankshaft is once driven in reverse rotation and then driven in forward rotation. Performing the swing-back enables the rotation speed to rise in the compression stroke.

[0004] Generally in a rotary electric machine such as a starter generator, once the rotation speed rises to a certain extent, a generatable torque starts to decrease, and then the generatable torque decreases as the rotation speed rises. In the starter generator of Patent Document 1, the rotation speed at which the generatable torque of the starter generator starts to decrease is set low, in consideration of suppressing a size increase of the starter generator.

[0005] The control device of the Patent Document 1 is configured to, when directing the starter generator to rotate the crankshaft, raise a voltage to be supplied to the starter generator for the purpose of accelerating the crankshaft before reaching the compression top dead center. For example, the control device of Patent Document 1 raises the voltage by using a step-up chopper circuit that is formed by connecting a positive electrode of a battery to the neutral point where windings of the starter generator are coupled, the step-up chopper circuit including the windings. By raising the voltage, the control device of Patent Document 1 can widen a speed range where the starter generator is able to output a torque.

[0006] The control device of Patent Document 1 directs the starter generator to rotate the crankshaft with the raised voltage. Then, the control device starts a combustion control while terminating the rotation implemented by the starter generator, and directs the starter generator to generate power.

[PRIOR ART DOCUMENTS]

[PATENT DOCUMENTS]

[0007] Patent Document 1: Japanese Patent No. 5874315

[SUMMARY OF THE INVENTION]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

[0008] The control device of Patent Document 1 aims to shorten a time period until start of the combustion control after an engine start instruction, by widening a range of rotation speed of the starter generator until start of the combustion control.

[0009] In a straddled vehicle, it is demanded that a time period be shortened over the entire time period until completion of engine start after an engine start instruction.

[0010] An object of the present teaching is to provide a straddled vehicle that is able to shorten a time period until completion of engine start after an engine start instruction.

[MEANS FOR SOLVING THE PROBLEMS]

[0011] The present inventors conducted studies on a process from an engine start instruction to completion of the start at a time of engine start. The present inventors focused on an operation of a compression release mechanism (decompression mechanism). Patent Document 1 also mentions a compression release mechanism.

[0012] For example, the compression release mechanism opens an exhaust valve in a compression stroke where a piston compresses air (mixed gas) contained in a cylinder. This is how the compression release mechanism lowers a load torque. Adoption of the compression release mechanism allows the piston to compress air with a weaker force.

[0013] It can therefore be contemplated that adoption of the compression release mechanism helps removal of problems that are involved in lowness of the torque applied to the crankshaft.

[0014] Patent Document 1, however, concludes that providing the compression release mechanism cannot solve the problems that are involved in lowness of the torque applied to the crankshaft.

[0015] The present inventors conducted further studies on the operation of the compression release mechanism, resulting in discovery that shortening a time period until completion of engine start may be difficult under some operating condition of the compression release mechanism.

[0016] If the compression release mechanism operates in a compression stroke, air (mixed gas) contained in the cylinder is partially discharged through the exhaust valve. In a combustion stroke that follows the compression stroke, the piston operates in response to power caused by combustion of the mixed gas. The crankshaft is rotated along with the operation of the piston.

[0017] Due to the operation of the compression release mechanism, the amount of mixed gas contained in the cylinder is reduced. That is, a reduced amount of mixed gas is combusted in the combustion stroke. Power caused by the combustion is reduced accordingly.

[0018] Combustion occurring after reception of a start instruction allows the piston and the crankshaft to continue operation until a compression stroke subsequent to the combustion. During this operation, the piston and the crankshaft receives a resistance such as a friction. In a time period from the combustion stroke to the compression stroke, the piston and the crankshaft operate while consuming power caused in the combustion stroke. During this operation, the rotation speed of the crankshaft continues decreasing. Particularly in a single-cylinder engine, each of the combustion stroke and the compression stroke comes only once in two rotations of the crankshaft. Therefore, a time period from the combustion stroke to the next compression stroke is long.

[0019] In the compression stroke, the piston compresses air, and thus the rotation speed of the crankshaft further decreases because of a compression reaction force.

[0020] If combustion power is reduced due to the operation of the compression release mechanism, the rotation speed of the crankshaft further decreases in a second compression stroke coming after the combustion.

[0021] For example, if the rotation speed in the second compression stroke is equal to or less than an operation upper limit speed which defines the operation of the compression release mechanism, the compression release mechanism re-operates in the second compression stroke.

[0022] The re-operation of the compression release mechanism makes it easy for the piston to complete the second compression stroke. When the compression release mechanism operates in the second compression stroke, however, the amount of mixed gas contained in the cylinder is reduced. The compression ratio of the mixed gas is also reduced accordingly. This results in just small power being caused in a combustion stroke subsequent to the second compression stroke. Thus, the rotation speed of the crankshaft is low after the combustion stroke subsequent to the second compression stroke. As a consequence, the compression release mechanism may re-operate in a compression stroke included in a third combustion cycle.

[0023] Particularly a single-cylinder engine, in which a high-load region and a low-load region occur during four strokes, has characteristics that a torque required for rotating the crankshaft largely varies.

[0024] In the single-cylinder engine, the compression release mechanism is required to sufficiently discharge air from the cylinder in order to enable the piston to complete its operation in the compression stroke after reception of a start instruction. If, however, the compression release mechanism discharges air from the cylinder to such an extent that the piston is able to complete its operation in the compression stroke of the single-cylinder engine, the amount and compression ratio of mixed gas combusted in the next combustion stroke subsequent to the current compression stroke are likely to be insufficient. As a result, the compression release mechanism tends to re-operate in the second compression stroke coming after the combustion stroke.

[0025] Due to the operation of the compression release mechanism, the rotation speed of the crankshaft decreases after the combustion stroke, and the rotation speed further decreases until the compression stroke coming after the combustion stroke. This can cause a cycle of operations of the compression release mechanism. Even if the number of times the compression release mechanism operates is not large, a time period until completion of engine start is prolonged according to a time period during which the operation of the compression release mechanism is repeated a plurality of times.

[0026] The present inventors considered an option of continuously operating the piston by using a motor after completion of air compression which is a primary purpose of operating the piston by the motor.

[0027] After the piston compresses air, the piston operates in response to power caused by combustion. After the piston compresses air, the motor applies a force to the piston, the force cooperating with a combustion force to assist the operation of the piston. Due to the assistance of the motor, a decrease in the rotation speed of the crankshaft is suppressed. Suppression of a decrease in the rotation speed of the crankshaft makes it possible to avoid operating the compression release mechanism in a compression stroke coming after the combustion. As a result, a larger amount of air (mixed gas) is combusted in the combustion stroke, as compared with when the compression release mechanism operates. Accordingly, the rotation speed of the crankshaft increases by a large increment.

[0028] Once the rotation speed of the crankshaft increases by a large increment, an operation of the compression release mechanism in compression strokes included in subsequent combustion cycles is further avoided. Accordingly, the rotation speed of the crankshaft further increases.

[0029] The control device of Patent Document 1, when starting a combustion control, terminates rotation caused by the starter generator, and directs the starter generator to generate power. That is, upon completion of air compression which is a primary purpose of operating the piston, the operation of the piston performed by the starter generator is stopped. In the next combustion cycle, therefore, the compression release mechanism operates, which makes it likely that combustion of a small amount of mixed gas continues. A time period required for increasing the rotation speed of the crankshaft tends to be prolonged.

[0030] In the present teaching, on the other hand, the compression release mechanism is operated in a first compression stroke, and upon completion of compression which is one of primary purposes of operating the piston, a force is intentionally applied to the piston by using the motor. Thus, characteristics obtained when the compression release mechanism operates and characteristics obtained when the compression release mechanism does not operate are exerted at appropriate times. As a result, the rotation speed of the crankshaft increases in a short time. This shortens a time period until completion of engine start after start of the combustion control.

[0031] The present teaching is a teaching accomplished based on the findings described above.

[0032] To solve the problems described above, the present teaching adopts the following configurations.

(1) A straddled vehicle including:

a single-cylinder engine including a piston and a crankshaft, the piston provided in a cylinder and moved to and fro by combustion of a mixed gas, the crankshaft configured to be rotated along with to-and-fro movement of the piston;
a compression release mechanism operable to reduce pressure in the cylinder in a compression stroke of the single-cylinder engine, in a case where the rotation speed of the crankshaft is equal to or less than a pressure-reduction upper limit speed;
a drive wheel configured to receive a rotational force outputted from the single-cylinder engine via the crankshaft and drive the straddled vehicle;
a permanent magnet type motor including a rotor and a permanent magnet, the rotor connected directly or indirectly to the crankshaft so as to be rotatable in response to rotation of the crankshaft, the permanent magnet provided to the rotor;
a battery;
an inverter including a plurality of switching parts by which a current flowing between the battery and the permanent magnet type motor is controlled; and
a control device configured to control the plurality of switching parts in such a manner that, upon reception of a start instruction for starting the single-cylinder engine, the permanent magnet type motor applies a force to the piston via the crankshaft such that the rotation speed of the crankshaft in a first combustion cycle coming after the start instruction is equal to or less than the pressure-reduction upper limit speed for the compression release mechanism, so that the piston is moved to operate the compression release mechanism in a compression stroke of the first combustion cycle, and then the permanent magnet type motor applies a force to the piston via the crankshaft such that the rotation speed of the crankshaft in a second combustion cycle exceeds the pressure-reduction upper limit speed for the compression release mechanism, so that the piston is moved without operating the compression release mechanism, thus assisting compression of the mixed gas in a compression stroke of the second combustion cycle.

[0033] In the single-cylinder engine of the straddled vehicle of (1), the piston provided in the cylinder is moved to and fro by combustion of the mixed gas. The crankshaft is rotated along with the to-and-fro movement of the piston. The drive wheel receives the rotational force of the crankshaft, to drive the straddled vehicle.

[0034] The rotor of the permanent magnet type motor is connected to the crankshaft. The rotor is provided with the permanent magnet. The plurality of switching parts arranged between the permanent magnet type motor and the battery control the current flowing between the battery and the permanent magnet type motor. The switching parts are controlled by the control device. The control device is able to control a force to be supplied from the permanent magnet type motor to the piston via the crankshaft. The compression release mechanism reduces pressure in the cylinder in a compression stroke. The compression release mechanism reduces pressure in the cylinder in a case where the rotation speed of the crankshaft is equal to or less than the pressure-reduction upper limit speed.

