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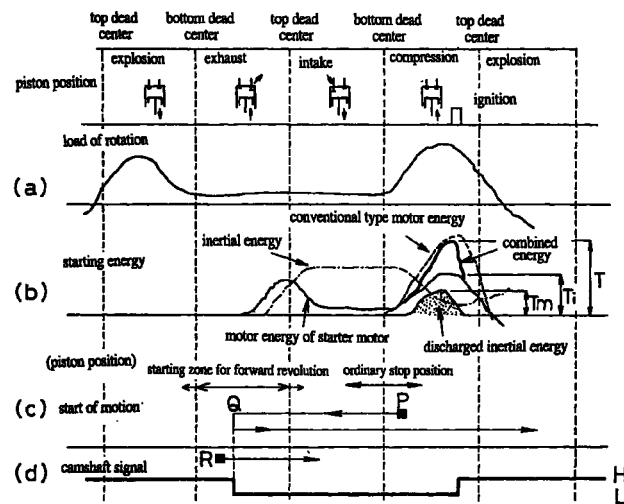
(54) **STARTING DEVICE FOR INTERNAL COMBUSTION ENGINES AND STARTING CONTROL DEVICE**

(57) When the internal combustion engine is made to start moving, the starter motor is made to turn backward along with the crankshaft to bring the piston temporarily back into the exhaust stroke. Thereafter, the starter motor is made to turn forward and the engine is made to start moving with the piston located in the exhaust stroke. After the starter motor is turned backward for time t_1 of energization for backward revolution, the crankshaft is made to turn by inertia for time t_2 of suspension of energization in order to place the piston in the exhaust stroke. The times t_1 and t_2 may be selected from a map of duration of energization for backward revolution and a map of duration of suspension of energization respectively or, alternatively, controlled on a feedback basis by determining the rotational speed and the rate of change of the rotational speed and/or the rotational angle of the starter motor from the pulse signal indicating the commutation position. With this arrangement, inertial energy for forward revolution is accumulated in the rotary system of the crankshaft during the exhaust stroke and the intake stroke so that the compression stroke of the piston can be got through by the effect of combining the inertial energy and the rotational energy of the starter motor. Then, the starter

motor can be down-sized to reduce its cost. Alternatively, the crankshaft may be turned backward to the explosion stroke to compress the gas in the combustion chamber so that energy for forward revolution is accumulated as a result of the reaction force of the compression. Additionally, when turning forward, the performance of the motor may be selectively utilized, that is, the starter motor may be made to start operating by intensifying the field by means of control magnetic poles and, when the number of revolutions of the motor gets to a predetermined level, the field may be weakened to increase the maximum number of revolutions of the motor.

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Fig. 4



Description

Technical Field

[0001] This invention relates to a starter of internal combustion engine that can be used for a motor bicycle or an automobile and also to a start control device of internal combustion engine to be used for controlling such a starter.

Background Art

[0002] For causing an internal combustion engine to start operating, the crankshaft of the engine has to be driven to rotate by applying external force until it gets to and maintains a certain number of revolutions per unit time required to suck, compress and explode fuel. Therefore, internal combustion engines are normally provided with a battery-powered starter for making the engine to start moving.

[0003] Known starters includes those of the type adapted to transmit the rotary motion of the starter motor to the crankshaft by way of a reduction mechanism and those of the type with which the crankshaft is directly linked to the starter motor. Starters of the type adapted to drive the crankshaft to rotate by way a reduction mechanism involve the use of a ring gear arranged on the outer periphery of the flywheel of the engine and engaged with a pinion, which is designed to move back and forth along the motor shaft so that the rotary power of the motor is transmitted to the crankshaft to start the engine as the speed of revolution of the motor is reduced as a result of the engagement of the pinion and the ring gear. After the end of the operation of starting the engine, the pinion is disengaged from the ring gear to restore the original position.

[0004] Normally, when the engine is made to stop, the crankshaft keeps on revolving for some time due to the force of inertia and then stops temporarily as the load of compression of the engine in the compression stroke exerts an braking effect on the crankshaft, but often it turns back slightly thereafter until the engine stops at or near the bottom dead center of the compression stroke. Accordingly, when starting the engine the crankshaft often starts from the position near the bottom dead center of the compression stroke.

[0005] However, when driving the crankshaft to start a cranking motion from this position, the speed of revolution of the crankshaft would not increase quickly because the load of compression is applied to the crankshaft immediately after the start of the cranking motion so that the electric current flowing to the starter motor at the position where the reaction is maximized in the compression stroke is as almost large as the one that flows when the starter motor is locked. Then, the torque generated at this time is as large as the lock torque that is large enough for riding over the top dead center. Therefore, the starter motor is required to gener-

ate a lock torque greater than the torque for riding over the top dead center.

[0006] Particularly, a starter motor of the type directly linked to the crankshaft of the engine without a reduction mechanism is inevitably large and costly because the large lock torque is required to generate. If a magnet is used for the magnetic field system, the rotational resistance of the internal combustion engine is enormous to consequently reduce the output power of the engine with a high rate of fuel consumption due to the core loss produced as a result of generating the required strong magnetic field.

[0007] An object of the present invention is to provide a small starter motor to be used for starting an internal combustion engine.

[0008] Another object of the invention is to start an internal combustion engine by means of a starter motor that shows a low rate of power consumption.

[0009] Still another object of the invention is to reduce the cost of the start control device of internal combustion engine for controlling the starter motor.

[0010] The above-described and other objects and novel feature of the present invention will become apparent more fully from the description of the following specification in conjunction with the accompanying drawings.

Disclosure of Invention

[0011] A starter of internal combustion engine according to the invention comprises a starter motor linked to a crankshaft of the internal combustion engine having the exhaust stroke as starting position and having an output torque smaller than the maximum load of rotation of the internal combustion engine, and a control means for getting through the compression stroke with the combined effect of the inertial energy of revolution of said crankshaft and the rotational energy of said starter motor, as a result, the compression stroke where the load of revolution increases can be got through by means of the combined effect of the inertial energy of the engine and the rotational energy of the starter motor. Additionally, the number of revolutions per unit time of the crankshaft rises to store the inertial energy of forward revolution in the rotary system of the crankshaft while the internal combustion engine passes through the exhaust stroke and the intake stroke. Thus, the rotational energy required for the starter motor to get through the first compression stroke is reduced to make it possible to down-size and reduce the cost of the starter motor.

[0012] As the starter motor is driven to revolve reversely by the control means to get back to the exhaust stroke, the internal combustion engine can always be started under a condition where the piston is found in the exhaust stroke if it is stopped somewhere outside the exhaust stroke.

[0013] Furthermore, a starter of internal combus-

tion engine according to the invention comprises a starter motor linked to a crankshaft of the internal combustion engine, and a control means adapted to place the piston of said internal combustion engine in the exhaust stroke by making said starter motor turn back-
ward during a predetermined time of energization and subsequently making said crankshaft turn by inertia during a predetermined time of suspension of energiza-
tion and thereafter make said starter motor turn forward so as to cause said internal combustion engine to start moving.

[0014] Then, as a result, it is possible to start moving the internal combustion engine with the piston of the engine found in the exhaust stroke without using any sensor for detecting the position of the piston such as a crankshaft sensor, therefore, it is possible to provide an inexpensive starter system of internal combustion engine omitting the sensors.

[0015] Additionally, the starter motor further comprises a memory means storing a map of duration of energization for backward revolution defined by using at least either the temperature or the supply voltage as parameter and a map of duration of suspension of energization defined by using the temperature as parameter, as a result, a starter system can compensate any changes in the temperature and the voltage in terms of duration of power supply for backward revolution and that of suspension of power supply so that it is possible to return the piston to the exhaust stroke regardless of changes in the environment.

[0016] Still additionally, said control means may include a means for computing the time of energization of the motor for backward revolution adapted to determine the time of energization of the motor for backward revolution from the temperature and the supply voltage and a means for computing the time of suspension of energization of the motor adapted to determine the time of suspension of energization from the temperature.

[0017] On the other hand, a start control device of an internal combustion engine according to the invention comprises a motor rotational speed computing means for computationally determining the rotational speed of the starter motor linked to the crankshaft of the internal combustion engine on the basis of the rotary pulse signal output as a result of the revolution of said starter motor, a motor rotational angle computing means for computationally determining the rotational angle of said starter motor also on the basis of the said rotary pulse signal, a means for directing energization of said starter motor for backward revolution for a predetermined period of time, an extent of backward turn correcting means for correcting the time of energization for backward revolution on the basis of the rotational speed of said starter motor, a means for directing suspension of energization of the motor adapted to suspend the energization of said starter motor for a predetermined period of time after driving said crankshaft to turn backward, cause said crankshaft to turn by inertia and place

the piston of said internal combustion engine in the exhaust stroke, an extent of inertial turn correcting means for correcting the extent of revolution by inertia of said crankshaft on the basis of the rotational speed and the rotational angle of said starter motor and a means for directing a start of forward revolution of the motor adapted to make said starter motor turn forward from the state of said piston as located in the exhaust stroke and causes said internal combustion engine to start moving after the termination of said time of suspension of energization.

[0018] Thus, it is now possible to feedback the duration of power supply for backward revolution and that of suspension of power supply on the basis of the rotational speed or the rotational angle. As a result, it is possible to start moving the internal combustion engine with the piston of the engine found in the exhaust stroke without using any sensor for detecting the position of the piston such as a crankshaft sensor, therefore, it is possible to provide an inexpensive starter system of internal combustion engine omitting the sensors.

[0019] In this case, said extent of backward turn correcting means may compare the rate of change of the rotational speed of said starter motor as computationally determined from the rotational speed thereof with a predetermined reference value. It raises the target rotational speed of said starter motor to increase the inertial energy of said crankshaft if the rate of change is smaller than the reference value, but lowers the target rotational speed of said starter motor to decrease the inertial energy of said crankshaft if the rate of change is greater than the reference.

[0020] Further, said extent of backward turn correcting means may suspend the energization of said starter motor when the rotational speed of said starter motor gets to a target value even within said time of energization for backward revolution, but extend said time of energization for backward revolution and continue the energization of said starter motor when the rotational speed of said starter motor does not get to the target value within said time of energization for backward revolution.

[0021] Furthermore, said extent of backward turn correcting means may terminate the energization of said starter motor within said time of energization for backward revolution when the rotational speed of said starter motor falls below a predetermined lower limit within said time of energization for backward revolution.

[0022] Additionally, said extent of inertial turn correcting means may terminate said time of suspension of energization and make said starter motor turn forward by said means for directing a start of forward turn of the motor even within said time of suspension of energization when the rotational angle of said starter motor due to energization exceeds a predetermined backward turn reference angle (e.g. 180°), but terminate said time of suspension of energization and make said starter motor turn backward again by said means for directing ener-

gization of the motor for backward revolution even within said time of suspension of energization when the rotational speed of said starter motor falls below a predetermined value (e.g. 0) while the rotational angle undergoes said predetermined backward turn reference angle.

[0023] Still additionally, said extent of inertial turn correcting means may terminate said time of suspension of energization and make said starter motor turn forward by said means for directing a start of forward turn of the motor even within said time of suspension of energization when the rate of decrease of rotational speed as computationally determined from the rotational speed of said starter motor exceeds a predetermined upper limit value.

[0024] Also, a starter of internal combustion engine according to the invention comprises a starter motor linked to the crankshaft of the internal combustion engine, a commutation position detection means adapted to output a pulse signal representing the detected commutation position of said starter motor and a control means adapted to control said starter motor so as to make said internal combustion engine get through the compression stroke by causing the piston of said internal combustion engine to turn backward to the explosion stroke and compress the gas in the combustion chamber in order to accumulate energy for forward revolution due to the reaction of the compression and then accumulate inertial energy in the rotary system surrounding said crankshaft by the effect of combining said energy and the rotational energy due to said starter motor, said control means being also adapted to detect the sense of rotation of said crankshaft on the basis of the change in the pulse intervals of the pulse signal output from said commutation position detecting means when making said starter motor turn backward.

[0025] In this case, said control means may judge that the piston gets to the explosion stroke when the pulse intervals of the pulse signal output from said commutation position detecting means exceeds a predetermined value.

[0026] Further, a starter of an internal combustion engine according to the invention comprises a starter motor linked to the crankshaft of the internal combustion engine, a crank angle sensor for detecting the angle of said crankshaft and a control means adapted to control said starter motor so as to make said internal combustion engine get through the compression stroke by causing the piston of said internal combustion engine to turn backward to the explosion stroke and compress the gas in the combustion chamber in order to accumulate energy for forward revolution due to the reaction of the compression and then accumulate inertial energy in the rotary system surrounding said crankshaft by the effect of combining said energy and the rotational energy due to said starter motor, said control means being also adapted to detect if said piston gets to the explosion stroke or not on the basis of the crank angle detected by

said crank angle sensor when making said starter motor turn backward.

[0027] In this case, said control means may determine the start of energization for turning said crankshaft forward on the basis of the crank angle detected by said crank angle sensor.