[0035] Upon reception of the start instruction, the control device starts the single-cylinder engine. The control device directs the permanent magnet type motor to apply a force to the piston via the crankshaft, to move the piston. In the first combustion cycle coming after the start instruction, the rotation speed of the crankshaft is equal to or less than the pressure-reduction upper limit speed. As a result, the compression release mechanism operates in the compression stroke of the first combustion cycle. That is, the compression release mechanism reduces pressure in the cylinder in the compression stroke. The pressure reduction in the cylinder allows the piston to compress air contained in the cylinder. Thus, the piston and the crankshaft overcome the peak of a compression reaction force, and complete the compression stroke. In a combustion stroke coming after the compression stroke, air contained in the cylinder is combusted, so that a combustion force is applied to the piston and the crankshaft.

[0036] The control device controls the switching parts so as to direct the permanent magnet type motor to apply a force to the piston such that, in the second combustion cycle, the rotation speed of the crankshaft exceeds the pressure-reduction upper limit speed. The piston is therefore moved by energy caused by combustion in the first combustion cycle and energy supplied from the permanent magnet type motor. The permanent magnet type motor is controlled such that the rotation speed of the crankshaft in the second combustion cycle exceeds the pressure-reduction upper limit speed. Thus, the compression release mechanism does not operate in the compression stroke of the second combustion cycle. Reduction of the mixed gas contained in the cylinder is suppressed in the compression stroke. Reduction of the compression ratio of the mixed gas contained in the cylinder is also suppressed.

[0037] In a combustion stroke of the second combustion cycle, as compared with in the first combustion cycle, a larger amount of mixed gas is combusted, because the compression release mechanism does not operate. Accordingly, a stronger combustion force is obtained as compared with in the first combustion cycle. The rotation speed of the crankshaft increases by a greater increment as compared with in the first combustion cycle. The increase in the rotation speed makes it further less likely that the compression release mechanism operates in subsequent combustion cycles. The rotation speed of the crankshaft further increases.

[0038] The straddled vehicle of (1), in which the rotation speed increases by a large increment, provides a shortened time period until completion of engine start. Accordingly, a time period until completion of engine start after an engine start instruction can be shortened.

[0039] A combustion cycle of the single-cylinder engine of the present teaching is a time period starting at an intake stroke and ending at an exhaust stroke. One combustion cycle corresponds to two rotations of the crankshaft.

(2) The straddled vehicle of (1), in which
the control device controls the plurality of switching parts in such a manner that the permanent magnet type motor continues application of a force to the piston via the crankshaft until at least a compression stroke of the second combustion cycle.

In the configuration of (2), the permanent magnet type motor continues application of a force to the piston until the compression stroke of the second combustion cycle. This ensures that the permanent magnet type motor applies a force to the piston for a long period before the compression stroke of the second combustion cycle. Particularly in a single-cylinder engine, a low-load region is, when viewed based on the rotation angle of the crankshaft as a reference, wider than a high-load region in which a load on operations of the piston and the crankshaft increases along with air compression. This ensures that the permanent magnet type motor applies a force to the piston for a particularly long period. Therefore, for example, even when the permanent magnet type motor is downsized from the viewpoint of mountability to the straddled vehicle, movement of the piston is assisted to such an extent as to suppress an operation of the compression release mechanism in the compression stroke of the second combustion cycle. Early-start ability of the single-cylinder engine is enabled with improvement in mountability of the permanent magnet type motor.

(3) The straddled vehicle of (2), in which
the control device controls the plurality of switching parts to such an extent that the rotation speed of the crankshaft does not increase but decreases after a combustion stroke that follows the compression stroke of the first combustion cycle and until the compression stroke of the second combustion cycle.

[0040] If the rotation speed of the crankshaft increases to a sufficient level in the combustion stroke that follows the compression stroke of the first combustion cycle, it is possible to, even when the rotation speed of the crankshaft subsequently decreases, ensure that the rotation speed of the crankshaft be higher than the pressure-reduction upper limit speed for the compression release mechanism. Thus, the configuration of (3) allows the permanent magnet type motor to be downsized to such an extent that the rotation speed of the crankshaft decreases after the aforesaid combustion stroke. The configuration of (3) enables early-start ability of the single-cylinder engine with improvement in mountability of the permanent magnet type motor.

[0041] The straddled vehicle of the present teaching includes a drive wheel. Examples of the straddled vehicle of the present teaching include motorcycles, motor tricycles, and ATVs (All-Terrain Vehicles). The straddled vehicle of the present teaching includes, for example, a compression release mechanism for which the pressure-reduction upper limit speed is set as follows: upon completion of a first combustion, the rotation speed of the crankshaft exceeds the pressure-reduction upper limit speed, and if the permanent magnet type motor does not apply a force to the piston in a second combustion cycle, the rotation speed of the crankshaft can possibly decrease to or below the pressure-reduction upper limit speed.

[0042] The engine of the present teaching includes a cylinder, a piston, a crankshaft, and a connecting rod. Examples of the crankshaft of the present teaching include a crankshaft coupled to the piston with the connecting rod, and a crankshaft coupled to the piston with another member in addition to the connecting rod. The crankshaft is configured such that, for example, movement of the piston is converted into rotational motion which is then transmitted to the crankshaft.

[0043] The engine of the present teaching causes the piston to move by combusting a mixed gas including air and a fuel. The engine of the present teaching includes engines of direct injection type and engines of intake manifold injection type.

[0044] The compression release mechanism of the present teaching includes a device configured to reduce pressure in the cylinder by opening the exhaust valve in the compression stroke, a device configured to reduce pressure in the cylinder by opening the intake valve in the compression stroke, and the like. The compression release mechanism of the present teaching may be a device configured to reduce pressure in the cylinder by opening a pressure release valve in the compression stroke, the pressure release valve provided separately from the exhaust valve and the intake valve.

[0045] In the present teaching, whether or not the rotation speed of the crankshaft in n-th combustion cycle is equal to or less than the pressure-reduction upper limit speed for the compression release mechanism is determined based on, for example, whether or not the rotation speed obtained at a time of decision to operate the compression release mechanism in the n-th combustion is equal to or less than the pressure-reduction upper limit speed. Here, "n" is a positive integer. For example, in a case where decision to operate the compression release mechanism is made based on the rotation speed in the compression stroke; whether or not the rotation speed of the crankshaft is equal to or less than the pressure-reduction upper limit speed is determined based on whether or not the rotation speed in the compression stroke is equal to or less than the pressure-reduction upper limit speed. Alternatively, for example, whether or not the rotation speed of the crankshaft is equal to or less than the pressure-reduction upper limit speed may be determined based on the rotation speed in a stroke other than the compression stroke.

[0046] The permanent magnet type motor of the present teaching is a motor including a permanent magnet. The permanent magnet type motor of the present teaching includes a stator and a rotor. The rotor of the permanent magnet type motor of the present teaching includes a permanent magnet. The rotor of the permanent magnet type motor of the present teaching includes no winding. The stator of the permanent magnet type motor of the present teaching includes windings. The permanent magnet type motor of the present teaching includes windings corresponding to a plurality of phases. The permanent magnet type motor of the present teaching may include windings corresponding to two phases, four phases, or more, for example. The permanent magnet type motor of the present teaching, however, is able to easily perform a vector control and a phase control when provided with windings corresponding to three phases, for example. The windings of the stator are wound on a stator core. The rotor is rotated with the permanent magnet facing the stator core with an air gap therebetween. The permanent magnet type motor of the present teaching includes a motor of radial gap type and a motor of axial gap type. The motor of radial gap type, which is the permanent magnet type motor of the present teaching, includes a motor of outer rotor type and a motor of inner rotor type, the motor of outer rotor type provided with a rotor that rotates outside a stator, the motor of inner rotor type provided with a rotor that rotates inside a stator.

[0047] The permanent magnet type motor of the present teaching may generate power, for example. The permanent magnet type motor of the present teaching includes a permanent magnet type motor having a function as a generator and a permanent magnet type motor not having a function as a generator.

[0048] In the present teaching, the rotor of the permanent magnet type motor includes a rotor connected directly to the crankshaft, a rotor connected indirectly to the crankshaft with interposition of a transmission mechanism, and the like. Examples of the transmission mechanism include belts, chains, gears, speed reducers, speed increasers, and the like. The rotor of the present teaching is preferably connected to the crankshaft with its speed ratio fixed relative to the crankshaft.

[0049] The inverter of the present teaching includes the plurality of switching parts by which a current outputted from the battery to the permanent magnet type motor is controlled. The switching parts are transistors, for example. The switching parts include FETs (Field Effect Transistors), thyristors, and IGBTs (Insulated Gate Bipolar Transistors), for example. The inverter includes a bridge inverter composed of a plurality of switching parts, for example.

[0050] The control device of the present teaching includes a control device configured to control operations of the engine, for example. The control device of the present teaching, however, also includes a control device different from a device configured to control operations of the engine, for example.

[0051] The start instruction of the present teaching is an instruction to start the single-cylinder engine. The start instruction is inputted from a starter switch to the control device upon actuation of the starter switch, for example. In a case of the straddled vehicle having an idling stop function, the control device determines a predefined engine start condition, and executes a restart instruction by itself. Fulfillment of the predefined engine start condition is included in the input of the start instruction.

[0052] For example, the control device of the present teaching may perform swing-back by, after reception of a start instruction, driving the crankshaft once in reverse rotation and then in forward rotation. For example, the control device may perform such processing that forward rotation of the crankshaft in response to a start instruction is started from a position where forward rotation of the crankshaft has stopped in response to an engine stop instruction.

[0053] For example, the permanent magnet type motor of the present teaching may be configured to continue application of a force to the piston, which application has been started subsequent to a start instruction, even after a compression stroke of a first combustion cycle. For example, the permanent magnet type motor of the present teaching may be configured to stop application of a force after a compression stroke of a first combustion cycle, and restart the application before a compression stroke of a second combustion cycle.

[0054] How the control device of the present teaching controls the switching part so as to direct the permanent magnet type motor to rotate the crankshaft includes, for example, performing a direct control of a voltage phase corresponding to a rotor position, performing a vector control in which a current component divided into a component contributing to a torque and another component is controlled, or performing 120-degree conduction.

[EFFECTS OF THE INVENTION]

[0055] The present teaching is able to shorten a time period until completion of engine start after an engine start instruction.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[0056]

[FIG. 1] FIG. 1 shows an external appearance of a straddled vehicle according to an embodiment of the present teaching.
[FIG. 2] FIG. 2 is a partial cross-sectional view schematically showing an outline configuration of an engine unit shown in FIG. 1.
[FIG. 3] FIG. 3 is an illustrative diagram schematically showing the relationship between a crank angle position and a required torque of a single-cylinder engine.
[FIG. 4] FIG. 4 is a cross-sectional view of a permanent magnet type motor shown in FIG. 2, as sectioned perpendicular to its rotation axis line.
[FIG. 5] FIG. 5 is a block diagram outlining an electrical configuration of the straddled vehicle shown in FIG. 1.
[FIG. 6] FIG. 6 is a flowchart illustrating operations concerning start of the straddled vehicle.
[FIG. 7] FIG. 7(A) is a timing chart showing a state at a time of start of a single-cylinder engine according to this embodiment; and FIG. 7(B) is a timing chart showing a state at a time of start of a single-cylinder engine according to a comparative example.