[0028] Furthermore, a starter of an internal combustion engine according to the invention comprises a starter motor linked to the crankshaft of the internal combustion engine, a camshaft sensor for detecting the cam position of said internal combustion engine and a control means adapted to control said starter motor so as to make said internal combustion engine get through the compression stroke by causing the piston of said internal combustion engine to turn backward to the explosion stroke and compress the gas in the combustion chamber in order to accumulate energy for forward revolution due to the reaction of the compression and then accumulate inertial energy in the rotary system surrounding said crankshaft by the effect of combining said energy and the rotational energy due to said starter motor, said control means being also adapted to detect if said piston gets to the explosion stroke or not on the basis of the signal from said camshaft sensor when making said starter motor turn backward.

[0029] In this case, said control means may determine the start of energization for turning said crankshaft forward on the basis of the crank angle detected by said camshaft sensor.

[0030] Additionally, in the starter of an internal combustion engine, said control means may energize said starter motor for forward revolution after allowing said crankshaft to turn by inertia for a predetermined period of time after the termination of the energization of said starter motor for backward revolution. Further, said control means may start energizing said starter motor when it detects that the sense of revolution of said crankshaft is switched to forward revolution by the reaction force of the compression in the explosion stroke. Furthermore, said starter motor may be made to turn the piston forward to the compression stroke before it is turned backward to the explosion stroke.

[0031] According to the invention, the piston of the engine is made to turn backward from the halted position to the explosion stroke by the starter motor in order to compress the gas in the combustion chamber and store the energy for forward revolution due to the reaction of the compression so that the crankshaft may be driven to turn forwardly by the above energy to which the rotational energy of the starter motor is added. Thus, the internal combustion engine can be started with a starter motor that shows a small torque and hence consumes little power.

[0032] Additionally, according to the invention, the crankshaft is made to turn forward midway of the compression stroke before it is made to turn backward in order to compress the gas in the combustion chamber and stores the energy for backward revolution due to the

reaction of the compression, subsequently the inertial energy is stored in the rotary system by using the above energy when driving the crankshaft to turn backward to the explosion stroke so that energy for forward revolution can be sufficiently stored by the compressed gas in the combustion chamber produced as a result of the subsequent backward revolution in the next explosion stroke. The inertial energy will be large enough for driving the crankshaft to turn forward and get through the compression stroke. As a result, the internal combustion engine can be reliably started if no long stroke exists between the explosion stroke and the compression stroke as in the case of a 2-cycle engine.

[0033] Still additionally, a starter of an internal combustion engine according to the invention is characterized in that the internal combustion engine is designed to get through the compression stroke by the effect of combining the inertial energy of rotation of the crankshaft and the rotational energy of the starter motor when the internal combustion engine is made to start moving, said starter motor is linked to the crankshaft of said internal combustion engine and its performance is selectively used depending on its rotational speed.

[0034] Finally, according to the invention, when the starter motor is driven to turn forward to get into the compression stroke after having been driven to turn backward in order to make the piston return from the compression stroke, the starting torque of the starter motor can be raised to enhance the rising rate of rotational speed by means of changing a motor characteristics. When the predetermined rotational speed is reached, the maximum rotational speed can be raised further and the inertial energy can be efficiently added to the rotary system.

Brief Description of Drawings

[0035]

FIG. 1 is a schematic cross sectional view of Embodiment 1 of engine starter motor according to the invention.

FIG. 2 is a schematic front view of the starter motor of FIG. 1 from which the housing and the cover are removed.

FIG. 3 is a schematic block diagram of the control system of the starter motor of FIG. 1.

FIG. 4 is a chart illustrating the starting motion of a 4-stroke engine that can be triggered by the starter motor of FIG. 1, where (a) shows the load of revolution in each of the strokes, (b) shows the starting energy of the engine, (c) shows the position of the piston at the start and (d) shows the signal of the camshaft sensor.

FIG. 5 is a chart illustrating the starting motion of a 2-stroke engine in case of applying the starter motor of the invention to the 2-stroke engine, where (a) shows the load of revolution in each of the

strokes, (b) shows the starting energy of the engine, (c) shows the position of the piston at the start and (d) shows the signal of the camshaft sensor.

FIG. 6 is a schematic block diagram of the control system of Embodiment 2 of starter motor according to the invention.

FIG. 7 is a chart illustrating the starting motion of a 4-stroke engine that can be triggered by Embodiment 2 of starter motor according to the invention, where (a) shows the load of revolution in each of the strokes, (b) shows the starting energy of the engine, (c) shows the pulse signal of the commutation position sensor and (d) shows the position of the piston at the start.

FIG. 8 is a schematic illustration of an example of a map of duration of energization for backward revolution that can be used for the purpose of the invention.

FIG. 9 is a schematic illustration of an example of a map of duration of deenergization.

FIG. 10 is a chart illustrating the starting motion of a 2-stroke engine in case of applying the starter motor of the invention to the 2-stroke engine, where (a) shows the load of revolution in each of the strokes, (b) shows the starting energy of the engine, (c) shows the position of the piston at the start and (d) shows the signal of the camshaft sensor.

FIG. 11 is a schematic block diagram of the control system of Embodiment 3 of starter motor according to the invention.

FIG. 12 is a schematic diagram of the functional blocks of Embodiment 3 of starter motor of engine according to the invention.

FIG. 13 is a chart illustrating the starting motion of a 4-stroke engine that can be triggered by Embodiment 3 of starter motor according to the invention, where (a) shows the load of revolution in each of the strokes, (b) shows the starting energy of the engine, (c) shows the pulse signal of the commutation position sensor and (d) shows the position of the piston at the start.

FIG. 14 is a chart illustrating the starting motion of a 2-stroke engine in case of applying the engine start control device of the invention to the 2-stroke engine, where (a) shows the load of revolution in each of the strokes, (b) shows the starting energy of the engine, (c) shows the position of the piston at the start and (d) shows the signal of the camshaft sensor.

FIG. 15 is a schematic block diagram of the control system of Embodiment 4 of starter motor according to the invention.

FIG. 16 is a chart illustrating the starting motion of an engine that can be triggered by Embodiment 4 of starter motor according to the invention, where (a) shows the load of revolution in each of the strokes,

(b) shows the starting energy of the engine, (c) shows the position of the piston at the start, (d) shows the pulse signal of the commutation position sensor and (e) shows the signal of the camshaft sensor.

FIG. 17 is a chart illustrating the starting motion of an engine that can be triggered by Embodiment 4 of starter motor according to the invention, where (a) shows the change in the piston position, (b) shows the change in the number of revolutions of the crankshaft, (c) shows the energy change, (d) shows the change in the motor output energy and (e) shows the change in the ride-over energy.

FIG. 18 is a chart illustrating the energy accumulation process at the time of starting the engine by means of Embodiment 4 of starter motor according to the invention, where (a) shows the change in the energy generated by the motor and (b) shows the change in the rotational energy of the rotary system.

FIG. 19 is a chart of the starting motion of an engine that can be triggered by a starter motor obtained by modifying Embodiment 4.

FIG. 20 is a chart illustrating the energy accumulation process at the time of starting the energy by means of the starter motor of FIG. 19, where (a) shows the change in the energy generated by the motor and (b) shows the change in the rotational energy of the rotary system.

FIG. 21 is a chart obtained when the starter motor of FIG. 20 is applied to a 2-cylinder engine.

FIG. 22 is a schematic cross sectional view of Embodiment 5 of engine starter motor according to the invention.

FIG. 23 is a schematic front view of the starter motor of FIG. 22 from which the housing and the cover are removed.

FIG. 24 is a graph illustrating the performance of the starter motor of FIGS. 22 and 23.

FIG. 25 is a graph illustrating the operation of controlling the switched utilization of the performance of the starter motor.

FIG. 26 is a schematic block diagram of the control circuit of Embodiment 5 of starter motor according to the invention.

FIG. 27 is a chart illustrating the starting motion of the Embodiment 5 of starter motor according to the invention.

FIG. 28 is a schematic block diagram of the control circuit of a starter motor obtained by modifying Embodiment 5.

FIG. 29 is a chart illustrating the starting motion of the starter motor of FIG. 28.

FIG. 30 is a schematic illustration of an example of a map of duration of energization for backward.

FIG. 31 is a schematic illustration of an example of a map of duration of deenergization.

FIG. 32 is a schematic diagram of the functional

blocks of the engine start control section of another control unit that can be used for controlling the starting motion illustrated in FIG. 29.

FIG. 33 is a chart illustrating the starting motion of another starter motor obtained by modifying Embodiment 5.

FIG. 34 is a chart illustrating the accumulation of energy produced as a result of a reaction to compression due to the starting motion as shown in FIG. 33.

FIG. 35 is a chart illustrating the starting motion of still another starter motor obtained by modifying Embodiment 5.

FIG. 36 is a chart illustrating the energy accumulation process of the starter motor of FIG. 35.

Best Mode for Carrying Out the Invention

[0036] Now, the present invention will be described by referring to the accompanying drawings that illustrate preferred embodiments of the invention.

(Embodiment 1)

[0037] FIG. 1 is a schematic cross sectional view of Embodiment 1 of engine starter motor according to the invention, FIG. 2 is a schematic front view of the starter motor of FIG. 1 from which the housing and the cover are removed and FIG. 3 is a schematic block diagram of the control system of the starter motor of FIG. 1.

[0038] A starter motor 10 of FIG. 1 (hereinafter simply referred to as motor) is linked directly to a 4-cycle engine of motor bicycle and provided with a stator 12 rigidly secured to an engine case 11 of the engine and a rotor 14 linked to a crankshaft 13 of the engine.

[0039] The rotor 14 is provided with a yoke 15 made of a magnetic material such as iron and having a shape of a bottomed short cylinder. A boss section 16 having a cylindrical profile is integrally formed on and concentrically projecting from the inner surface the bottom wall of the yoke 15. As the boss section 16 and the crankshaft 13 are coupled together by means of a set nut 17 at the respective tapered surfaces thereof to give rise to a wedge effect, the rotor 14 is rigidly secured to the crankshaft 13 so as to integrally revolve with the latter. A plurality of permanent magnets 18 for producing field poles are arranged peripherally on the inner peripheral surface of the yoke 15 in such a way that any two adjacently located ones shows opposite polarities.

[0040] The stator 12 of the motor 10 comprises a core 19 made of a magnetic material such as iron and having a shape of a low profile disk that rather resembles a star. The core 19 is rigidly secured by means of a bolt 21 to a housing 20 arranged on the outer surface of the engine case 11 concentrically with the crankshaft 13. A cover 26 is arranged to the outside of the housing 20. The rotor 14 is arranged within the housing 20 to surround the stator 12 and it is adapted to move around

the stator 12 as it is driven by the crankshaft 13.

[0041] The core 19 is formed by laying a number of thin plates of a magnetic material such as iron one on the other to form an integral entity and has a doughnut-shaped main body 22. A plurality of salient poles 23 are radially projecting from the outer periphery of the core main body 22. Each of the salient poles 23 is wound by a stator coil 24 for three-phase winding, which the coil 24 is connected to a motor driver 31 via a terminal (not shown) by means of a lead wire and a wire harness (not shown). In short, the motor 10 is a brushless motor driven by the motor driver 31.

[0042] The motor 10 is also provided with a plurality of (e.g., three) commutation position sensors 25 that are arranged in the housing 20 and adapted to sense the magnetism of the permanent magnets 18 and detect the rotary position of the rotor 14. The output of the commutation position sensors 25 is fed to the motor driver 31 by way of a CPU 32 so that the motor driver 31 generates an energization signal corresponding to the detection signal from the commutation position sensors 25 and feeds the stator coils 24 with an electric current on the basis of the signal in order to sequentially and magnetically energize the stator coils 24. As the stator coils 24 are sequentially and magnetically energized, a rotating magnetic field is formed by the stator coils 24. Then, the rotating magnetic field acts on the permanent magnets 18 and the rotor 14 is driven to rotate by the rotating magnetic field. Thus, the turning effort of the rotor 14 is transmitted to the crankshaft 13 by way of the boss section 16 of the yoke 15 to cause the engine to start moving.

[0043] As shown in FIG. 3, the motor 10 is driven by the motor driver 31 under the control of the CPU (control means) 32. The CPU 32 is connected to a camshaft sensor 33 for detecting the movement of a valve cam, a starter switch 34 and an ignition switch 39 of the engine. The CPU 32 is also connected to an ignition coil 35 for igniting the fuel in the engine by way of an ignition unit 36. It is further connected to a ROM 37 storing the motor driver drive logic and various control programs including the engine control program and a RAM 38 storing the data from various sensors. Thus, it sends control signals to various components of the system including the motor driver 31 and the ignition unit 36 on the basis of the detected values of the various sensors to control the motor 10 and also the operation of igniting the fuel in the engine. Note that the motor 10 itself and the CPU 32 are powered by a power source that is a battery (not shown) loaded in the vehicle.