[EMBODIMENTS FOR CARRYING OUT THE INVENTION]

[0057] Hereunder, the present teaching is described based on preferred embodiments with reference to the drawings.
[0058] FIG. 1 shows an external appearance of a straddled vehicle according to an embodiment of the present teaching.
[0059] A straddled vehicle 1 shown in FIG. 1 includes a vehicle body 2 and wheels 3a, 3b. The straddled vehicle 1 is, to be specific, a motorcycle.
[0060] The straddled vehicle 1 includes an engine unit EU. The engine unit EU includes a single-cylinder engine 10 (see FIG. 2).
[0061] The rear wheel 3b is a drive wheel. The wheel 3b receives a rotational force outputted from the single-cylinder engine 10, to drive the straddled vehicle 1.
[0062] The straddled vehicle 1 includes a main switch 5. The main switch 5 is a switch for supplying power to each part of the straddled vehicle 1. The straddled vehicle 1 includes a starter switch 6. The starter switch 6 is a switch for starting the single-cylinder engine 10. The straddled vehicle 1 includes an acceleration command part 8. The acceleration command part 8 is an operation element for instructing acceleration of the straddled vehicle 1 in accordance with an operation thereon. The acceleration command part 8 is, to be specific, an accelerator grip.
[0063] The straddled vehicle 1 includes a battery 4. The straddled vehicle 1 includes a control device 60 that controls each part of the straddled vehicle 1.
[0064] FIG. 2 is a partial cross-sectional view schematically showing an outline configuration of the engine unit EU shown in FIG. 1.
[0065] The engine unit EU includes the single-cylinder engine 10 and a permanent magnet type motor 20.
[0066] The single-cylinder engine 10 includes a crank case 11, a cylinder 12, a piston 13, a connecting rod 14, and a crankshaft 15. The piston 13 is arranged in the cylinder 12 such that the piston 13 is freely movable to and fro.
[0067] The crankshaft 15 is rotatably arranged in the crank case 11. The crankshaft 15 is coupled to the piston 13 with the connecting rod 14. A cylinder head 16 is attached to an upper portion of the cylinder 12. The cylinder 12, the cylinder head 16, and the piston 13 define a combustion chamber.
[0068] The cylinder head 16 is provided with an exhaust valve 18 and an intake valve (not shown). The exhaust valve 18 controls discharge of an exhaust gas from the cylinder 12. The intake valve controls supply of a mixed gas to a combustion chamber provided in the cylinder 12. The exhaust valve 18 and the intake valve are moved by operations of a cam (not shown) provided to a cam shaft Cs which is rotatable together with the crankshaft 15.
[0069] The crankshaft 15 is supported on the crank case 11 via a pair of bearings 17 in a freely rotatable manner. The permanent magnet type motor 20 is attached to one end portion 15a of the crankshaft 15. A transmission CVT is attached to the other end portion 15b of the crankshaft 15. The transmission CVT is configured to change the gear ratio which is the ratio of an output rotation speed to an input rotation speed. The transmission CVT is configured to change the gear ratio corresponding to the rotation speed of the wheel relative to the rotation speed of the crankshaft 15.
[0070] The engine unit EU includes a compression release mechanism D. FIG. 2 schematically illustrates the compression release mechanism D. The compression release mechanism D is operable to reduce pressure in the cylinder 12 in a compression stroke. In the compression stroke, the compression release mechanism D opens the exhaust valve 18, to discharge part of the mixed gas from the cylinder 12. The compression release mechanism D is configured to open the exhaust valve 18 in the compression stroke if the rotation speed of the crankshaft 15 is equal to or less than a pressure-reduction upper limit speed which is set for the compression

release mechanism D.

[0071] The compression release mechanism D opens the exhaust valve 18 by means of a mechanism provided to the cam shaft Cs which is rotatable together with the crankshaft 15. For example, the compression release mechanism D performs the operation of opening the exhaust valve 18 by using a centrifugal force generated by rotation of the cam shaft Cs.

[0072] As the compression release mechanism D reduces pressure of the mixed gas contained in the cylinder 12 in the compression stroke, a compression reaction force received by the piston 13 is reduced. A load put on operation of the piston 13 is lowered in a high-load region.

[0073] The engine unit EU is also provided with a throttle valve (not shown) and a fuel injector device J (see FIG. 5). The degree to which the throttle valve opens is based on the amount of operation on the acceleration command part 8 (see FIG. 1). The throttle valve adjusts the amount of air flowing therethrough in accordance with the degree of opening, thus adjusting the amount of air to be supplied into the cylinder 12. The fuel injector device J injects a fuel, so that the fuel is supplied to a combustion chamber provided in the cylinder 12. A mixed gas, which is a mixture of the air flowing through the throttle valve and the fuel injected from the fuel injector device J, is supplied to the combustion chamber provided in the cylinder 12.

[0074] The single-cylinder engine 10 is provided with a spark plug 19. The spark plug 19 ignites the mixed gas contained in the cylinder 12, so that the mixed gas is combusted.

[0075] The single-cylinder engine 10 is an internal combustion engine. The single-cylinder engine 10 is supplied with a fuel. The single-cylinder engine 10 outputs a rotational force by performing a combustion operation in which the mixed gas is combusted.

[0076] More specifically, the mixed gas containing the fuel supplied to the combustion chamber is combusted, to move the piston 13. The combustion of the mixed gas makes the piston 13 move to and fro. The crankshaft 15 is rotated along with the to-and-fro movement of the piston 13. The rotational force is outputted to the outside of the single-cylinder engine 10 via the crankshaft 15. The wheel 3b (see FIG. 1) receives the rotational force outputted from the single-cylinder engine 10 via the crankshaft 15, to drive the straddled vehicle 1.

[0077] The single-cylinder engine 10 outputs the rotational force via the crankshaft 15. The rotational force of the crankshaft 15 is transmitted to the wheel 3b via the transmission CVT and a clutch CL (see FIG. 1). The straddled vehicle 1 is driven by the wheel 3b receiving the rotational force from the single-cylinder engine 10 via the crankshaft 15.

[0078] FIG. 3 is an illustrative diagram schematically showing the relationship between a crank angle position and a required torque of the single-cylinder engine 10. FIG. 3 shows the torque required for rotating the crankshaft 15 under a state where the single-cylinder engine 10 does not perform the combustion operation.

[0079] The single-cylinder engine 10 is a four-stroke engine. The single-cylinder engine 10 has, during four strokes which correspond to one combustion cycle, a high-load region TH in which a high load is put on rotation of the crankshaft 15 and a low-load region TL in which a load put on rotation of the crankshaft 15 is lower than that of the high-load region TH. The high-load region means a region in one combustion cycle of the single-cylinder engine 10 where a load torque is higher than an average value Av of the load torque over the one combustion cycle. From the viewpoint of the rotation angle of the crankshaft 15, 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. During rotation, the single-cylinder engine 10 repeats a combustion stroke (expansion stroke), an exhaust stroke, an intake stroke, and a compression stroke. The compression stroke overlaps the high-load region TH.

[0080] One combustion cycle of the single-cylinder engine 10 includes one combustion stroke, one exhaust stroke, one intake stroke, and one compression stroke.

[0081] In the intake stroke, the mixed gas is supplied to the combustion chamber. In the compression stroke, the piston 13 compresses the mixed gas contained in the combustion chamber. In the expansion stroke, the mixed gas ignited by the spark plug 19 is combusted, and pushes the piston 13. In the exhaust stroke, an exhaust gas existing after the combustion is discharged from the combustion chamber.

[0082] FIG. 4 is a cross-sectional view of the permanent magnet type motor 20 shown in FIG. 2, as sectioned perpendicular to its rotation axis line.

[0083] The permanent magnet type motor 20 is described with reference to FIGS. 2 and 4.

[0084] The permanent magnet type motor 20 is a three-phase brushless motor of permanent magnet type. The permanent magnet type motor 20 functions also as a three-phase brushless generator of permanent magnet type.

[0085] The permanent magnet type motor 20 includes a rotor 30 and a stator 40. The permanent magnet type motor 20 of this embodiment is of radial gap type. The permanent magnet type motor 20 is of outer rotor type. That is, the rotor 30 is an outer rotor, and the stator 40 is an inner stator.

[0086] The rotor 30 includes a rotor body part 31. The rotor body part 31 is made of, for example, a ferromagnetic material. The rotor body part 31 is in the shape of a cylinder with a bottom. The rotor 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 bottom wall portion 33 and the back yoke portion 34 are integrally formed. Here, it may also be acceptable that the bottom wall portion 33 and the back yoke portion 34 are formed as separate parts. The bottom wall portion 33 and the back yoke portion 34 are secured to the crankshaft 15 via the cylindrical boss portion 32. A winding to which a current is supplied is not provided in the rotor 30.

[0087] The rotor 30 includes a permanent magnet part 37. The rotor 30 includes a plurality of magnetic pole portions 37a. The plurality of magnetic pole portions 37a are formed by the permanent magnet part 37. The plurality of magnetic pole portions 37a are provided on an inner circumferential surface of the back yoke portion 34. In this embodiment, the permanent magnet part 37 includes a plurality of permanent magnets. That is, the rotor 30 includes a plurality of permanent magnets. The plurality of magnetic pole portions 37a are provided in the plurality of permanent magnets, respectively.

[0088] The permanent magnet part 37 may alternatively be configured as a single annular permanent magnet. In such a configuration, the single permanent magnet is magnetized such that the plurality of magnetic pole portions 37a appear side by side on the inner circumferential surface.

[0089] The plurality of magnetic pole portions 37a are provided such that N pole and S pole appear alternately with respect to the circumferential direction of the permanent magnet type motor 20. In this embodiment, the number of magnetic poles of the rotor 30 opposed to the stator 40 is twenty-four. The number of magnetic poles of the rotor 30 means the number of magnetic poles opposed to the stator 40. No magnetic material is arranged between the magnetic pole portions 37a and the stator 40.

[0090] The magnetic pole portions 37a are provided outside the stator 40 with respect to the radial direction of the permanent magnet type motor 20. The back yoke portion 34 is provided outside the magnetic pole portions 37a with respect to the radial direction. The number of magnetic pole portions 37a included in the permanent magnet type motor 20 is more than the number of teeth 43.