[0044] Now, the operation of the motor for causing the engine to start moving will be described. FIG. 4 is a chart illustrating the starting motion of a 4-stroke engine that can be triggered by the starter motor of FIG. 1, where (a) shows the load of revolution in each of the strokes and (b) show the starting energy of the engine, while (c) shows the position of the piston at the start and (d) shows the signal of the camshaft sensor.

[0045] As shown in (a) of FIG. 4, the load for driving the crankshaft 13 to revolve varies as a function of the strokes of the operation of the engine. More specifically, the load required for driving the crankshaft 13 is relatively small in the exhaust stroke and the intake stroke because the piston moves up and down while a valve is kept open in those strokes. On the other hand, the load required for driving the crankshaft 13 is large in the compression stroke and maximized at a position slightly before the top dead center because the piston has to move up and down while the valve is kept closed in that stroke. Therefore, the piston of the engine normally stops at a position before entering the compression stroke and any conventional starter motor is designed to cause the engine to start moving from that piston position. Thus, the known motor is required to supply the crankshaft with energy in a manner as indicated by a broken line in FIG. 4 in order to cause the engine to overcome the load in the compression stroke when the engine starts moving.

[0046] On the other hand, with this embodiment of motor 10 according to the invention, the piston located before the compression stroke is temporarily moved back to the exhaust stroke by reversely turning the motor 10 prior to causing the engine to start moving. As a result, the engine enters the compression stroke after making a short approach with a small load of revolution and overcome the largest load by the combined effect of the inertial energy of the rotary system including the fly-wheel of the engine and the drive torque of the motor to consequently reduce the load of the motor so that the motor may be down-sized and operate at a low power consumption rate.

[0047] As the ignition switch 39 is turned ON, the CPU 32 firstly recognizes the current position of the piston on the basis of the detection signal of the camshaft sensor 33 and determines if it is necessary to return the piston to the exhaust stroke or not. In other words, the CPU 32 recognizes the current position of the piston by means of the signal from the camshaft sensor 33 so as to reliably cause the piston to move into the exhaust stroke.

[0048] If the piston is found in a stroke other than the exhaust stroke, the CPU 32 determines to cause the piston to move back to the exhaust stroke and issues a command to the motor driver 31 to make the motor 10 turn backward temporarily so as to cause the crankshaft 13 to rotate into the exhaust stroke. For example, if the piston is found at position P as shown in (c) of FIG. 4 when the ignition switch is turned ON, it is temporarily moved back to the exhaust stroke as indicated by the arrow. The position of the piston is constantly monitored by the camshaft sensor 33 so that the latter issues an H signal when the piston gets to the exhaust stroke. As the detection signal (H) is issued from the camshaft sensor 33 to tell that the piston is in the exhaust stroke, the CPU 32 causes the motor 10 to cease the reverse turn and temporarily halt at position Q.

[0049] Thus, while the piston is returned to position Q in the exhaust stroke that is found within the "range for starting forward turn" in (c) of FIG. 4, it is desirable that the piston is moved back to a position near the bottom dead center before the start of the exhaust stroke that allows the piston to have the longest approach run. Note, however, the position Q "in the exhaust stroke" where the piston starts turning forward may include a position near the bottom dead center in the explosion stroke and a position near the top dead center in the intake stroke before or after the exhaust stroke.

[0050] If, on the other hand, it is detected by the camshaft sensor 33 that the piston is already located at position R in the exhaust stroke when the latter starts moving, the CPU 32 determines that it is not necessary to return the piston to the exhaust stroke and hence does not cause it to turn backward in a manner as described above.

[0051] Note that the motor 10 is made to revolve backward when the ignition switch 39 is turned ON in order for the motor 10 to start revolving forward immediately to eliminate any time lag before the start of the engine when the starter switch 34 is turned ON. Therefore, the motor 10 does not necessarily have to revolve backward when the ignition switch is turned ON. Alternatively, it may be so arranged that the motor 10 starts revolving backward when the starter switch 34 is turned ON. Still alternatively, it may be so arranged that the motor 10 revolves backward when the engine is stopped.

[0052] Then, as the starter switch 34 inputs an engine start signal, the CPU 32 outputs a signal for causing the motor driver 31 to make the motor 10 revolve forward so that the engine may start moving from the exhaust stroke. Since the crankshaft 13 turns with a small load in the exhaust stroke and the intake stroke, the motor 10 will substantially gets to the largest number of revolutions per unit time that can taken place when it revolves without load before it gets into the compression stroke. In other words, the motor 10 will be in an almost saturated state. Therefore, the crankshaft 13 is also driven by the motor 10 to turn at the largest number of revolutions immediately before the compression stroke and the inertial energy stored in the inertial mass of the rotary system is maximized when the engine enters the compression stroke.

[0053] Thus, as a result, the crankshaft 13 is driven to rotate by the combined effect (thick solid line) of the inertial energy of the engine (dotted broken line) and the rotational energy of the starter motor (solid line) in the compression stroke as shown in (b) of FIG. 4. In other words, the crankshaft 13 is driven by the torque T_i due to the inertial energy produced as a result of the reduction in the number of revolutions of the crankshaft 13 and the drive torque T_m of the motor, which are added to each other to give rise to a torque sufficient to overcome the load of the initial compression stroke, or a ride over torque $T = T_m + T_i$, as the sum thereof.

[0054] Then, in an engine to which this embodiment of motor according to the invention is applied, the drive torque of the motor is made $T_m \leq T/2$ when $T_m \leq T_i$ as seen from (b) in FIG. 4. In other words, the embodiment is designed to get over the load of the compression stroke mainly by means of the inertial energy subordinatedly by the motor energy and the engine can be made to start moving by means of a motor 10 whose largest torque (lock torque) is less than 1/2 of the ride over torque T necessary for getting over the load of the compression stroke. Additionally, as shown in (b) of FIG. 4, the motor 10 is designed to divide its drive energy into two parts and delivers them to the crankshaft 13 respectively during the approach run and during the time of riding over. Therefore, a motor with a relatively low output level according to the invention can be used to generate a large ride over torque if compared with conventional motors that are required to get over a large load in the compression stroke with a single delivery of energy.

[0055] If the operation of starting the engine fails, the backward turn sequence down to the exhaust stroke of the attempt of restarting the engine immediately thereafter is automatically followed if the halt of the engine is detected while the ignition switch 39 is held ON. Therefore, when the starter switch 34 is turned ON for another time, the motor 10 immediately starts revolving forward without giving rise to any time lag. Additionally, the motor 10 is allowed to operate only when the brake is being operated and/or when the gear is found in the neutral position so that any unintended burst of the vehicle is inhibited.

[0056] Once the initial compression stroke is got through, inertial energy is accumulated thereafter and the load of any subsequent compression stroke can be easily surmounted. Then, the engine will start moving as the ignition coil 35 throws out sparks at predetermined timing.

[0057] While the above embodiment is described in terms of a 4-stroke engine to which it is applied, this embodiment can also be applied to a 2-stroke engine as well. FIG. 5 is a chart illustrating the starting motion of a 2-stroke engine that can be triggered by the embodiment. Unlike the 4-stroke engine, the strokes of intake, compression, explosion and exhaust proceeds within a single turn of the crankshaft of the 2-stroke engine. While the 2-stroke engine is not provided with an intake valve and an exhaust valve unlike the 4-stroke engine, the piston of the engine itself takes the part of the valves.

[0058] As shown in FIG. 5, the intake port and the exhaust port of the cylinder of the 2-stroke engine are blocked by the piston both in the compression stroke and in the explosion stroke. Additionally, the exhaust stroke and the intake stroke take place simultaneously. In other words, both the exhaust port and the intake port are open when the piston is located near the bottom dead center. The exhaust stroke of the 4-stroke engine corresponds to the period between the time when at

least either the exhaust port or the intake port is opened and the time when the piston gets to the bottom dead center of the 2-stroke engine as the engine is operated (to turn forward).

[0059] Thus, as may be clear from the charts of FIGS. 4 and 5, the effect described above in terms of the 4-stroke engine can also be achieved for the 2-stroke engine by operating the motor in a manner as described above except the above differences.

[0060] As described above, the piston of the engine provided with a motor 10 according to the invention is temporarily returned to the exhaust stroke before it is made to start moving in order to utilize the inertial energy of the crankshaft 13 so that the initial compression stroke can be got through with a torque smaller than that of any conventional motor of the type under consideration. Then, the motor can be downsized to reduce the manufacturing cost and the power consumption rate of the motor. Still additionally, if a starter according to the invention uses a magnet for the magnetic field system of the motor, the magnet is not required to show excessive magnetic force so that it is possible to reduce the rotational resistance of the motor and hence the specific fuel consumption of the engine without sacrificing the output power of the engine.

(Embodiment 2)

[0061] Now, Embodiment 2 of starter motor of engine according to the invention will be described. However, since the configuration of this embodiment is basically identical with that of Embodiment 1, the parts that are common to those embodiments will not be described any further.

[0062] FIG. 6 is a schematic block diagram of the control system of Embodiment 2 of starter motor according to the invention. As shown in FIG. 6, the motor 10 is driven by motor driver 31 under the control of CPU (control means) 32. The CPU 32 is connected to various sensors including a motor temperature sensor 42, a commutation position sensor 25 and a battery voltage sensor 43 and various switches including an engine starter switch 34 and an ignition switch 39. The CPU 32 is also connected to an ignition coil 35 for igniting the fuel in the engine by way of an ignition unit 36. It is further connected to a ROM (storage means) 37 storing the motor driver drive logic and various control programs including the engine control program and a RAM 38 storing the data from various sensors. Thus, it sends control signals to various components of the system including the motor driver 31 and the ignition unit 36 on the basis of the detected values of the various sensors to control the motor 10 and also the operation of igniting the fuel in the engine. Note that the motor 10 itself and the CPU 32 are powered by a power source that is a battery (not shown) loaded in the vehicle.

[0063] Now, the operation of the motor for causing the engine to start moving will be described. FIG. 7 is a

chart illustrating the starting motion of a 4-stroke engine that can be triggered by the starter motor 10 of FIG. 6, where (a) shows the load of start in each of the strokes, (b) shows the starting energy produced by the drive force of the motor 10 and the inertia of the crankshaft 13, (c) shows the pulse signal from the commutation position sensor 25 and (d) shows the signal of the camshaft sensor.

[0064] As shown in (a) of FIG. 7, the load for driving the crankshaft 13 to revolve varies as a function of the strokes of the operation of the engine. More specifically, the load required for driving the crankshaft 13 is relatively small in the exhaust stroke and the intake stroke because the piston moves up and down while a valve is kept open in those strokes. On the other hand, the load required for driving the crankshaft 13 is large in the compression stroke and maximized at a position slightly before the top dead center because the piston has to move up and down while the valve is kept closed in that stroke. Therefore, the piston of the engine normally stops at a position before entering the compression stroke and any conventional starter motor is designed to cause the engine to start moving from that piston position. Thus, the known motor is required to supply the crankshaft with energy in a manner as indicated by a broken line in FIG. 7 in order to cause the engine to overcome the load in the compression stroke when the engine starts moving.

[0065] On the other hand, with this embodiment of motor 10 according to the invention, when the engine is made to start moving, the crankshaft 13 is driven to turn backward by a predetermined period of time or a predetermined angle to move the piston temporarily to the exhaust stroke before actually causing the engine to start moving. However, when moving the piston back to the exhaust stroke, the position of the piston is not detected by means of any sensor such as camshaft sensor. Instead, the piston is moved back to the exhaust stroke simply by controlling the time during which the motor 10 is energized to turn backward or the time at which the energization of the motor 10 is terminated. As a result, the engine enters the compression stroke after making a short approach with a small load of revolution and overcome the largest load by the combined effect of the inertial energy of the rotary system including the flywheel of the engine and the drive torque of the motor to consequently reduce the load of the motor so that the motor may be down-sized and operate at a low power consumption rate.

[0066] When the starter switch 34 is turned ON while the ignition switch 39 is held ON, the CPU 32 issues a command to the motor driver 31 to energize and make it turn backward for a predetermined period of time in order to cause the crankshaft 13 to turn backward to the exhaust stroke. Additionally, after the energization for backward revolution, the energization of the motor 10 is suspended for a predetermined period of time to cause the crankshaft 13 to rotate simply by iner-

tia. After the suspension of energization for the predetermined period of time, the motor 10 is energized to turn forward and cause the crankshaft 13 to revolve forward, thereby making the engine start moving.

[0067] While the motor 10 is made to turn backward when the starter switch 34 is turned ON in the above description, it may alternatively be so arranged that the motor 10 is made to turn backward when the ignition switch 39 is turned ON so that the motor 10 may be able to turn forward once the starter switch 34 is turned ON and, therefore, the engine may be made to start moving without any time lag. Therefore, the motor 10 does not necessarily have to revolve backward when the starter switch 34 is turned ON. Alternatively, it may be so arranged that the motor 10 starts revolving backward when the ignition switch 39 is turned ON. Still alternatively, it may be so arranged that the motor 10 revolves backward when the engine is stopped.

[0068] The above starting motion generally follows one of the three patterns of motion as described below depending on the position at which the position is halted. They include the one that appears when the piston is located at the ordinary halt position before the compression stroke (pattern ①), the one that appears when the piston is located immediately before or after the top dead center between the exhaust stroke and the intake stroke (pattern ②) and the one that appears when the piston is located near the bottom dead center before the exhaust stroke (pattern ③).

[0069] Firstly, the starting motion that follows the pattern ① will be discussed. As the starter switch 34 is turned ON, the CPU 32 issues a command to make the motor 10 turn backward for t_1 seconds and the piston move from position A to position B. Thereafter, the energization of the motor 10 is suspended for t_2 seconds. However, the crankshaft 13 keeps on turning backward due to the inertial force obtained by the energization for t_1 seconds. Since the piston does not compress any gas from the intake stroke to the exhaust stroke and hence the load torque is small, the crankshaft 13 can easily keep on revolving by inertia. However, the inertial energy is consumed by the load torque to gradually reduce the rotational speed until the piston stops at position C.

[0070] The duration t_1 of energization for backward revolution is made longer than the time by which the piston can return to a position near the bottom dead center before the exhaust stroke due to the inertial force obtained by the energization. If the duration t_1 is too long, the rotational speed of the crankshaft 13 can become too high and generate too large inertial energy so that the explosion stroke can be got through during the time t_2 . Thus, the duration t_1 has to be so selected that the explosion stroke would not be got through while the crankshaft 13 is turning by inertia if the crankshaft 13 is driven to turn backward when the position is located at the bottom dead center before the compression stroke. Thus, the lower and higher limits of the

duration t_1 of energization have to be defined so as to satisfy the above requirements.

[0071] After the time t_2 , the motor 10 is energized to turn forward. However, there may be occasions where the piston cannot get back to the exhaust stroke while it is turning by inertia if the time t_2 of suspension of energization is too short. Thus, the lower limit of the time t_2 is defined by taking this situation into consideration. The piston will successfully move from position B to position C in the exhaust stroke during the time t_2 if the above limits for the time t_2 and the duration t_1 are observed.

[0072] Note, while the piston is returned to position C in the exhaust stroke that is found within the "range for starting forward turn" in (d) of FIG. 7, it is desirable that the piston is moved back to a position near the bottom dead center before the start of the exhaust stroke that allows the piston to have the longest approach run. However, the position C "in the exhaust stroke" where the piston starts turning forward may include a position near the bottom dead center in the explosion stroke and a position near the top dead center in the intake stroke before or after the exhaust stroke.

[0073] When the time t_2 is over, the CPU 32 outputs a signal for causing the motor driver 31 to make the motor 10 revolve forward so that the engine may start moving from the exhaust stroke. Since the crankshaft 13 turns with a small load in the exhaust stroke and the intake stroke, the motor 10 will substantially get to the largest number of revolutions per unit time that can taken place when it revolves without load before it gets into the compression stroke. In other words, the motor 10 will be in an almost saturated state. Therefore, the crankshaft 13 is also driven by the motor 10 to turn at the largest number of revolutions immediately before the compression stroke and the inertial energy stored in the inertial mass of the rotary system is maximized when the engine enters the compression stroke.

[0074] Thus, as a result, the crankshaft 13 is driven to rotate by the combined effect (thick solid line) of the inertial energy of the engine (dotted broken line) and the rotational energy of the starter motor (solid line) in the compression stroke as shown in (b) of FIG. 7. In other words, the crankshaft 13 is driven by the torque T_i due to the inertial energy produced as a result of the reduction in the number of revolutions of the crankshaft 13 and the drive torque T_m of the motor, which are added to each other to give rise to a torque sufficient to overcome the load of the initial compression stroke, or a ride over torque $T = T_m + T_i$, as the sum thereof.

[0075] Then, in an engine to which this embodiment of motor according to the invention is applied, the drive torque of the motor is made $T_m \leq T/2$ when $T_m \leq T_i$ as seen from (b) in FIG. 7. In other words, the embodiment is designed to get over the load of the compression stroke mainly by means of the inertial energy subordinatedly by the motor energy and the engine can be made to start moving by means of a motor 10 whose largest torque (lock torque) is less than 1/2 of the ride over

torque T necessary for getting over the load of the compression stroke. Additionally, as shown in (b) of FIG. 7, the motor 10 is designed to divide its drive energy into two parts and delivers them to the crankshaft 13 respectively during the approach run and during the time of riding over. Therefore, a motor with a relatively low output level according to the invention can be used to generate a large ride over torque if compared with conventional motors that are required to get over a large load in the compression stroke with a single delivery of energy.

[0076] Once the initial compression stroke is got through, inertial energy is accumulated thereafter and the load of any subsequent compression stroke can be easily surmounted. Then, the engine will start moving as the ignition coil 35 throws out sparks at predetermined timing.

[0077] Now, the starting motion that follows the pattern ② will be discussed below. The piston is located near the top dead center between the exhaust stroke and the intake stroke (position D) and then driven to turn backward from there to position E as the motor is energized for the time t_1 . Thereafter, the piston returns to the bottom dead center of the exhaust stroke by inertia and then enters the explosion stroke. However, the torque of the load of revolution increases due to the load of compression generated by the piston in the explosion stroke and the inertial energy is consumed quickly by the torque of the load to make the rotational speed falls and eventually cause the piston to completely halt (position F). At this time, the crankshaft 13 may be driven to turn forward slightly by the reaction force of compression produced by the piston but eventually stops at position G near the bottom dead center.

[0078] When the time t_2 is over, the engine piston is caused to start moving from the position G of the exhaust stroke. Then, the initial load of the compression stroke can be got through by the sum of the torque T_i due to the inertial energy obtained as a result of the approach run in the exhaust stroke and the intake stroke and the drive torque T_m as pointed out earlier.

[0079] Now, the starting motion that follows the pattern ③ will be discussed below. In this instance, the piston is located near the bottom dead center before the exhaust stroke (position H) and then driven to turn backward. Since it enters the explosion stroke immediately after the start of the backward revolution, the torque of the load of revolution is generated by the piston due to the load of compression of the latter also immediately after the start of the backward revolution. Therefore, the number of revolutions per unit time of the crankshaft 13 is not raised remarkably nor any substantial inertial energy is generated. On the other hand, since the torque of the motor 10 is selected to be less than 1/2 of the ride over torque T necessary for getting over the load of the compression stroke, the explosion stroke would not be got through by the backward revolution and the motor is locked and stops moving when the reaction force of compression produced by the piston

and the motor torque are balanced by each other (position I).

[0080] When the time t_1 is over, the motor torque is lost as the motor has not been energized and the crankshaft 13 gradually starts revolving forward by the reaction force of the piston during the time t_2 and turns at an increasing rate. Subsequently, the reaction force of the piston is lost at or near the bottom dead center and thereafter the inertial energy of rotation is gradually consumed by the torque of the load of revolution so that the piston stops at position J before it enters into the intake stroke from the exhaust stroke. Then, in a manner as described above, the cranking motion starts from this position. Note, however, that the time t_2 has to be terminated before the piston enters the intake stroke by the reaction force because, otherwise, the piston can enter the intake stroke from the exhaust stroke during the time t_2 . In other words, the largest value of the time t_2 is defined by taking this situation into consideration.

[0081] Thus, as discussed above. Embodiment 2 of motor 10 according to the invention is made to turn backward for the time t_1 set under the conditions described above by referring to the pattern ① before the engine is made to start moving. Then, the crankshaft 13 is made to turn by inertia, while the power supply is suspended for the time t_2 set under the conditions as discussed above by referring to the patterns ① and ③. Thereafter, the motor 10 is made to turn forward to temporarily bring the piston back to the exhaust stroke in order to make it possible to cause the engine to start moving. As discussed above, the motor 10 can reliably bring the piston back to the exhaust stroke by selecting appropriate values for the times t_1 and t_2 respectively. Thus, the engine can be reliably made to start moving from the exhaust stroke without providing a sensor for detecting the position of the piston such as a camshaft sensor so that the cost of the engine can be reduced for the reason of the absence of such sensors.

[0082] Additionally, since the initial compression stroke can be got through by utilizing the inertial energy of the crankshaft 13, the load of the motor 10 can be reduced and hence the motor 10 can be downsized to make it energy-saving. Still additionally, if a starter according to the invention uses a magnet for the magnetic field system of the motor, the magnet is not required to show excessive magnetic force so that it is possible reduce the rotational resistance of the motor and hence the specific fuel consumption of the engine without sacrificing the output power of the engine.

[0083] If the operation of starting the engine fails, the backward turn sequence down to the exhaust stroke of the attempt of restarting the engine immediately thereafter is followed immediately if the halt of the engine is detected while the ignition switch is held ON or automatically if the halt of the engine is detected when the starter switch 34 is released. Therefore, when the starter switch 34 is turned ON for another time, the motor 10 immediately starts revolving forward without

giving rise to any time lag as described earlier. Additionally, the motor 10 is allowed to operate only when the brake is being operated and/or when the gear is found in the neutral position so that any unintended burst of the vehicle is inhibited.

[0084] With the above described Embodiment 2, the extent (angle) of reverse turn can vary enormously as a function of the change in the performance of the motor due to fluctuations of the battery voltage and/or those of the temperature and/or the change in the torque of the load of revolution (friction) of the engine caused by the change in the oil viscosity also due to fluctuations of the temperature if appropriate values are selected respectively for the time t_1 and the time t_2 . In view of this fact, the ROM 37 of this embodiment of motor 10 is made to store a map 1 for the time t_1 that carries values for the time t_1 obtained by using the temperature of the starter motor and the supply voltage as parameters and another map 2 for the time t_2 that carries values for the time t_2 also obtained by using the temperature of the starter motor and the supply voltage as parameters so that appropriate values may be selected for t_1 and t_2 by referring to the respective maps. FIGS. 8 and 9 show examples of the maps 1 and 2.

[0085] The output power of the motor 10 falls as the voltage of the battery falls so that the time required to store the rotational energy necessary for returning the piston to the right position increases. The oil viscosity rises as the temperature falls so that the time required to store the rotational energy necessary for moving the piston increases. Then, inertial energy will be consumed at a high rate when the piston is made to turn by inertia so that a large volume of inertial energy has to be stored. In FIG. 8, appropriate values are selected for the time t_1 by taking the temperature of the starter motor and the battery voltage into consideration, and it shows the relationship between the time t_1 and these factors as a map.

[0086] On the other hand, the rotational speed of the crankshaft 13 falls quickly when the temperature is low because the rolling friction of the crankshaft 13 rises so that it takes time for the piston to return to the target position. Therefore, in FIG. 9, appropriate values are selected for the time t_2 by taking the temperature of the starter motor into consideration, and it shows the relationship between the time t_2 and the temperature as a map.

[0087] While the time t_2 is selected only as a function of the temperature of the starter motor in this embodiment, the map 2 may be made to additionally contain data on the battery voltage so that the crankshaft 13 can reliably return to the predetermined position by prolonging the time t_2 which is the time during which the crankshaft 13 turns by inertia in order to compensate the loss of inertial energy stored in the energization process for backward revolution caused by a fall of the battery.

[0088] Then, the CPU 32 obtains the motor temper-

ature T_s from the motor temperature sensor 42 and the battery voltage V from the battery voltage sensor 43 and determines both the times t_1 and t_2 on the basis of these values by referring to the map 1 for the time t_1 and the map 2 for the time t_2 . As a result, both the times t_1 and t_2 are compensated in terms of temperature and fluctuations of the voltage so that the piston can reliably be made to return to the exhaust stroke regardless of any changes in the environmental factors.

[0089] While the ROM 37 stores the maps 1 and 2 to be used for selecting appropriate values for the time t_1 and the time t_2 in the above description, it may alternatively be so arranged that the CPU 32 comprises a means for computationally determining the time t_1 from the motor temperature T_s and the battery voltage V , and a means for computationally determining the time t_2 from the temperature so that it can computationally determine those values. Then, the approximate expressions as shown below can be used for determining the time t_1 and time t_2 from the motor temperature and the battery voltage.

$$t_1 = 0.18 + (12 - V) \times 0.02 + T_s$$

$$t_2 = 0.12 + T_s \times 0.01$$

[0090] While the times t_1 and t_2 are determined by using the temperature of the motor 10 in the above description, the temperature that can be used as parameter is not limited to that of the motor and that of the engine cooling water, that of the engine oil or that of the ambient air may alternatively be used. Still alternatively, any of the above temperatures may be used as parameters in addition to the temperature of the motor 10 when preparing a map and an approximate expression.

[0091] While the above embodiment is described in terms of a 4-stroke engine to which it is applied, this embodiment can also be applied to a 2-stroke engine as well. FIG. 10 is a chart illustrating the starting motion of a 2-stroke engine that can be triggered by the embodiment. Unlike the 4-stroke engine, the strokes of intake, compression, explosion and exhaust proceeds within a single turn of the crankshaft of the 2-stroke engine. While the 2-stroke engine is not provided with an intake valve and an exhaust valve unlike the 4-stroke engine, the piston of the engine itself takes the part of the valves.