[0091] The rotor 30 may be of interior permanent magnet type (IPM type) in which the magnetic pole portions 37a are embedded in a magnetic element, but it preferably is of surface permanent magnet type (SPM type) in which the magnetic pole portions 37a are exposed from a magnetic element as illustrated in this embodiment.

[0092] A cooling fan F is provided to the bottom wall portion 33 of the rotor 30.

[0093] The stator 40 includes a stator core ST and a plurality of stator windings W. The stator core ST includes a plurality of teeth 43 arranged at intervals with respect to the circumferential direction. The plurality of teeth 43 integrally extend from the stator core ST toward radially outside. 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. The teeth 43 are arranged at equal intervals with respect to the circumferential direction.

[0094] The number of magnetic pole portions 37a included in the rotor 30 is more than the number of teeth 43. The number of magnetic pole portions is equal to 4/3 of the number of slots.

[0095] The stator winding W is wound around each of the teeth 43. That is, the multi-phase stator windings W are arranged through the slots SL. In the state shown in FIG. 4, the stator windings W are in 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.

[0096] The rotor 30 includes, on its outer surface, a plurality of detection object parts 38 for detection of the rotation position of the 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 rotor 30. The detection object parts 38 are made of a ferromagnetic material.

[0097] The rotor position detection device 50 is a device that detects the position of the 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. The rotor position detection device 50 includes a pick-up coil and a magnet. The rotor position detection device 50 magnetically detects the detection object parts 38. The rotor position detection device for detecting the position of the rotor may be implemented as a Hall IC configured to detect the magnetic pole portions 37.

[0098] The rotor 30 of the permanent magnet type motor 20 is connected to the crankshaft 15 such that the rotor 30 is rotated along with rotation of the crankshaft 15. More specifically, the rotor 30 of the permanent magnet type motor 20 is connected to the crankshaft 15 such that the rotor 30 is rotated with its speed ratio fixed relative to the crankshaft 15. The rotor 30 is directly connected to the crankshaft 15 of the single-cylinder engine 10.

[0099] In this embodiment, the rotor 30 is attached to the crankshaft 15 without interposition of a power transmission mechanism (such as a belt, a chain, a gear, a speed reducer, or a speed increaser). The rotor 30 is rotated with a speed ratio of 1:1 relative to the crankshaft 15. The permanent magnet type motor 20 is configured such that the rotor 30 is driven in forward rotation at a time of combustion operation of the single-cylinder engine 10.

[0100] The rotation axis line of the permanent magnet type motor 20 is substantially coincident with the rotation axis line of the crankshaft 15.

[0101] At a time of engine start, the permanent magnet type motor 20 drives the crankshaft 15 in forward rotation to start the single-cylinder engine 10. At a time of combustion operation of the single-cylinder engine 10, the permanent magnet type motor 20 is driven by the single-cylinder engine 10 to generate power. That is, the permanent magnet type motor 20 has both the function for driving the crankshaft 15 in forward rotation to start the single-cylinder engine 10 and the function for being driven by the single-cylinder engine 10 to generate power at a time of combustion operation of the single-cylinder engine 10. During at least part of a time period following the start of the single-cylinder engine 10, the permanent magnet type motor 20 is driven in forward rotation by the crankshaft 15 to function as a generator.

[0102] FIG. 5 is a block diagram outlining an electrical configuration of the straddled vehicle 1 shown in FIG. 1.

[0103] The straddled vehicle 1 includes an inverter 61. The control device 60 controls components of the straddled vehicle 1 including the inverter 61.

[0104] The permanent magnet type motor 20 and the battery 4 are connected to the inverter 61. When the permanent magnet type motor 20 operates as a motor, the battery 4 supplies power to the permanent magnet type motor 20. The battery 4 is charged with power generated by the permanent magnet type motor 20.

[0105] The battery 4 is connected to the inverter 61 and a power consuming apparatus via the main switch 5. The power consuming apparatus 70 is an apparatus that consumes power when operating. The power consuming apparatus 70 includes a headlight 7 (see FIG. 1), for example.

[0106] The inverter 61 includes a plurality of switching parts 611 to 616. In this embodiment, the inverter 61 includes six switching parts 611 to 616.

[0107] The switching parts 611 to 616 constitute a three-phase bridge inverter. The plurality of switching parts 611 to 616 are connected to the respective phases of the multi-phase stator windings W. More specifically, among the plurality of switching parts 611 to 616, every two switching parts that are connected in series constitute a half bridge. The half bridge corresponding to each phase is connected in parallel with the battery 4. Ones of the switching parts 611 to 616 constituting the half bridge of each phase are connected to the corresponding phase of the multi-phase stator windings W.

[0108] The switching parts 611 to 616 control a current flowing between the battery 4 and the permanent magnet type motor 20. The switching parts 611 to 616 selectively allow or block the passing of a current between the battery 4 and the multi-phase stator windings W.

[0109] In more detail, when the permanent magnet type motor 20 functions as a motor, switching between causing and stopping conduction of the multi-phase stator windings W is implemented by on/off-operation of the switching parts 611 to 616.

[0110] When the permanent magnet type motor 20 functions as a generator, switching between allowing and blocking the passing of a current between each of the stator windings W and the battery 4 is implemented by on/off-operation 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 permanent magnet type motor 20 are performed. The switching parts 611 to 616 control a current outputted from the permanent magnet type motor 20 to the battery 4.

[0111] Each of the switching parts 611 to 616 has a switching element. The switching element is, for example, a transistor and in more detail, an FET (Field Effect Transistor).

[0112] The fuel injector device J, the spark plug 19, and the battery 4 are connected to the control device 60.

[0113] The rotor position detection device 50 is also connected to the control device 60. The control device 60 obtains the rotation speed of the crankshaft 15 based on a result of detection performed by the rotor position detection device 50.

[0114] The control device 60 obtains the amount of operation on the acceleration command part 8 and the rate of increase in the amount of operation based on, for example, a result of detection performed by a throttle position sensor (not shown).

[0115] The control device 60 includes a starter power-generator control unit 62 and a combustion control unit 63.

[0116] The starter power-generator control unit 62 controls on/off-operation of each of the switching parts 611 to 616, to control the operation of the permanent magnet type motor 20. The starter power-generator control unit 62 includes a start control unit 621 and a power generation control unit 622.

[0117] The combustion control unit 63 controls the spark plug 19 and the fuel injector device J, to control the combustion operation of the single-cylinder engine 10. The combustion control unit 63 controls the spark plug 19 and the fuel injector device J, to control a rotational force of the single-cylinder engine 10. The combustion control unit 63 controls the spark plug 19 and the fuel injector device J in accordance with the degree of opening of the throttle valve SV which is represented by an output signal of the throttle position sensor.

[0118] The control device 60 is composed of a computer including a central processing unit (not shown) and a storage device (not shown). The central processing unit executes arithmetic processing based on a control program. The storage device stores data relating to programs and arithmetic operations.

[0119] The combustion control unit 63 and the starter power-generator control unit 62 including the start control unit 621 and the power generation control unit 622 are implemented by a computer (not shown) and a control program executable by the computer. Thus, below-described operations performed respectively by the combustion control unit 63 and the starter power-generator control unit 62 including the start control unit 621 and the power generation control unit 622 can be considered as operations performed by the control device 60. The starter power-generator control unit 62 and the combustion control unit 63 may be, for example, either configured as separate devices placed at a distance from each other, or integrated as a single device.

[0120] The starter switch 6 is connected to the control device 60. The starter switch 6 is actuated by a rider at a time of starting the single-cylinder engine 10.

[0121] The main switch 5 supplies power to the control device 60 in accordance with operations performed thereon.

[0122] The starter power-generator control unit 62 and the combustion control unit 63 of the control device 60 control the single-cylinder engine 10 and the permanent magnet type motor 20. The starter power-generator control unit 62 controls the inverter 61.

[0123] FIG. 6 is a flowchart illustrating operations concerning engine start of the straddled vehicle 1.

[0124] Operations of the straddled vehicle 1 are described with reference to FIGS. 5 and 6. The operations of the straddled vehicle 1 are controlled by the control device 60.

[0125] Upon reception of a start instruction for starting the single-cylinder engine 10 (S11:Yes), the control device 60 starts the single-cylinder engine 10. More specifically, when the main switch 5 is in on-state and the starter switch 6 is in on-state, the control device 60 starts the single-cylinder engine 10. In starting the single-cylinder engine 10, the control device 60 operates the piston 13 (S12). To be exact, the start control unit 621 of the starter power-generator control unit 62 operates the piston 13 (S12). The start control unit 621 controls the switching parts 611 to 616 of the inverter 61 such that the permanent magnet type motor 20 rotates the crankshaft 15. The permanent magnet type motor 20 applies a force to the piston 13 via the crankshaft 15. As a result, the piston 13 is operated.

[0126] In operating the piston 13, the control device 60 performs on/off-operation of the plurality of switching parts 611 to 616 at predefined timings such that the permanent magnet type motor 20 is rotated with power of the battery 4.

[0127] The control device 60 rotates the permanent magnet type motor 20 such that, in a first combustion cycle following a start instruction, the rotation speed of the crankshaft 15 is equal to or less than the pressure-reduction upper limit speed for the compression release mechanism D. More specifically, the control device 60 rotates the permanent magnet type motor 20 such that the rotation speed of the crankshaft 15 in a compression stroke of the first combustion cycle be equal to or less than the pressure-reduction upper limit speed. The rotation speed of the crankshaft 15, in general, increases after start of the rotation. After start of the rotation, the permanent magnet type motor 20 rotates the crankshaft 15 such that the increased rotation speed is equal to or less than the pressure-reduction upper limit speed in the compression stroke.

[0128] The control device 60 rotates the permanent magnet type motor 20 such that, in a second combustion cycle, the rotation speed of the crankshaft 15 exceeds the pressure-reduction upper limit speed for the compression release mechanism D. Combustion that occurs subsequent to the compression stroke of the first combustion cycle results in application of a force to the piston 13, the force rotating the crankshaft 15 at a rotation speed higher than the pressure-reduction upper limit speed. The permanent magnet type motor 20 rotates the crankshaft 15 to such an extent that the rotation speed of the crankshaft 15 does not fall to or below the pressure-reduction upper limit speed. The control device 60 rotates the permanent magnet type motor 20 to such an extent that the rotation speed of the crankshaft 15 does not increase but decreases after the combustion stroke that follows the compression stroke of the first combustion cycle and until a compression stroke of the second combustion cycle.

[0129] The control device 60 drives the permanent magnet type motor 20 with power of the battery 4 by, for example, controlling the switching parts 611 to 616 based on a vector control scheme. For example, the control device 60 controls a command value that contributes to a torque of the permanent magnet type motor 20, to control the torque to be outputted from the permanent magnet type motor 20. Thus, the control device 60 controls a force to be applied from the permanent magnet type motor 20 to the piston 13 via the crankshaft 15.

[0130] The permanent magnet type motor 20 rotates the crankshaft 15 to such an extent that the rotation speed of the crankshaft 15 decreases but does not fall to or below the pressure-reduction upper limit speed after the combustion stroke that follows the compression stroke of the first combustion cycle and until the compression stroke of the second combustion cycle. During this operation, the permanent magnet type motor 20 does not increase the rotation speed of the crankshaft 15. This allows a small-size motor to be adopted as the permanent magnet type motor 20.

[0131] Then, the control device 60 performs initial combustion operation processing (S13). To be exact, the combustion control unit 63 performs the initial combustion operation processing.

[0132] In the initial combustion operation processing of step S13 mentioned above, the combustion control unit 63 supplies a fuel to the single-cylinder engine 10 when the crankshaft 15 is at a predefined fuel supply position within the combustion cycle. The combustion control unit 63 directs the fuel injector device to inject the fuel. The fuel supply position of this embodiment is, for example, a position before the intake stroke. The combustion control unit 63 directs the fuel injector device to inject the fuel before the intake stroke. The combustion control unit 63 counts the number of times the fuel is injected after the start instruction.

[0133] In the initial combustion operation processing of step S13 mentioned above, the combustion control unit 63 ignites a mixed gas contained in the cylinder 12 when the crankshaft 15 is at a predefined ignition position within the combustion cycle. The ignition position is a position near the top dead center. The combustion control unit 63 directs the spark plug 19 to ignite the mixed gas when the crankshaft 15 is at the ignition position.

[0134] Then, the control device 60 determines whether or not the number of times the fuel is injected is equal to or greater than a predefined initial injection frequency (S14). For example, the initial injection frequency is set to a value equal to or greater than "2". In one example, the initial injection frequency is set to "2". In another example, the initial injection frequency may be set to a value equal to or greater than "3".

[0135] If the number of times the fuel is injected is less than at least the initial injection frequency, the control device 60 directs the permanent magnet type motor 20 to continue the operation of the piston 13 (S12) and the initial combustion operation (S13). The permanent magnet type motor 20 continues the application of the force to the piston 13 via the crankshaft 15 until the compression stroke of the second combustion cycle.

[0136] If the number of times the fuel is injected is equal to or greater than the initial injection frequency (S14:Yes), the control device 60 determines whether or not the rotation speed of the crankshaft 15 is equal to or more than a predefined start completion speed (S 15).

[0137] For example, the start completion speed is set so as to ensure that the rotation speed in the compression stroke be higher than the pressure-reduction upper limit speed for the compression release mechanism D when the rotation speed of the crankshaft 15 decreases after the permanent magnet type motor 20 terminates the application of the force. The start completion speed is a speed lower than an engagement speed of the clutch CL.

[0138] Upon determination in step S 15 that the rotation speed of the crankshaft 15 is equal to or less than the start completion speed (S15:No), the control device 60 directs the permanent magnet type motor 20 to continue the operation of the piston 13 (S12) and the initial combustion operation (S13).

[0139] In the operation of the piston 13 performed by the permanent magnet type motor 20 (S12), the control device 60 controls the plurality of switching parts 611 to 616 included in the inverter 61 such that power is supplied from the battery 4 to the permanent magnet type motor 20. In this manner, the control device 60 directs the permanent magnet type motor 20 to move the piston 13 to and fro. The control device 60 causes power running of the permanent magnet type motor 20. After combustion occurs in the single-cylinder engine 10, the permanent magnet type motor 20 applies a force to the piston 13 via the crankshaft 15, thus cooperating with a combustion force of the single-cylinder engine 10 to move the piston 13 to and fro.

[0140] Upon determination in step S15 mentioned above that a maximum rotation speed of the crankshaft 15 exceeds the start completion speed (S15:Yes), the control device 60 directs the permanent magnet type motor 20 to stop operating the piston 13 (S16).

[0141] Depending on results of determination made in steps S14 and S15 mentioned above, the control device 60 directs the permanent magnet type motor 20 to continue the operation of the piston 13 (S12) and the initial combustion operation (S 13), thus applying a force to the piston 13 via the crankshaft 15 such that, in the second combustion cycle, the rotation speed of the crankshaft 15 exceeds the pressure-reduction upper limit speed. More specifically, the control device 60 directs the permanent magnet type motor 20 to continue the operation of the piston 13 (S12) until expectation is obtained that the rotation speed of the crankshaft 15 in the compression stroke of the second combustion cycle will exceed the pressure-reduction upper limit speed.

[0142] Upon determination in step S 15 mentioned above that the rotation speed of the crankshaft 15 exceeds the start completion speed (S15:Yes), the control device 60 directs the permanent magnet type motor 20 to stop operating the piston 13 (S16). Also, the control device 60 starts a power generation control (S17). To be exact, the power generation control unit 622 of the starter power-generator control unit 62 performs the power generation control. In the power generation control, the control device 60 controls the switching parts 611 to 616 such that the permanent magnet type motor 20 acts as a generator. As the permanent magnet type motor 20 generates power, the battery 4 is charged.

[0143] Then, the control device 60 starts a normal combustion operation (S18). In the normal combustion operation, the control device 60 controls the amount of fuel supply based on the amount of air supplied into the cylinder 12. The control device 60 also controls the amount of fuel supply based on the amount of operation on the acceleration command part 8.

[0144] FIGS. 7(A) and 7(B) are timing charts showing states at a time of start of the single-cylinder engine 10. FIG. 7(A) schematically shows a state of the single-cylinder engine 10 according to this embodiment. FIG. 7(B) shows a state according to a comparative example.

[0145] In the charts of FIG. 7, the rotation speeds V1, V2 of the crankshaft are shown. In the charts of FIG. 7, the degrees E1, E2 of opening of the exhaust valve, and time periods P1, P2 during which the piston 13 is operated by the permanent magnet type motor 20 are shown, too. Open of the exhaust valve occurs mainly in an exhaust stroke. In a case of the compression release mechanism D operating, the exhaust valve is opened in a compression stroke.

[0146] As shown in FIG. 7(A), upon reception of a start instruction at time t11, the permanent magnet type motor 20 moves the piston 13 by applying a force to the piston 13 via the crankshaft 15. The rotation speed V1 of the crankshaft 15 rises from "0". The permanent magnet type motor 20 rotates the crankshaft 15 such that the rotation speed V1 of the crankshaft 15 is equal to or less than the pressure-reduction upper limit speed Ld in a first combustion cycle after the reception of the start instruction. More specifcally, the permanent magnet type motor 20 rotates the crankshaft 15 such that, in a compression stroke of the first combustion cycle, the rotation speed V1 of the crankshaft 15 is equal to or less than the pressure-reduction upper limit speed Ld.

[0147] In this embodiment, the crankshaft 15 starts rotation at a position at least before an intake stroke. Thus, a fuel injection is performed before the intake stroke.

[0148] As a result, at time t12, the compression release mechanism D operates. At time t12, the degree E1 of opening of the exhaust valve rises from 0, which indicates that the exhaust valve is opened. Since the exhaust valve is opened in the compression stroke, the mixed gas contained in the cylinder 12 is partially discharged. This enables the piston 13 to compress the mixed gas contained in the cylinder 12, so that the compression top dead center can be overcome.

[0149] In a combustion stroke that follows the compression stroke, the mixed gas contained in the cylinder 12 is combusted. Since the piston 13 receives a combustion force, the rotation speed V1 of the crankshaft 15 rises.

[0150] The permanent magnet type motor 20 continues the application of the force to the piston 13 via the crankshaft 15. After the combustion subsequent to the compression stroke of the first combustion cycle, the crankshaft 15 and the piston 13 are driven by energy of the combustion as well as the force applied from the permanent magnet type motor 20. Here, the combustion subsequent to the compression stroke of the first combustion cycle means combustion occurring in a combustion stroke of a second combustion cycle.

[0151] The permanent magnet type motor 20 applies a force to the piston 13 via the crankshaft 15 such that, in the second combustion cycle, the rotation speed of the crankshaft 15 exceeds the pressure-reduction upper limit speed Ld for the compression release mechanism D. The permanent magnet type motor 20 applies a force to the piston 13 via the crankshaft 15. This ensures that, in a compression stroke of the second combustion cycle, the rotation speed of the crankshaft 15 exceeds the pressure-reduction upper limit speed Ld for the compression release mechanism D. As a result, at time t14 which is in the compression stroke of the second combustion cycle, compression of the mixed gas is assisted by the permanent magnet type motor 20.

[0152] After the combustion stroke of the second combustion cycle, the permanent magnet type motor 20 applies a force to the piston 13 to such an extent that the rotation speed of the crankshaft 15 does not increase but decreases until the compression stroke of the second combustion cycle. Accordingly, the rotation speed of the crankshaft 15 does not increase but decreases in a period from the combustion stroke of the second combustion cycle to the compression stroke of the second combustion cycle.

[0153] At time t14 which is in the compression stroke of the second combustion cycle, the compression release mechanism D does not operate, because the rotation speed of the crankshaft 15 exceeds the pressure-reduction upper limit speed Ld. At time t14, therefore, the exhaust valve is not opened.

[0154] At time t15 which is in a combustion stroke of a third combustion cycle, combustion occurs so that the rotation speed of the crankshaft 15 further rises.

[0155] In the comparative example shown in FIG. 7(B), the permanent magnet type motor 20 stops application of a force to the piston 13 in a combustion stroke of a first combustion cycle. A combustion force makes the rotation speed of the crankshaft 15 exceed the pressure-reduction upper limit speed Ld for the compression release mechanism D at time t23. The rotation speed of the crankshaft 15, however, decreases and falls below the pressure-reduction upper limit speed Ld. In a second combustion cycle, therefore, the compression release mechanism D re-operates. As indicated by the degree E2 of opening of the exhaust valve, the exhaust valve is opened at time t24 which is in a compression stroke of the second combustion cycle.

[0156] At time t25 which is in a combustion stroke of the second combustion cycle, combustion occurs so that the rotation speed of the crankshaft 15 further rises. In the immediately preceding compression stroke, however, the mixed gas contained in the cylinder 12 is reduced. The compression ratio of the mixed gas is also reduced.

[0157] This is why just small power is caused in the combustion stroke which follows the compression stroke. Thus, the rotation speed of the crankshaft 15 after the combustion stroke of the second combustion cycle is lower than that shown in FIG. 7(A).