[0092] As shown in FIG. 10, the intake port and the exhaust port of the cylinder of the 2-stroke engine are blocked by the piston both in the compression stroke and in the explosion stroke. Additionally, the exhaust stroke and the intake stroke take place simultaneously. In other words, both the exhaust port and the intake port are open when the piston is located near the bottom dead center. The exhaust stroke of the 4-stroke engine corresponds to the period between the time when at least either the exhaust port or the intake port is opened

and the time when the piston gets to the bottom dead center of the 2-stroke engine as the engine is operated (to turn forward).

[0093] Thus, as may be clear from the charts of FIGS. 7 and 10, the effect described above in terms of the 4-stroke engine can also be achieved for the 2-stroke engine by operating the motor in a manner as described above except the above differences.

(Embodiment 3)

[0094] Now, Embodiment 3 of starter motor of engine according to the invention will be described. However, since the configuration of this embodiment is basically identical with that of Embodiment 1, the parts that are common to those embodiments will not be described any further.

[0095] FIG. 11 is a schematic block diagram of the control system of Embodiment 2 of starter motor according to the invention. As shown in FIG. 11, the motor 10 is driven by motor driver 31 under the control of CPU 32. The CPU 32 is connected to various sensors including a commutation position sensor 25 and various switches including an engine starter switch 34 and an ignition switch 39. The CPU 32 is also connected to an ignition coil 35 for igniting the fuel in the engine by way of an ignition unit 36. It is further connected to a ROM (storage means) 37 storing the motor driver drive logic and various control programs including the engine control program and a RAM 38 storing the data from various sensors. Thus, it sends control signals to various components of the system including the motor driver 31 and the ignition unit 36 on the basis of the detected values of the various sensors to control the motor 10 and also the operation of igniting the fuel in the engine. Note that the motor 10 itself and the CPU 32 are powered by a power source that is a battery (not shown) loaded in the vehicle.

[0096] Now, the operation of the motor 10 for causing the engine to start moving will be described. The starting operation of the motor is conducted under the control of the CPU 32 that is a control unit for controlling the starting operation. The CPU 32 has various functional means for controlling the starting operation of the motor 10. FIG. 12 is a schematic diagram of the functional blocks of the CPU 32. As shown in FIG. 12, a pulse signal indicating the commutation position is input to the CPU 32 from the commutation position sensor 25 and the CPU 32 has a motor rotational speed computing means 51 for computationally determining the rotational speed of the motor 10 on the basis of the pulse signal and a motor rotational angle computing means 52 for computationally determining the rotational angle of the motor 10 also on the basis of the pulse signal. It also has an extent of backward turn correcting means 53 and an extent of inertial turn correcting means 54 adapted to respectively receive the time t_1 of energization for backward revolution and the time t_2 of suspen-

sion of energization, which will be discussed hereinafter, and correct them on the basis of the rotational speed and the rotational angle of the motor 10.

[0097] Additionally, the CPU 32 has a means 55 for directing energization of the motor for backward revolution to the motor driver 31 and a means 56 for directing suspension of energization of the motor respectively on the basis of the time t_1 and the time t_2 selected by the means 53 and 54. Finally, the CPU 32 also has a means 57 for directing a start of forward turn of the motor to cause the engine to start moving after the time t_2 .

[0098] Now, the operation of the CPU 32 for controlling the operation of causing the engine to start moving will be discussed by referring to FIG. 13. FIG. 13 is a chart illustrating the starting motion of an engine that can be triggered by starter motor, where (a) shows the load of revolution in each of the strokes, (b) shows the starting energy of the engine produced by the drive force of the motor 10 and the inertia of the crankshaft 13, (c) shows the pulse signal from the commutation position sensor 25 and (d) shows the position of the piston when the engine starts moving.

[0099] As shown in (a) of FIG. 13, the load for driving the crankshaft 13 to revolve varies as a function of the strokes of the operation of the engine. More specifically, the load required for driving the crankshaft 13 is relatively small in the exhaust stroke and the intake stroke because the piston moves up and down while a valve is kept open in those strokes. On the other hand, the load required for driving the crankshaft 13 is large in the compression stroke and maximized at a position slightly before the top dead center because the piston has to move up and down while the valve is kept closed in that stroke. Therefore, the piston of the engine normally stops at a position before entering the compression stroke and any conventional starter motor is designed to cause the engine to start moving from that piston position. Thus, the known motor is required to supply the crankshaft with energy in a manner as indicated by a broken line in FIG. 13 in order to cause the engine to overcome the load in the compression stroke when the engine starts moving.

[0100] On the other hand, with this embodiment of motor 10 according to the invention, when the engine is made to start moving, the crankshaft 13 is driven to turn backward by a predetermined period of time or a predetermined angle to move the piston temporarily to the exhaust stroke before actually causing the engine to start moving. However, when moving the piston back to the exhaust stroke, the position of the piston is not detected by means of any sensor such as camshaft sensor. Instead, the piston is moved back to the exhaust stroke simply by controlling the time during which the motor 10 is energized to turn backward or the time at which the energization of the motor 10 is terminated. As a result, the engine enters the compression stroke after making a short approach with a small load of revolution and overcome the largest load by the combined effect of

the inertial energy of the rotary system including the fly-wheel of the engine and the drive torque of the motor to consequently reduce the load of the motor so that the motor may be down-sized and operate at a low power consumption rate.

[0101] When the starter switch 34 is turned ON while the ignition switch 39 is held ON, the CPU 32 issues a command to the motor driver 31 to energize and make it turn backward for the predetermined period of time t_1 in order to cause the crankshaft 13 to turn backward to the exhaust stroke. Additionally, after the energization for backward revolution, the energization of the motor 10 is suspended for the predetermined period of time t_2 to cause the crankshaft 13 to rotate simply by inertia. After the suspension of energization for the predetermined period of time, the motor 10 is energized to turn forward and cause the crankshaft 13 to revolve forward, thereby making the engine start moving.

[0102] While the motor 10 is made to turn backward when the starter switch 34 is turned ON in the above description, it may alternatively be so arranged that the motor 10 is made to turn backward when the ignition switch 39 is turned ON so that the motor 10 may be able to turn forward once the starter switch 34 is turned ON and, therefore, the engine may be made to start moving without any time lag. Therefore, the motor 10 does not necessarily have to revolve backward when the starter switch 34 is turned ON. Alternatively, it may be so arranged that the motor 10 starts revolving backward when the ignition switch 39 is turned ON. Still alternatively, it may be so arranged that the motor 10 revolves backward when the engine is stopped or the starter switch 34 is released (OFF).

[0103] The above starting motion generally follows one of the three patterns of motion as described below depending on the position at which the position is halted. They include the one that appears when the piston is located at the ordinary halt position before the compression stroke (pattern ①), the one that appears when the piston is located immediately before or after the top dead center between the exhaust stroke and the intake stroke (pattern ②) and the one that appears when the piston is located near the bottom dead center before the exhaust stroke (pattern ③).

[0104] Firstly, the starting motion that follows the pattern ① will be discussed. As the starter switch 34 is turned ON, the motor 10 turn backward for t_1 seconds by means of a command issued from the means 55 for directing energization of the motor for backward revolution of the CPU 32 and the piston move from position A to position B. Thereafter, the energization of the motor 10 is suspended for t_2 seconds by a command issued from the means 56 for directing suspension of energization of the motor. However, the crankshaft 13 keeps on turning backward due to the inertial force obtained by the energization for t_1 seconds. Since the piston does not compress any gas from the intake stroke to the exhaust stroke and hence the load torque is small, the

crankshaft 13 can easily keep on revolving by inertia. However, the inertial energy is consumed by the load torque to gradually reduce the rotational speed until the piston stops at position C.

[0105] The CPU 32 constantly monitors the rotational speed and the rotational angle of the motor 10 by way of the motor rotational speed computing means 51 and the motor rotational angle computing means 52, using the pulse signal indicating the commutation position from the commutation position sensor 25. More specifically, it computationally determines the rotational speed of the motor on the basis of the number of pulses and the pulse intervals of the pulse signal indicating the commutation position as counted in during the time of energization and also the rotational angle on the basis of the accumulated number of the pulses. It also computationally determines the rate of change of the rotational speed (dv/dt) of the motor 10 on the basis of the pulse signal indicating the commutation position. On the other hand, the ROM 37 stores the reference value X_r for the rate of change of the rotational speed and the target rotational speed N_r of the motor 10 to be achieved during the time t_1 . The extent of backward turn correcting means 53 recognizes the friction of the engine on the basis of the increasing rotational speed and feeds it back for controlling the rotational motion of the motor 10.

[0106] More specifically, the extent of backward turn correcting means 53 compares the rate of change of the rotational speed as determined by observing the rotational motion of the motor 10 with the above reference value X_r . If the rate of change of the rotational speed is lower than the reference value and hence the rate of change of the rotational speed is low, the time required for the motor 10 to get to the target rotational speed will be longer than the estimated time, the means 53 judges that the load of rotation of the crankshaft 13 is greater than the expected value. If the operation is left uncorrected, the friction of the engine will be greater than the estimated value during the time of rotation by inertia so that the piston may not be able to return to the expected position. Therefore, the means 53 raises the target rotational speed N_r to increase the inertial energy to be stored in the crankshaft 13 so that the piston may be able to return to the exhaust stroke as expected.

[0107] If, on the other hand, the rate of change of the rotational speed exceeds the reference value, hence the rate of change of the rotational speed is high, the time required for the motor 10 to get to the target rotational speed will be shorter than the estimated time, the means 53 judges that the load of rotation of the crankshaft 13 is smaller than the expected value. If the operation is left uncorrected, the friction of the engine will be smaller than the estimated value during the time of rotation by inertia so that the piston may pass by the expected position. Therefore, the means 53 lowers the target rotational speed N_r to decrease the inertial energy to be stored in the crankshaft 13 so that the pis-

ton may be able to return to the exhaust stroke as expected.

[0108] The extent of backward turn correcting means 53 also monitors the rotational speed of the motor itself to recognize the inertial energy of rotation. More specifically, when the rotational speed gets to the target value N_r , it judges that inertial energy is stored by the predetermined amount if the current time is before the end of the time t_1 . Then, it carries out a correcting operation of reducing the time t_1 and causes the means 55 for directing energization of the motor for backward revolution to suspend the energization of the motor 10. When, on the other hand, the rotational speed does not get to the target value N_r , the means 53 judges that inertial energy is not sufficiently stored if the current time is at the end of the time t_1 . Then, it carries out a correcting operation of extending the time t_1 and causes the means 55 to continue the energization of the motor 10.

[0109] On the other hand, the ROM 37 also stores the reference angle θ_r for backward revolution of the motor 10 and, during the rotation by inertia, the extent of inertial turn correcting means 54 compares the angle of backward revolution as a function of the time of energization for backward revolution and the reference angle θ_r . In this embodiment, an angle of 180° is selected for the reference angle θ_r because the piston will probably be in the exhaust stroke with that angle if the backward revolution is started from the bottom dead center that is the possible remotest position before entering the compression stroke. Therefore, the means 54 of the CPU 32 judges if the rotational angle of the motor 10 has exceeded 180° or not and hence if the input pulse signal of the commutation position is good for 180° or not.

If it is determined by the means 54 that the rotational angle exceeds 180° , it judges that the piston has returned to the exhaust stroke and hence the objective of the suspension of energization is achieved so that it determines to terminate the energization if the current time is before the end of the time t_2 . Then, it notifies the means 56 for directing suspension of energization of the motor that the energization is terminated and issues a command to the means 57 for directing a start of forward turn of the motor to make the latter start driving the motor 10 to rotate immediately once the starter switch 34 is turned ON.

[0110] If, on the other hand, it is determined by the means 54 that the pulse signal of the motor 10 shows a period greater than the predetermined value at the time when the rotational angle is less than 180° so that the rotational speed of the motor undergoes a predetermined level (e.g., speed 0=halt), it judges that the piston has not returned to the exhaust stroke. Then, it judges that the objective of the suspension of energization is not achieved and temporarily stops the suspension of energization to make the motor turn backward for a short period of time even if the current time is in the time t_2 . Differently stated, it notifies the means 56 that the time of suspension of energization is temporarily

stopped and, at the same time, orders the means 55 to energize the motor so as to make it turn backward for a short period of time. After the short period of energizing the motor for backward revolution, the time t_2 is started once again and terminate it when the total rotational angle exceeds 180° .

[0111] Note, by the above backward operation, while the piston is returned to position C in the exhaust stroke that is found within the "range for starting forward turn" in (c) of FIG. 13, it is desirable that the piston is moved back to a position near the bottom dead center before the start of the exhaust stroke that allows the piston to have the longest approach run. However, the position C "in the exhaust stroke" where the piston starts turning forward may include a position near the bottom dead center in the explosion stroke and a position near the top dead center in the intake stroke before or after the exhaust stroke.