[0158] A low rotation speed of the crankshaft 15 in the second combustion cycle results in the rotation speed of the crankshaft 15 falling below the pressure-reduction upper limit speed Ld again in a third combustion cycle, though not shown in FIG. 7(B). The compression release mechanism may sometimes re-operate in a compression stroke of the third combustion cycle.

[0159] In the comparative example shown in FIG. 7(B), as described above, a time period until completion of engine start is prolonged in accordance with the number of combustion cycles in which the compression release mechanism D operates.

[0160] In the example of this embodiment shown in FIG. 7(A), on the other hand, the rotation speed of the crankshaft 15 in the second combustion cycle exceeds the pressure-reduction upper limit speed. Therefore, pressure of the mixed gas contained in the cylinder is not reduced, which is otherwise caused by the operation of the compression release mechanism D. A stronger combustion force is obtained as compared with in the first combustion cycle. The rotation speed of the crankshaft, which is rotated along with the piston to which the stronger force is applied, further increases. This results in shortening a time period until completion of engine start.

[0161] It should be understood that the terms and expressions used in the above embodiments are for descriptions and not to be construed in a limited manner, do not eliminate any equivalents of features shown and mentioned herein, and allow various modifications falling within the claimed scope of the present teaching. The present teaching may be embodied in many different forms. The present disclosure is to be considered as providing embodiments of the principles of the teaching. The embodiments are described herein with the understanding that such embodiments are not intended to limit the teaching to preferred embodiments described herein and/or illustrated herein. The embodiments described herein are not limiting. The present teaching includes any and all embodiments having equivalent elements, modifications, omissions, combinations, adaptations and/or alterations as would be appreciated by those in the art based on the present disclosure.

[0162] The limitations in the claims are to be interpreted broadly based on the language employed in the claims and not limited to embodiments described in the present specification or during the prosecution of the present application. The present teaching is to be interpreted broadly based on the language employed in the claims.

[DESCRIPTION OF THE REFERENCE SIGNS]

[0163]

1	straddled vehicle
3b	wheel (drive wheel)
4	battery
8	acceleration command part
10	single-cylinder engine
12	cylinder
13	piston
15	crankshaft
20	permanent magnet type motor
30	rotor
40	stator
60	control device
61	inverter
611 to 616	switching part

Claims

1. A straddled vehicle (1) comprising:

   a single-cylinder engine (10) including a piston (13) and a crankshaft (15), the piston (13) provided in a cylinder (12) and moved to-and-fro by combustion of a mixed gas, the crankshaft (15) confgured to be rotated along with to-and-fro movement of the piston (13);
   a compression release mechanism (D) operable to reduce pressure in the cylinder (12) in a compression stroke of the single-cylinder engine (10), in a case where the rotation speed of the crankshaft (15) is equal to or less than a pressure-reduction upper limit speed (Ld);
   a drive wheel (3b) configured to receive a rotational force outputted from the single-cylinder engine (10) via the crankshaft (15) and drive the straddled vehicle (1);
   a permanent magnet type motor (20) including a rotor (30) and a permanent magnet (37), the rotor (30) connected directly or indirectly to the crankshaft (15) so as to be rotatable in response to rotation of the crankshaft (15), the permanent magnet (37) provided to the rotor (30);
   a battery (4);
   an inverter (61) including a plurality of switching parts (611-616) by which a current flowing between the battery (4) and the permanent magnet type motor (20) is controlled; and
   a control device (60) configured to control the plurality of switching parts (611-616) in such a manner that, upon reception of a start instruction for starting the single-cylinder engine (10), the permanent magnet type motor (20) applies a force to the piston (13) via the crankshaft (15) such that the rotation speed of the crankshaft (15) in a first combustion cycle coming after the start instruction is equal to or less than the pressure-reduction upper limit speed (Ld) for the compression release mechanism (D), so that the piston (13) is moved to operate the compression release mechanism (D) in a compression stroke of the first combustion cycle, and then the permanent magnet type motor (20) applies a force to the piston (13) via the crankshaft (15) such that the rotation speed of the crankshaft (15) in a second combustion cycle exceeds the pressure-reduction upper limit speed (Ld) for the compression release mechanism (D), so that the piston (13) is moved without operating the compression release mechanism (D), thus assisting compression of the mixed gas in a compression stroke of the second combustion cycle.

2. The straddled vehicle (1) according to claim 1, wherein
   the control device (60) controls the plurality of switching parts (611-616) in such a manner that the permanent magnet type motor (20) continues application of a force to the piston (13) via the crankshaft (15) until at least a compression stroke of the second combustion cycle.

3. The straddled vehicle (1) according to claim 2, wherein
   the control device (60) controls the plurality of switching parts (611-616) to such an extent that the rotation speed of the crankshaft (15) does not increase but decreases after a combustion stroke that follows the compression stroke of the first combustion cycle and until the compression stroke of the second combustion cycle.

FIG.1

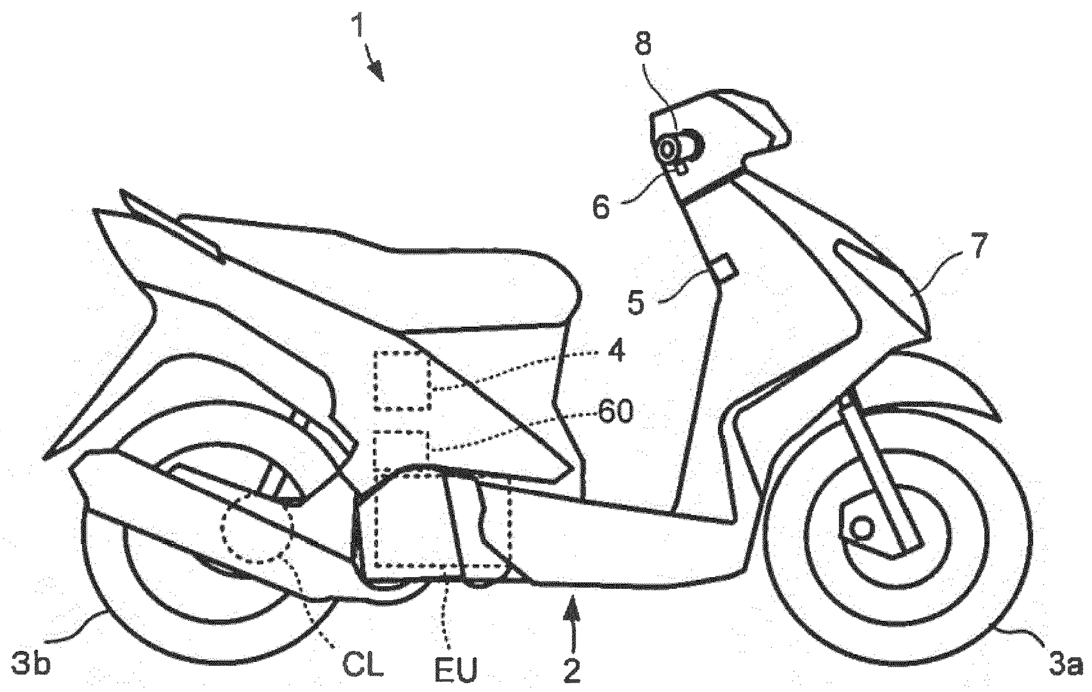
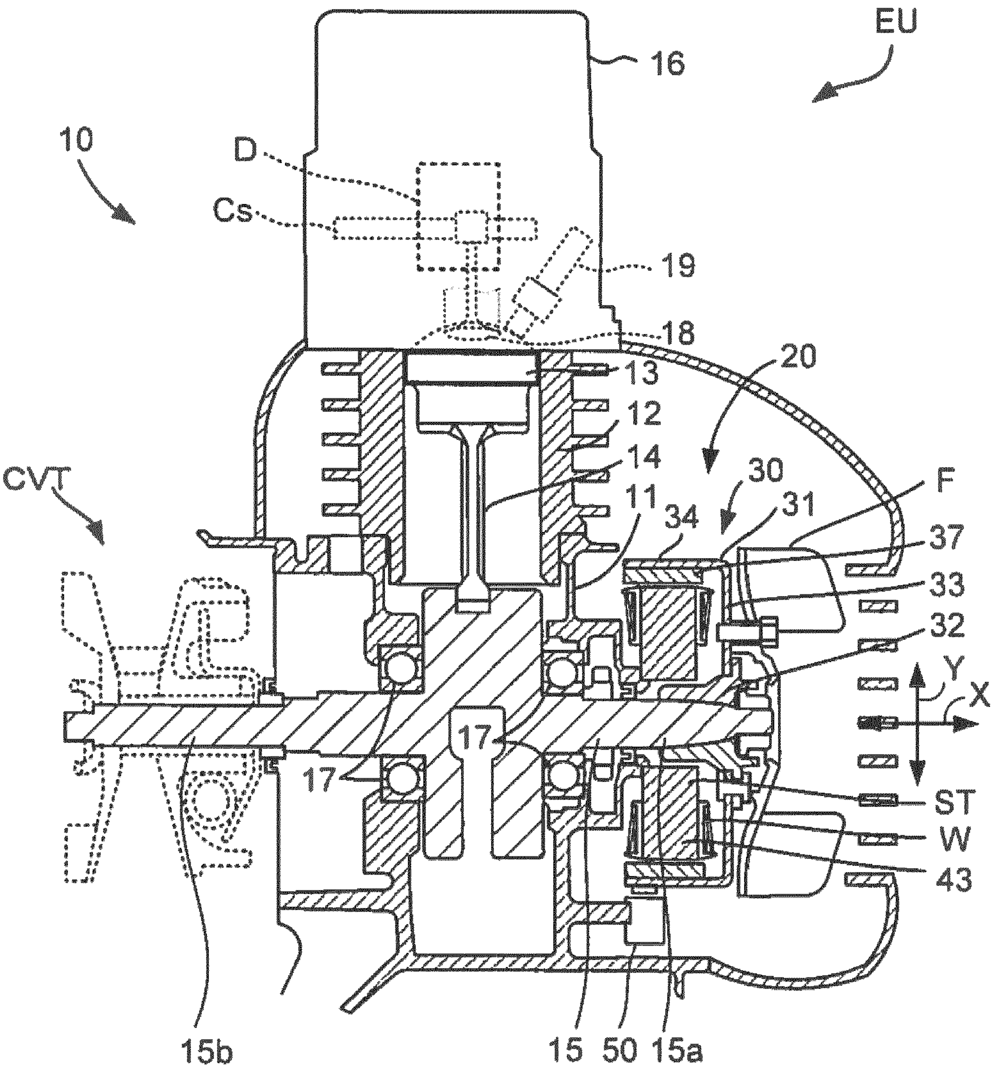