[0112] When the time t_2 is over as mentioned above, the means 57 for directing a start of forward turn of the motor of the CPU 32 outputs a signal for causing the motor driver 31 to make the motor 10 revolve forward so that the engine may start moving from the exhaust stroke. Since the crankshaft 13 turns with a small load in the exhaust stroke and the intake stroke, the motor 10 will substantially gets to the largest number of revolutions per unit time that can taken place when it revolves without load before it gets into the compression stroke. In other words, the motor 10 will be in an almost saturated state. Therefore, the crankshaft 13 is also driven by the motor 10 to turn at the largest number of revolutions immediately before the compression stroke and the inertial energy stored in the inertial mass of the rotary system is maximized when the engine enters the compression stroke.

[0113] Thus, as a result, the crankshaft 13 is driven to rotate by the combined effect (thick solid line) of the inertial energy of the engine (dotted broken line) and the rotational energy of the starter motor (solid line) in the compression stroke as shown in (b) of FIG. 13. In other words, the crankshaft 13 is driven by the torque T_i due to the inertial energy produced as a result of the reduction in the number of revolutions of the crankshaft 13 and the drive torque T_m of the motor, which are added to each other to give rise to a torque sufficient to overcome the load of the initial compression stroke, or a ride over torque $T = T_m + T_i$, as the sum thereof.

[0114] Then, in an engine to which this embodiment of motor according to the invention is applied, the drive torque of the motor is made $T_m \leq T/2$ when $T_m \leq T_i$ as seen from (b) in FIG. 13. In other words, the embodiment is designed to get over the load of the compression stroke mainly by means of the inertial energy subordinately by the motor energy and the engine can be made to start moving by means of a motor 10 whose largest torque (lock torque) is less than $1/2$ of the ride over torque T necessary for getting over the load of the compression stroke. Additionally, as shown in (b) of

FIG. 13, the motor 10 is designed to divide its drive energy into two parts and delivers them to the crankshaft 13 respectively during the approach run and during the time of riding over. Therefore, a motor with a relatively low output level according to the invention can be used to generate a large ride over torque if compared with conventional motors that are required to get over a large load in the compression stroke with a single delivery of energy.

[0115] Once the initial compression stroke is got through, inertial energy is accumulated thereafter and the load of any subsequent compression stroke can be easily surmounted. Then, the engine will start moving as the ignition coil 35 throws out sparks at predetermined timing.

[0116] Now, the starting motion that follows the pattern ② will be discussed below. The piston is located near the top dead center between the exhaust stroke and the intake stroke (position D) and then driven to turn backward from there to position E as the motor is energized for the time t_1 . Thereafter, the piston returns to the bottom dead center of the exhaust stroke by inertia and then enters the explosion stroke. However, the torque of the load of revolution increases due to the load of compression generated by the piston in the explosion stroke and the inertial energy is consumed quickly by the torque of the load to make the rotational speed falls and eventually cause the piston to completely halt (position F).

[0117] At this time, the pulse signal of the motor 10 indicating the commutation position shows a period that rapidly increases to by turn rapidly increase the rate of change of the rotational speed (the rate of decreasing speed) of the motor 10 until the latter exceeds the upper limit value X_{max} . Upon recognizing that the rate of change of the rotational speed exceeds the upper limit value X_{max} , the extent of inertial turn correcting means 54 judges that the piston passes by the bottom dead center before the exhaust stroke and enters the explosion stroke to start receiving the compression resistance of the engine. As a result, the piston enters a region where the extent of the approach run can be maximized and inertial energy can be maximally infused into the crankshaft 13. In other words, it is detected that the piston has got to the region suited to start turning forward.

[0118] Then, the means 54 terminates the time t_2 . It then notifies the means 56 of the fact and issues a command for making the motor 10 start turning forward immediately. While the crankshaft 13 may be returned forward slightly by the reaction force of the compression of the piston at this time, the piston halts at position G near the bottom dead center.

[0119] Then, as the time t_2 is terminated and an engine start signal is input from the starter switch 34, the engine is made to start moving from the condition where the piston is located at position G of the exhaust stroke. As a result, the initial load of the compression

stroke can be got through by the sum of the torque T_i due to the inertial energy obtained as a result of the approach run in the exhaust stroke and the intake stroke and the drive torque T_m as pointed out earlier.

[0120] Now, the starting motion that follows the pattern ③ will be discussed below. In this instance, the piston is located near the bottom dead center before the exhaust stroke (position H) and then driven to turn backward. Since it enters the explosion stroke immediately after the start of the backward revolution, the torque of the load of revolution is generated by the piston due to the load of compression of the latter also immediately after the start of the backward revolution. Therefore, the number of revolutions per unit time of the crankshaft 13 is not raised remarkably nor any substantial inertial energy is generated. On the other hand, since the torque of the motor is selected to be less than 1/2 of the ride over torque T necessary for getting over the load of the compression stroke, the explosion stroke would not be got through by the backward revolution and the motor is locked and stops moving when the reaction force of compression produced by the piston and the motor torque are balanced by each other (position I).

[0121] Then, the period of the pulse signal that is once reduced by energization as a result of the operation of the motor 10 increases to become longer than the predetermined value so that the rotational speed falls below the predetermined lower limit value V_{min} . Upon recognizing that the rotational speed falls below the predetermined lower limit value V_{min} , the extent of backward turn correcting means 53 judges that the piston passes by the bottom dead center of the explosion stroke and compression torque begins to be generated. In other words, it judges that the objective of the backward revolution is achieved and immediately terminates the time t_1 . It then notifies the means 55 of the fact and issues a command to the means 57 to make the latter start driving the motor 10 to rotate immediately once the starter switch 34 is turned ON.

[0122] When the time t_1 is terminated, the motor torque is lost as the motor has not been energized and the crankshaft 13 gradually starts revolving forward by the reaction force of the piston during the time t_2 and turns at an increasing rate. Subsequently, the reaction force of the piston is lost at or near the bottom dead center and thereafter the inertial energy of rotation is gradually consumed by the torque of the load of revolution so that the piston stops at position J before it enters into the intake stroke from the exhaust stroke. If the torque of the load of revolution is small, the piston can enter the intake stroke from the exhaust stroke during the time t_2 due to rotation by inertia so that the time t_2 has to be terminated before the piston enters the intake stroke. Therefore, the energization for forward revolution has to be started before the commutation pulse of the motor 10 exceeds the extent corresponding to 180° at maximum even before the termination of the time t_2 . Then, in a manner as described above, the cranking

motion starts from this position.

[0123] Thus, as described above, with this embodiment of starter according to the invention, the motor 10 is made to turn backward for the time t_1 before the engine starts moving and then it is deenergized for the time t_2 to allow the crankshaft 13 to turn by inertia. Thereafter, the motor 10 is made to turn forward. At this time, the motor 10 computationally determines the rotational speed, the rate of change of the rotational speed and the rotational angle of the motor on the basis of the pulse signal indicating the commutation position and estimates the piston position to feed back and control the times t_1 and t_2 . Thus, the engine can be reliably made to start moving from the exhaust stroke without providing a sensor for detecting the position of the piston such as a camshaft sensor so that the cost of the engine can be reduced for the reason of the absence of such sensors.

[0124] Additionally, since the initial compression stroke can be got through by utilizing the inertial energy of the crankshaft 13, the load of the motor 10 can be reduced and hence the motor 10 can be downsized to make it energy-saving. Still additionally, if a starter according to the invention uses a magnet for the magnetic field system of the motor, the magnet is not required to show excessive magnetic force so that it is possible to reduce the rotational resistance of the motor and hence the specific fuel consumption of the engine without sacrificing the output power of the engine.

[0125] If the operation of starting the engine fails, the backward turn sequence down to the exhaust stroke of the attempt of restarting the engine immediately thereafter is followed immediately and automatically if the halt of the engine is detected while the ignition switch is held ON. Therefore, when the starter switch 34 is turned ON for another time, the motor 10 immediately starts revolving forward without giving rise to any time lag as described earlier. Additionally, the motor 10 is allowed to operate only when the brake is being operated and/or when the gear is found in the neutral position so that any unintended burst of the vehicle is inhibited.

[0126] While the above embodiment is described in terms of a 4-stroke engine to which it is applied, this embodiment can also be applied to a 2-stroke engine as well. FIG. 14 is a chart illustrating the starting motion of a 2-stroke engine that can be triggered by the embodiment. Unlike the 4-stroke engine, the strokes of intake, compression, explosion and exhaust proceeds within a single turn of the crankshaft of the 2-stroke engine. While the 2-stroke engine is not provided with an intake valve and an exhaust valve unlike the 4-stroke engine, the piston of the engine itself takes the part of the valves.

[0127] As shown in FIG. 14, the intake port and the exhaust port of the cylinder of the 2-stroke engine are blocked by the piston both in the compression stroke and in the explosion stroke. Additionally, the exhaust

stroke and the intake stroke take place simultaneously. In other words, both the exhaust port and the intake part are open when the piston is located near the bottom dead center. The exhaust stroke of the 4-stroke engine corresponds to the period between the time when at least either the exhaust port or the intake port is opened and the time when the piston gets to the bottom dead center of the 2-stroke engine as the engine is operated (to turn forward).

[0128] Thus, as may be clear from the charts of FIGS. 13 and 14, the effect described above in terms of the 4-stroke engine can also be achieved for the 2-stroke engine by operating the motor in a manner as described above except the above differences.

(Embodiment 4)

[0129] Now, Embodiment 4 of starter motor of engine according to the invention will be described. However, since the configuration of this embodiment is basically identical with that of Embodiment 1, the parts that are common to those embodiments will not be described any further.

[0130] FIG. 15 is a schematic block diagram of the control system of Embodiment 2 of starter motor according to the invention. As shown in FIG. 15, the motor 10 is driven by motor driver 31 under the control of CPU (control means) 32. The CPU 32 is connected to a camshaft sensor 33 for detecting the movement of a valve cam, an engine starter switch 34 and an ignition switch 39. The CPU 32 is also connected to an ignition coil 35 for igniting the fuel in the engine by way of an ignition unit 36. It is further connected to a ROM 37 storing the motor driver drive logic and various control programs including the engine control program and a RAM 38 storing the data from various sensors. Thus, it sends control signals to various components of the system including the motor driver 31 and the ignition unit 36 on the basis of the detected values of the various sensors to control the motor 10 and also the operation of igniting the fuel in the engine. Note that the motor 10 itself and the CPU 32 are powered by a power source that is a battery (not shown) loaded in the vehicle.

[0131] FIG. 16 is a chart illustrating the starting motion of an engine in case of applying a starter according to the invention to a 4-stroke engine including the intake stroke in which the piston is lowered from the top dead center and mixture gas is sucked into the cylinder under the condition where the intake valve is open and the exhaust valve is closed, the compression stroke in which the mixture gas is compressed under the condition where both the intake valve and the explosion valve are closed, the working stroke, that is, the explosion stroke in which the mixture gas is ignited little before the top dead center where the compression stroke ends and the piston is pressed down by the high pressure gas generated as a result of combustion under the condition where both the intake valve and the exhaust valve

are closed and the exhaust stroke in which the expanded gas is forced out under the condition where the intake valve is open and the exhaust valve is closed. Two turns of the crankshaft 13 or the above four strokes constitute a cycle.

[0132] When the motor 10 is driven to start turning while the engine at rest, the rotational load at the start of motion varies depending on the stroke where the engine found at the time of the start as illustrated in (a) of FIG. 16. More specifically, when the engine is in the exhaust stroke or the intake stroke, the load of driving the crankshaft 13 to turn is relatively small because the position moves up and down under the condition in which either the intake valve and the exhaust valve is open. To the contrary, when the engine is in the compression stroke and driven to start moving, the load of driving the crankshaft 13 to turn is large and maximized at a point little before the top dead center because the piston has to be raised under the condition in which both the intake valve and the exhaust valve is closed.

[0133] As pointed out above, the piston often stops near the bottom dead center in the compression stroke when the engine is made to stop. Since known starters have to make the engine to start moving from this position, the energy that has to be fed to the crankshaft 13 from the starter motor in order to make the crankshaft 13 get over the load in the compression stroke typically shows a profile as indicated by a broken line in FIG. 16.

[0134] On the other hand, when making the engine to start moving from position Pa in the ordinary stop zone P shown in (c) of FIG. 16 by means of a starter according to the invention, the crankshaft 13 is firstly made to turn backward in order to pass through the intake stroke and the exhaust stroke and get into the explosion stroke. In this backward turn process, the piston is moved in the direction opposite to the direction indicated by the arrow in FIG. 16. More specifically, it is moved toward the top dead center in the intake stroke, toward the bottom dead center in the exhaust stroke and toward the top dead center in the explosion stroke.

[0135] Therefore, the gas remaining in the combustion chamber is compressed by the backward turn in the explosion stroke under the condition in which both the intake valve and the exhaust valve are closed so that energy for forward revolution is accumulated in the combustion chamber as a result of the compression. The doubly dotted broken line in (b) of FIG. 16 indicates the accumulated energy. Note that, when the engine is made to start moving, it can be turned backward in a manner as described above not only when the piston is in the ordinary stop zone P but also when the piston is at pause in the intake stroke or the exhaust stroke.

[0136] The crankshaft 13 is turned forward by the motor 10 after it is turned backward to the turning point, or the position Qa from which it is turned forward, of starting zone Q for forward revolution in the explosion stroke. At this time, the energy for forward revolution accumulated in the compressed gas in the combustion

chamber is discharged to the rotary system of the crankshaft 13 including the flywheel. Thus, the rotary system is fed with the energy discharged as a result of the compression and the rotational energy delivered from the motor 10.

[0137] In (b) of FIG. 16, the changing energy fed to the crankshaft 13 from the motor 10 that is turning forward is indicated by a solid line, while the changing inertial energy stored in the rotary system is indicated by a dotted broken line. As seen from FIG. 16, inertial energy is rapidly accumulated in the rotary system in the initial stages of the forward revolution due to the discharge of gas energy that takes place as a result of the reaction of the compression and the accumulated inertial energy is increased gradually from the explosion stroke to the compression stroke by the rotational force of the motor 10. Therefore, in the compression stroke, the sum of the inertial energy accumulated in the rotary system and the energy of the motor 10 is fed to the crankshaft 13 as indicated by a thick solid line in FIG. 16. In other words, the crankshaft 13 is driven by the inertial energy that is discharged as the number of revolution decreases and consumed in the compression stroke and the torque of the motor 10, and the maximum ride-over torque T is the sum of the largest value T_i of the discharged energy of the inertial torque and the largest value T_m of the torque of the motor 10, which is sufficient for getting through the initial compression stroke.

[0138] FIG. 17 (a) shows the change in the piston position, (b) shows the change in the number of revolutions of the crankshaft, (c) shows the energy change, (d) shows the change in the motor output energy and (e) shows the change in the ride-over energy. FIG. 18 is a chart illustrating the change in the energy generated by the motor and the change in the energy of the rotary system that appear when the crankshaft 13 is tuned backward to the explosion stroke and subsequently tuned forward.

[0139] With this embodiment, the motor 10 is tuned backward into the explosion stroke of the piston to compress the gas in the combustion chamber when the internal combustion engine is made to start moving so that energy is accumulated for forward revolution by the reaction of the compression. Then, the motor 10 is so controlled that the rotational energy of the motor 10 is added to the accumulated energy and consequently inertial energy may be accumulated in the rotary system of the crankshaft 13 and used to get through the compression stroke. With this arrangement, the motor 10 may be significantly down-sized.

[0140] In the case where the embodiment is used for a 2-stroke engine, a crank angle sensor may be provided to directly detect the angle of the crankshaft 13 when the crankshaft is turned backward to the explosion stroke so that the turning point from backward revolution to forward revolution may be determined on the basis of the detected crank angle. On the other hand, in the case where the embodiment is used for a 4-stroke, not only

the signal from the crank angle sensor but also the signal from the camshaft sensor 33 may be used for detecting the stop position Pa of the crankshaft 13 and also the position Qa for forward revolution. Then, the time of terminating the energization for backward revolution and that of starting the energization for forward revolution can be determined by means of an angle sensor arranged on the crankshaft and an angle sensor arranged on the camshaft. Alternatively, it may be so arranged that the energization for forward revolution is started when the crankshaft is made to turn forward by the reaction of the compression and the change in the sense of revolution is detected. Still alternatively, the pulse signals generated by the angle sensors may be used as signals indicating the end of backward revolution and the start of forward revolution only when they show a reduction in the rotational speed. With this embodiment, the pulses in the exhaust stroke are simply ignored.

[0141] Both in the case of a 2-stroke engine and in the case of a 4-stroke engine, it may be so arranged that the motor 10 is made to turn backward from the halt position for a predetermined period of time and subsequently the piston is returned to the explosion stroke by inertia. Alternatively, the engine may be driven back to the explosion stroke by the motor 10. Note that any excessive current may be prevented from flowing to the motor and destroy any of the commutation elements such as FETs by making the motor 10 turn by inertia for a predetermined period of time after the termination of energization for backward revolution and subsequently energizing it for forward revolution. Then, unlike the case where the energization for backward revolution is instantaneously switched to the energization for forward revolution, the motor can be made to turn backward without subjecting FETs and other elements to an excessive load.

[0142] Since a pulse signal can be taken out from the commutation position sensor 25 as shown in (6) of FIG. 16 when the motor 10 is turning backward or forward, it may be so arranged that the turning point from backward revolution to forward revolution is detected by detecting the pulse signal. The turning point may be detected by counting the number of pulses when the motor 10 is changing the sense of turning. Alternatively, the speed of the motor may be detected by detecting the pulse intervals. In any case, the turning point can be reliably detected by feeding back the outcome of the above detection to the control section.

[0143] When the speed of the motor is detected by detecting the pulse intervals, there may be cases where the rotational resistance of the engine is large and the piston cannot return to the predetermined position if it takes more time than expected for the speed to get to the predetermined level. Therefore, it is necessary to provide and operate a feedback and control system in order to raise the target value of the speed. If, on the other hand, the speed gets to the predetermined level

too early, the rotational resistance of the engine can be small and the piston may pass by the predetermined position. Then, it is necessary to operate the feedback and control system in order to lower the target value of the speed.

[0144] It may alternatively be so arranged that the motor is energized until the rotational speed of the rotary system get to the target value and subsequently deenergized once the target value is reached if it is possible to detect the rotational inertial energy of the rotary system.

[0145] When the piston get through the intake stroke and moves into the explosion stroke from the exhaust stroke, it is exposed to compression resistance when it passes through the bottom dead center and moves upward. Then, as shown in (b) of FIG. 17, the speed increases gradually after the turning point and then becomes reduced. Thus, the pulse intervals are shortened as a result of the speed increase and then prolonged as a result of the speed reduction. Therefore, it is also possible to detect the time when the explosion stroke is reached by detecting the change in the pulse intervals. If the piston is made to return to the explosion stroke by inertia without energizing the motor, the rate of increase of the pulse intervals, or the rate of speed reduction, rapidly changes. Therefore, it is possible to detect the time when the explosion stroke is reached by detecting the change in the rate of increase of the pulse intervals.

[0146] Now, the sequence of operation of making the engine start moving will be described. As the ignition switch 39 is turned ON, the CPU 32 firstly recognizes the current position of the piston on the basis of the detection signal of the camshaft sensor 33. In other words, the CPU 32 recognizes the current position of the piston and makes it ready to cause the piston to turn backward to the explosion stroke by means of the signal from the camshaft sensor 33.

[0147] If a camshaft sensor 33 is provided and the piston is at rest at a position outside the ordinary stop zone P, the position can be detected from the detection signal of the camshaft sensor 33. Then, as an engine start signal is input by the starter switch 34, the CPU 32 determines that the piston is to be returned to the explosion stroke on the basis of the detection signal and issues a command to the motor driver 31 to temporarily turn backward the motor 10 and making the crankshaft 13 also turn backward to the explosion stroke. If a camshaft sensor 33 is provided, it outputs an H signal indicating that the piston has reached the explosion stroke so that it is possible to detect that the piston has turned backward and got to the position Qa in the explosion stroke from which it starts turning forward. Then, the CPU 32 makes the motor 10 stop its backward revolution and immediately start turning forward.

[0148] In this case, since the crankshaft 13 turns with a small load in the exhaust stroke and the intake stroke, the motor 10 will substantially gets to the largest

number of revolutions per unit time that can taken place when it revolves without load before it gets into the compression stroke. In other words, the motor 10 will be in an almost saturated state. Therefore, the crankshaft 13 is also driven by the motor 10 to turn at the largest number of revolutions immediately before the compression stroke and the inertial energy stored in the inertial mass of the rotary system is maximized when the engine enters the compression stroke.

[0149] Thus, as a result, the crankshaft 13 is driven to rotate by the combined effect (thick solid line) of the inertial energy of the engine (dotted broken line) and the rotational energy of the starter motor (solid line) in the compression stroke as shown in (b) of FIG. 16. Additionally, as shown in (b) of FIG. 16, the motor 10 is designed to divide its drive energy into two parts and delivers them to the crankshaft 13 respectively during the approach run and during the time of riding over. Therefore, a motor with a relatively low output level according to the invention can be used to generate a large ride over torque if compared with conventional motors that are required to get over a large load in the compression stroke with a single delivery of energy.

[0150] Additionally, the motor 10 is allowed to operate only when the brake is being operated and/or when the gear is found in the neutral position so that any unintended burst of the vehicle is inhibited.

[0151] Once the initial compression stroke is got through, inertial energy is accumulated thereafter and the load of any subsequent compression stroke can be easily surmounted. Then, the engine will start moving as the ignition coil 35 throws out sparks at predetermined timing.

[0152] As described above, with a motor 10 according to the present invention, the piston is temporarily returned to a position in the explosion stroke immediately before the position at which it is halted prior to the start of the engine in order to raise the inertial energy of the crankshaft 13 before the initial ride over. Therefore, the initial compression stroke can be got through by utilizing the inertial energy even if a motor according to the invention and having a torque smaller than any conventional motors of the type under consideration is used. Then, the motor can be downsized to reduce the manufacturing cost and the power consumption rate of the motor.

[0153] While the piston is firstly turned backward from the halt position to the explosion stroke and then turned forward when making the engine start moving in the above description, it may alternatively be so arranged that the piston is firstly made to turn forward and the bottom dead center before the compression stroke is detected from the change in the pulse intervals of the pulse signal from the commutation position sensor 25 so that the motor 10 may be energized to turn backward from that position and inertial energy may be accumulated by the time when the piston gets to the bottom dead center after the explosion stroke. Then, the

torque obtained as a result of the discharge of the inertial energy and the torque generated by the motor 10 will provide energy sufficient to raise the piston to position Qa in the explosion stroke.

[0154] Still alternatively, it may be so arranged that the crankshaft 13 is turned firstly forward to a position in the compression stroke, which may be immediately before the top dead center of the compression stroke, and then backward to the explosion stroke in a manner as described above. If such is the case, the piston can also be raised to position Qa in the explosion stroke by turning the crankshaft backward, utilizing the reaction force of the compression of the gas remaining in the combustion chamber in the compression stroke and also the motor energy. In any case, the energy necessary for raising the piston in the explosion stroke can be increased to obtain a large reaction force for turning it forward if a motor showing a relatively small torque is used.

[0155] The process of turning the crankshaft 13 firstly forward to compress the gas in the combustion chamber and then backward by utilizing the reaction of the compressed gas at the time of causing the engine to start moving is particularly effective for a 2-stroke engine because explosion takes place at each turn of the crankshaft of the 2-stroke engine and hence the engine immediately gets into the compression stroke if the crankshaft is simply turned backward so that it is difficult to secure an approach run sufficient for accumulating rotational energy.

[0156] FIG. 19 is a chart of the starting, where the crankshaft 13 is turned firstly forward to compress the gas in the combustion chamber and then backward by utilizing the reaction of the compressed gas at the time of causing the engine to start moving. FIG. 20 is a chart illustrating the energy change in the case of FIG. 19. Thus, by adding a forward turning motion before the backward turning motion, the 2-stroke engine can be made to start moving by means of a small motor 10.

[0157] This method of accumulating energy for getting over the compression point for forward revolution by using the reaction force of compression for forward revolution and that of compression for backward revolution is also effective when starting a multi - cylinder engine. Particularly, in the case of a 4-cycle 2-cylinder engine arranged with a 180° crank, either the piston of cylinder A or that of cylinder B is moved to compress the gas in the combustion chamber if the piston is turned forward or backward from the halt position so that it is not possible to provide an approach for accumulating rotational energy as shown in FIG. 21.

[0158] If such is the case, both the reaction force of compression for forward revolution and that of compression for backward revolution are utilized for a plurality of times to gradually raise the energy of the reaction of compression and obtain inertial energy sufficient for ultimately getting over the compression point for forward revolution.

[0159] On the other hand, when storing energy of compression by utilizing inertial energy directed toward explosion for backward revolution with any of the above described embodiments, the compression point can be got over due to the change of rotation load and the like that can take place depending on temperature. This can be prevented from occurring by detecting the position of the piston compressing the gas for backward revolution, suspending the energization of the motor for backward revolution when the crankshaft shows an angle with which the piston can get over the compression point for backward revolution and then energizing the motor for forward revolution. The piston position can be detected by means of a crank angle sensor or a camshaft angle sensor or by using the count of the commutation pulses of the brushless motor.

(Embodiment 5)

[0160] Next, Embodiment 5 of starter motor of engine according to the invention will be described. FIG. 22 is a schematic cross sectional view of Embodiment 5 of engine starter motor according to the invention, FIG. 23 is a schematic front view of the starter motor of FIG. 22 from which the housing and the cover are removed.

[0161] A starter motor 110 of FIG. 22 (hereinafter simply referred to as motor) is linked directly to a 4-cycle engine of motor bicycle and provided with a stator 112 rigidly secured to an engine case 111 of the engine and a rotor 114 linked to a crankshaft 113 of the engine.