FIG.2



EU
16
10
D
Cs
19
18
20
13
12
14
CVT
30
11
34
31
F
37
33
32
Y
X
17
17
ST
W
43
15b
15
50
15a

FIG.3

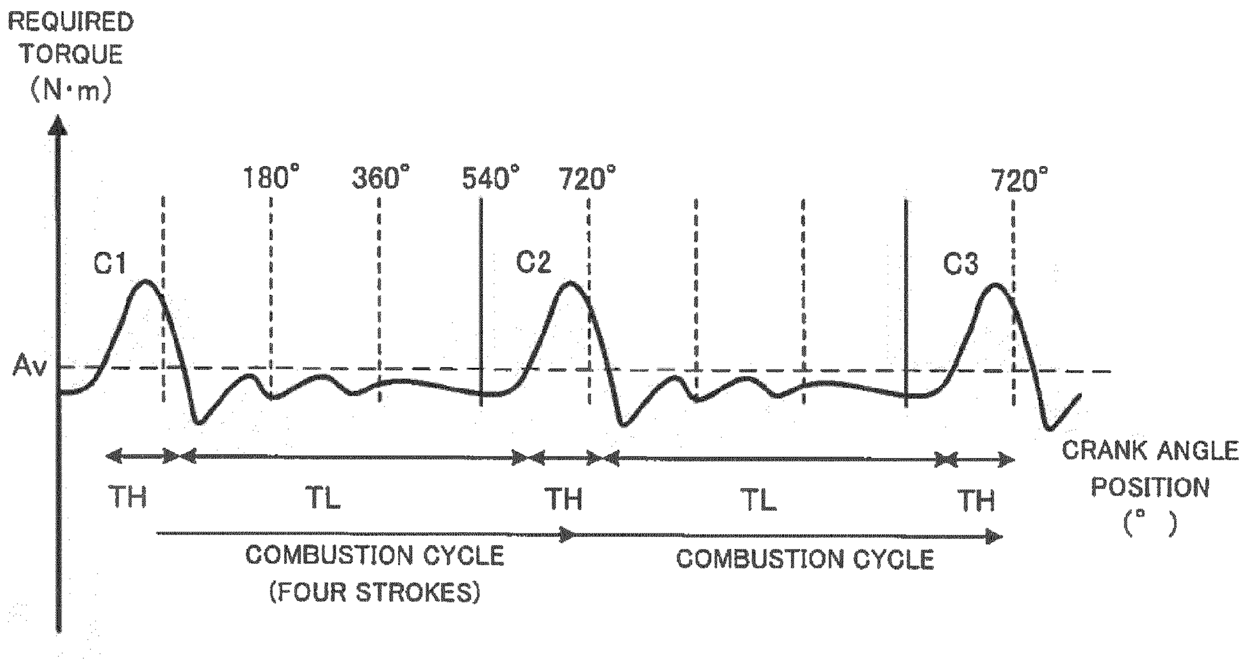

REQUIRED
TORQUE
(N·m)
180°
360°
540°
720°
720°
C1
C2
C3
Av
TH
TL
TH
TL
TH
CRANK ANGLE
POSITION
(°)
COMBUSTION CYCLE
(FOUR STROKES)
COMBUSTION CYCLE

FIG.4

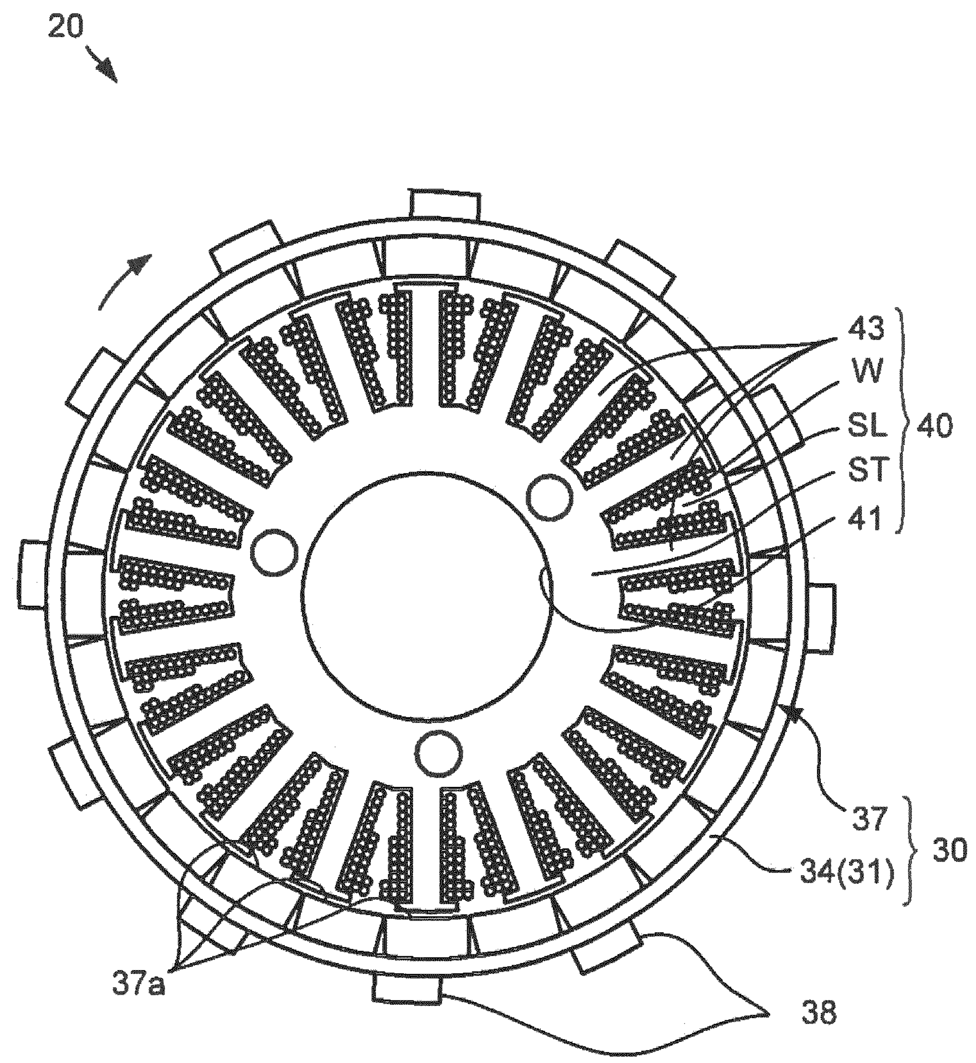


FIG.5

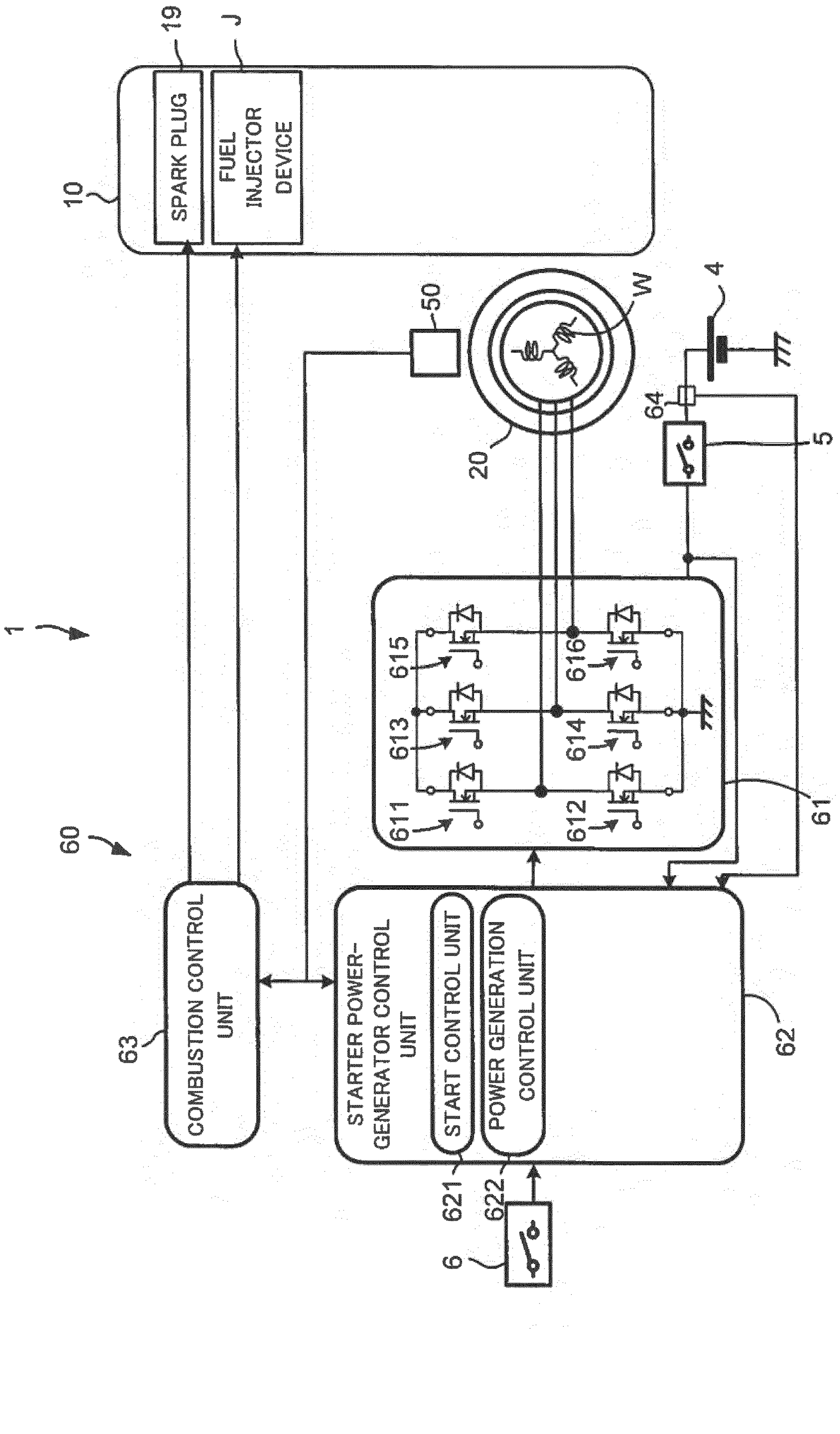

1
10
19
J
SPARK PLUG
FUEL INJECTOR DEVICE
50
W
20
4
64
5
60
611
612
613
614
615
616
61
63
COMBUSTION CONTROL UNIT
STARTER POWER-GENERATOR CONTROL UNIT
START CONTROL UNIT
POWER GENERATION CONTROL UNIT
62
621
622
6

FIG.6

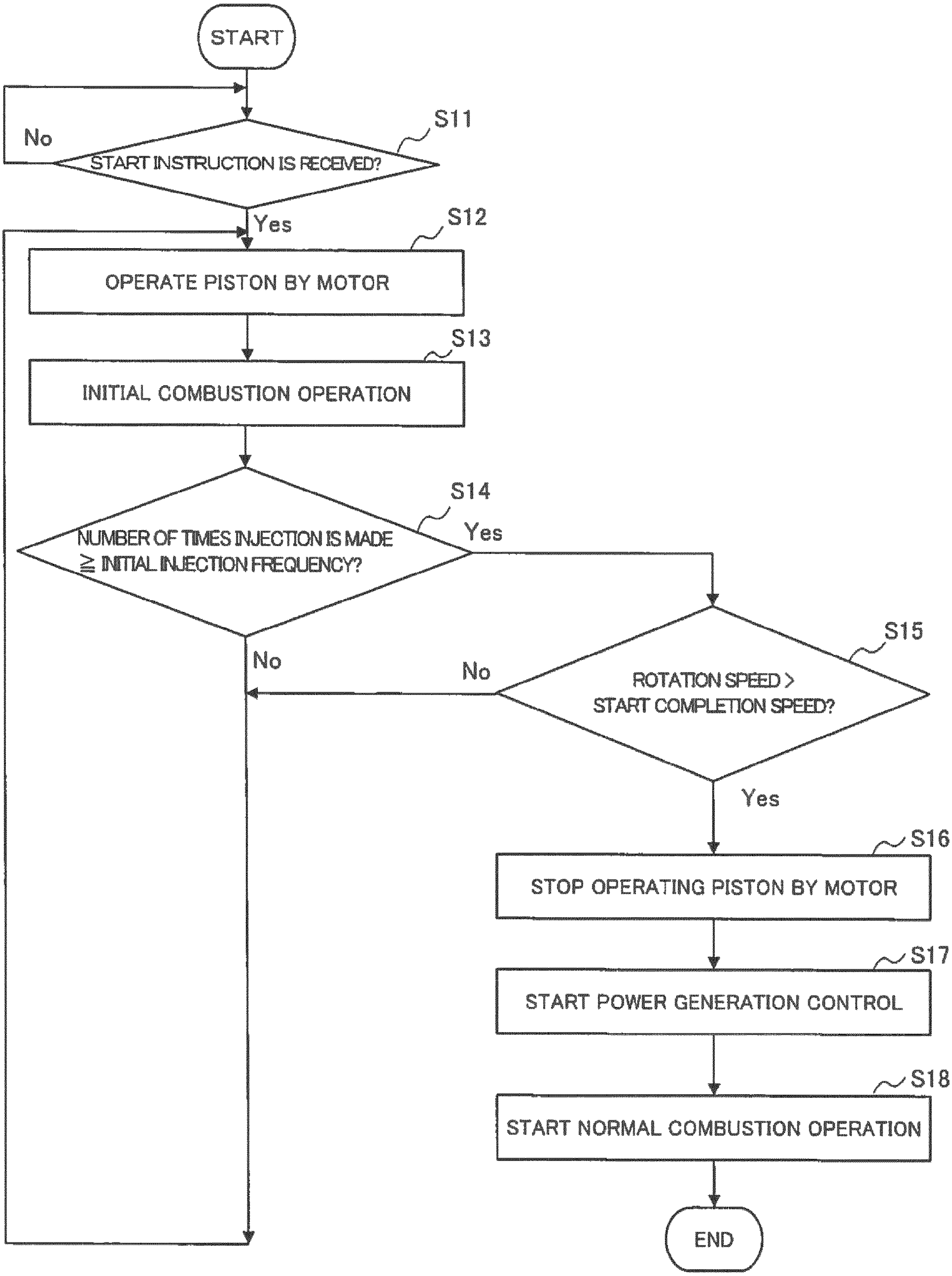

START
S11
No
START INSTRUCTION IS RECEIVED?
Yes
S12
OPERATE PISTON BY MOTOR
S13
INITIAL COMBUSTION OPERATION
S14
Yes
NUMBER OF TIMES INJECTION IS MADE
≧ INITIAL INJECTION FREQUENCY?
No
S15
No
ROTATION SPEED >
START COMPLETION SPEED?
Yes
S16
STOP OPERATING PISTON BY MOTOR
S17
START POWER GENERATION CONTROL
S18
START NORMAL COMBUSTION OPERATION
END

FIG.7A

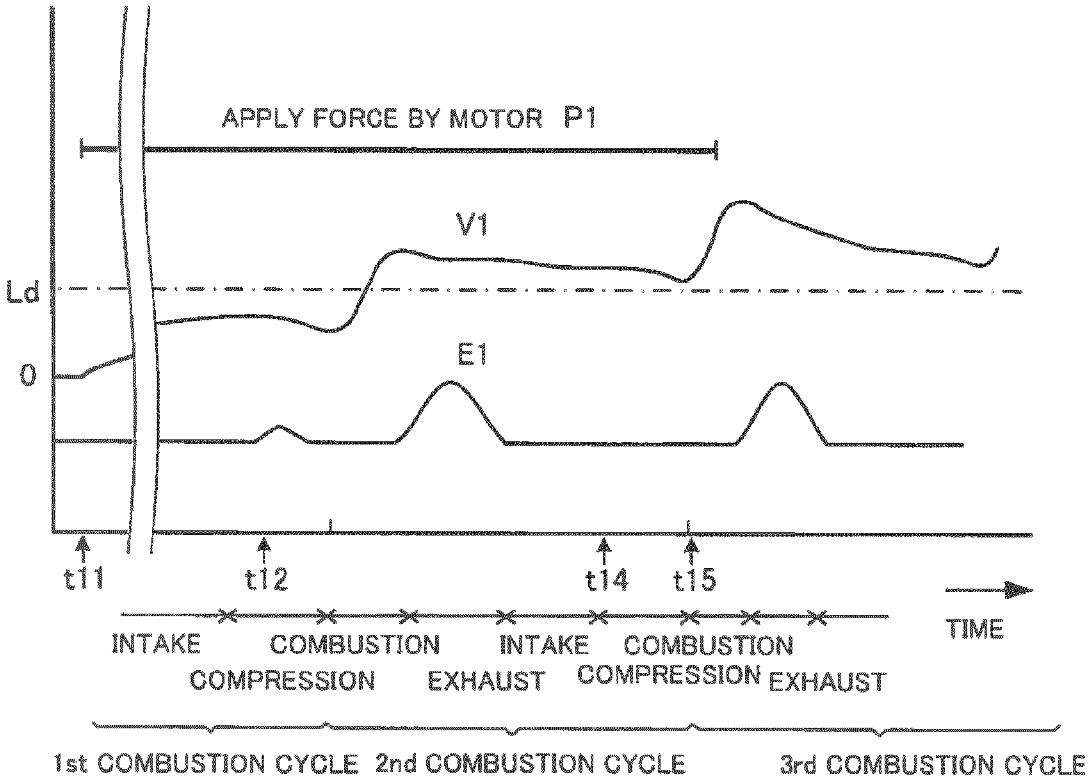
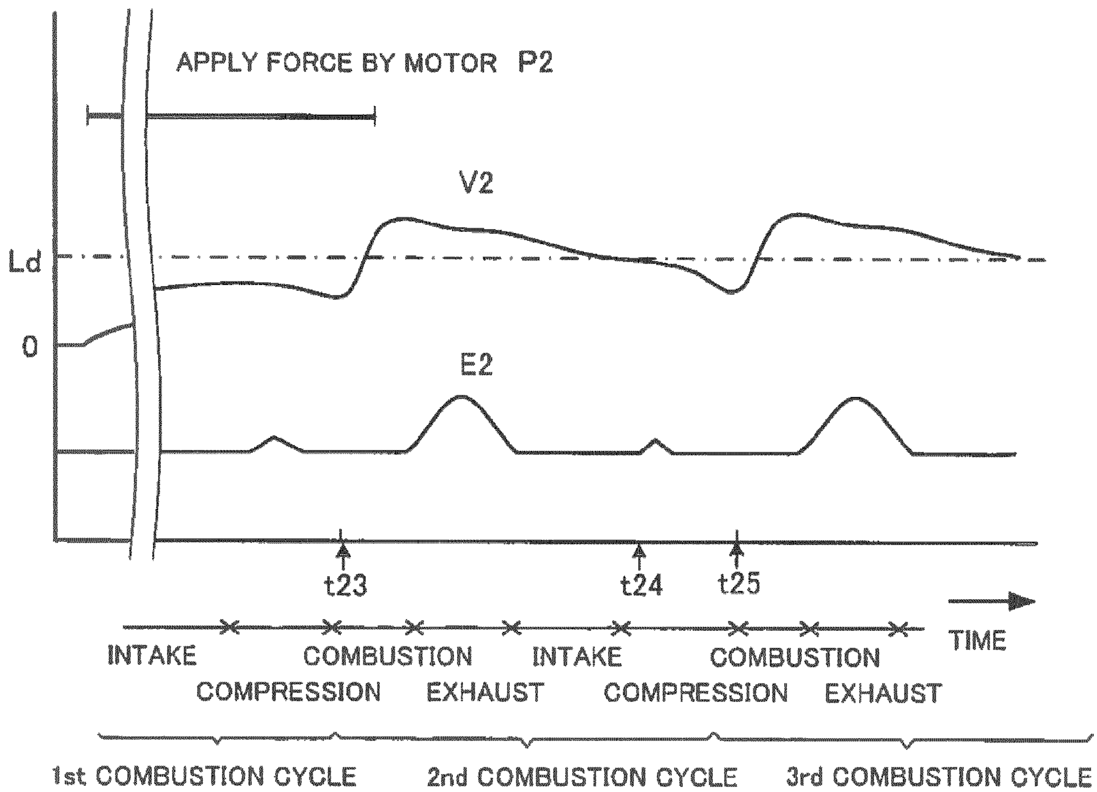

APPLY FORCE BY MOTOR P1
V1
Ld
0
E1
t11
t12
t14
t15
TIME
INTAKE
COMPRESSION
COMBUSTION
EXHAUST
INTAKE
COMPRESSION
COMBUSTION
EXHAUST
1st COMBUSTION CYCLE
2nd COMBUSTION CYCLE
3rd COMBUSTION CYCLE

FIG.7B


APPLY FORCE BY MOTOR P2
V2
Ld
0
E2
t23
t24
t25
TIME
INTAKE
COMPRESSION
COMBUSTION
EXHAUST
INTAKE
COMPRESSION
COMBUSTION
EXHAUST
1st COMBUSTION CYCLE
2nd COMBUSTION CYCLE
3rd COMBUSTION CYCLE

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 5874315 B **[0007]**