[0162] The rotor 114 is provided with a yoke 115 made of a magnetic material such as iron and having a shape of a bottomed short cylinder. A boss section 116 having a cylindrical profile is integrally formed on and concentrically projecting from the inner surface the bottom wall of the yoke 115. As the boss section 116 and the crankshaft 113 are coupled together by means of a set nut 117 at the respective tapered surfaces thereof to give rise to a wedge effect, the rotor 114 is rigidly secured to the crankshaft 113 so as to integrally revolve with the latter. A number of permanent magnets 118 and the same number of control magnetic poles 128 formed by using a magnetic material such as iron (having a high permeability) are arranged peripherally and alternately and rigidly secured to the inner peripheral surface of the yoke 115. Both the permanent magnets 115 and the control magnetic poles 128 have a substantially rectangularly parallelepipedic shape with slightly arcuate contour lines and a same size. They are peripherally arranged at regular intervals. Any adjacently located ones of the permanent magnets 118 are made to show a same polarity while the control magnetic pole arranged therebetween is made to show the opposite polarity.

[0163] The stator 112 of the motor 110 comprises a core 119 made of a magnetic material such as iron and having a shape of a low profile disk that rather resembles a star. The core 119 is rigidly secured by means of

a bolt 121 to a housing 120 arranged on the outer surface of the engine case 111 concentrically with the crankshaft 113. A cover 126 is arranged to the outside of the housing 120. The rotor 114 is arranged within the housing 120 to surround the stator 112 and it is adapted to move around the stator 112 as it is driven by the crankshaft 113.

[0164] The core 119 is formed by laying a number of thin plates of a magnetic material such as iron one on the other to form an integral entity and has a doughnut-shaped main body 122. A plurality of salient poles 123 are radially projecting from the outer periphery of the core main body 122. Each of the salient poles 123 is wound by a stator coil 124 for three-phase winding, which the coil 124 is connected to a motor driver which will be described hereinafter via a terminal (not shown) by means of a lead wire and a wire harness (not shown). In short, the motor 110 is a brushless motor driven by the motor driver.

[0165] A field control coil 129 for controlling the magnetic flux of the field is formed at the bottom side of the yoke 115 of the core main body 122 concentrically with the latter. The field control coil 129 is wound so as to show a concentric circle relative to the stator 112 and the rotor 114 as viewed from above. Therefore, the magnetic flux F of the field control coil 129 is mostly used to form a closed magnetic circuit that passes through the main body 122 of the core 119, the salient poles 123 opposite to the control magnetic poles 128, the control magnetic poles 128 of the rotor 114, the yoke 115, the boss member 116 and the core 119.

[0166] A field coil control section which will be described hereinafter is made responsible to the excitation control of the field control coil 129. When the field control coil 129 is excited so as to increase the effective magnetic flux acting on the stator coil 124, the magnetic flux of the magnetic field that crosses the stator coil 124 in an interwoven fashion will be such that can be obtained by laying the magnetic flux of the permanent magnets 118 on the magnetic flux F of the field control coil 129 so that the change in the overall magnetic flux becomes remarkable due to the increment produced as a function of the current energizing the field control coil 129 to consequently increase the magnetic force that is generated by the stator coil 124. As a result, the control magnetic poles 128 obtain magnetic force as much as that of the permanent magnets 118 but show the opposite polarity so that they can make the motor operate to provide a large lock torque.

[0167] On the other hand, when the field control coil 129 is energized reversely so as to make the control magnetic poles 128 and the permanent magnets 118 show a same polarity, the magnetic flux of the permanent magnets 118 and the magnetic flux F' of the field control coil 129 that appear on the stator coil 124 are interwoven differentially so that the change in the overall magnetic flux is made small as those magnetic fluxes are offset by each other depending on the electric cur-

rent energizing the field control coil 129. As a result, the effective magnetic flux acting on the stator coil 124 is reduced to by turn reduce the iron loss of the core 119. Then, the control magnetic poles 128 obtains only weak magnetic force to make the motor operate to provide a small lock torque.

[0168] The motor 110 is also provided with a plurality of (e.g., three) commutation position sensors 125 that are arranged in the housing 120 and adapted to sense the magnetism of the permanent magnets 118 and detect the rotary position of the rotor 114. The output of the commutation position sensors 125 is fed to the motor driver which will be described hereinafter by way of a CPU 132 so that the motor driver generates an energization signal corresponding to the detection signal from the commutation position sensors 125 and feeds the stator coils 124 with an electric current on the basis of the signal in order to sequentially and magnetically energize the stator coils 124. As the stator coils 124 are sequentially and magnetically energized, a rotating magnetic field is formed by the stator coils 124. Then, the rotating magnetic field acts on the permanent magnets 118 and the rotor 114 is driven to rotate by the rotating magnetic field. Thus, the turning effort of the rotor 114 is transmitted to the crankshaft 113 by way of the boss section 116 of the yoke 115 to cause the engine to start moving.

[0169] FIG. 24 is a graph illustrating the performance of the starter motor 110 and FIG. 25 is a graph illustrating the operation of controlling the switched utilization of the performance of the motor.

[0170] As seen from the graphs, the starting torque is raised to boost the rate of increase of the rotational speed when the motor is operating at low rotational speed if the field control coil 129 is energized to produce a strong magnetic field. However, since the rotational speed is low without any load, it gets to become saturated early to reduce the achievable maximum rotational speed. On the other hand, if the field control coil 129 is energized to produce only a weak magnetic field, the rotational speed is high without any load, it gets to become saturated late to raise the achievable maximum rotational speed, however, since the starting torque is small the rate of increase of the rotational speed becomes low when the speed is relatively low.

[0171] Therefore, it is possible to selectively use the performance of the motor as shown in FIG. 25 so that the rate of increase of the rotational speed can be raised by intensifying the magnetic flux in the low rotational speed zone whereas the maximum rotational speed can be raised by weakening the magnetic flux in the high rotational speed zone.

[0172] FIG. 26 is a schematic block diagram of the control circuit of the above described starter motor 110. Referring to FIG. 26, a CPU 131 is adapted to receive signals from a commutation position sensor 125 having a configuration as described above, a camshaft sensor 132 for detecting any motion of a valve cam of the

engine, a starter switch 133, an ignition switch 134 and an ACG pulser 135. The CPU 131, on the other hand, sends a control signal to a motor driver 136 for controlling the power supply to the stator coil 124 and a field coil control section 137 for controlling the power supply to the field control coil 129. It also sends a control signal to an ignition unit 139 for controlling the timing of ignition of an ignition coil 138 for igniting the gas in the engine. The CPU 131 is connected to a ROM 141 storing motor driver drive logic and various control programs necessary for controlling the engine and a RAM 142 storing data sent from various sensors. Note that the motor 110 and the CPU 131 are fed with power by a power source that is a battery loaded on the vehicle (not shown).

[0173] FIG. 27 is a chart illustrating the starting motion of an engine in case of applying a starter according to the invention to a 4- stroke engine including the intake stroke in which the piston is lowered from the top dead center and mixture gas is sucked into the cylinder under the condition where the intake valve is open and the exhaust valve is closed, the compression stroke in which the mixture gas is compressed under the condition where both the intake valve and the explosion valve are closed, the working stroke, that is, the explosion stroke in which the mixture gas is ignited little before the top dead center where the compression stroke ends and the piston is pressed down by the high pressure gas generated as a result of combustion under the condition where both the intake valve and the exhaust valve are closed and the exhaust stroke in which the expanded gas is forced out under the condition where the intake valve is open and the exhaust valve is closed. Two turns of the crankshaft 113 or the above four strokes constitute a cycle.

[0174] When the motor 110 is driven to start turning while the engine at rest, the rotational load at the start of motion varies depending on the stroke where the engine found at the time of the start as illustrated in (a) of FIG. 27. More specifically, when the engine is in the exhaust stroke or the intake stroke, the load of driving the crankshaft 113 to turn is relatively small because the position moves up and down under the condition in which either the intake valve and the exhaust valve is open. To the contrary, when the engine is in the compression stroke and driven to start moving, the load of driving the crankshaft 113 to turn is large and maximized at the top dead center because the piston has to be raised under the condition in which both the intake valve and the exhaust valve is closed. Similarly, when the engine is in the explosion stroke and driven to start moving, the load of driving the crankshaft 113 to turn is large because the piston has to be fallen toward the bottom dead center under the condition in which both the intake valve and the exhaust valve is closed.

[0175] As pointed out above, the piston often stops near the bottom dead center in the compression stroke when the engine is made to stop. The known starters have to make the engine to start moving from this posi-

tion, the energy that has to be fed to the crankshaft 113 from the starter motor in order to make the crankshaft 113 get over the load in the compression stroke typically shows a profile as indicated by a broken line in (b) of FIG. 27.

[0176] In the case of FIG. 27, if the engine is made to start moving from the state where the piston is held at rest at halt position Pa, the crankshaft 113 is made to turn backward to the exhaust stroke by the motor 110 and then made to turn forward. As a result, the crankshaft gets into the compression stroke with an approach run that covers a stretch showing a low load of and then rides over the largest load by the effect of combining the inertial energy of the rotary system produced by the flywheel of the engine and the torque of the motor so that the overall load and hence the power consumption of the motor can be reduced and the motor itself can be down-sized.

[0177] When causing the crankshaft 113 to turn forward, the field control coil 129 is energized to intensify the field and then the motor 110 is started. As the rotational speed of the motor 110 rises, the starting torque of the motor 110 is gradually reduced and, when the rotational speed of the motor exceeds about 1/2 of the no-load rotational speed, the power output of the motor exceeds the maximum output point so that the output of the motor can no longer be effectively transformed into rotational energy as seen from FIG. 24. In short, the rate of increase of the rotational speed falls.

[0178] If the field is made weak at this time, the torque and the output of the motor are raised when the rotational speed is high although the lock torque and the maximum output of the motor may be reduced. Therefore, it is again possible to effectively transform the motor output into rotational energy and hence raise the rate of increase of the rotational speed. Thus, the rotational speed can be raised and hence inertial energy can be accumulated in a most efficient way by repeating the above control sequence from the start of forward revolution of the motor 110 to the compression stroke and sequentially switching the level of energization of the field coil from a large current directed to intensify the field to a small current and then to deenergization or from a small current directed to weaken the field to a large current.

[0179] In this way, with a starter comprising a field coil adapted to make the magnetic field of the magnets variable, it is possible to efficiently raise the rotational speed simply by energizing the field coil in order to intensify the field at the time of start and subsequently controlling the energization of the field coil in synchronism with the timing of selective utilization of the performance of the motor.

[0180] While the rotational speed of the motor can be detected by arranging a device adapted to generate a pulse in synchronism with the revolution of the motor and observing the pulse intervals, no such sensor is needed when the motor is a brushless motor and the

pulse generated by the sensor for detecting the commutation position for energizing the armature coil of the motor is utilized.

[0181] Now, the starting operation of the engine shown in FIG. 27 will be discussed below. As the ignition switch 134 is turned ON, the CPU 131 firstly recognizes the current position of the piston on the basis of the detection signal of the camshaft sensor 132 and determines if it is necessary to return the piston to the exhaust stroke or not. In other words, the CPU 131 recognizes the current position of the piston by means of the signal from the camshaft sensor 132 so as to reliably cause the piston to move into the exhaust stroke.

[0182] If the piston is found in a stroke other than the exhaust stroke, the CPU 131 determines to cause the piston to move back to the exhaust stroke and issues a command to the motor driver 136 to make the motor 110 turn backward temporarily so as to cause the crankshaft 113 to rotate into the exhaust stroke. For example, if the piston is found at position Pa as shown in (c) of FIG. 27 when the ignition switch is turned ON, it is temporarily moved back to the exhaust stroke as indicated by the arrow. The position of the piston is constantly monitored by the camshaft sensor 132 so that the latter issues an H signal when the piston gets to the exhaust stroke. As the detection signal (H) is issued from the camshaft sensor 132 to tell that the piston is in the exhaust stroke, the CPU 131 causes the motor 110 to cease the reverse turn and temporarily halt at position Qa.

[0183] Thus, while the piston is returned to position Qa in the exhaust stroke that is found within the "range Q for starting forward turn" in (c) of FIG. 27, it is desirable that the piston is moved back to a position near the bottom dead center before the start of the exhaust stroke that allows the piston to have the longest approach run. Note, however, the position Qa in the exhaust stroke where the piston starts turning forward may include a position near the bottom dead center in the explosion stroke and a position near the top dead center in the intake stroke before or after the exhaust stroke.

[0184] If, on the other hand, it is detected by the camshaft sensor 132 that the piston is already located at position it in the exhaust stroke when the latter starts moving, the CPU 131 determines that it is not necessary to return the piston to the exhaust stroke and hence does not cause it to turn backward in a manner as described above.

[0185] Note that the motor 110 is made to revolve backward when the ignition switch 134 is turned ON in order for the motor 110 to start revolving forward immediately to eliminate any time lag before the start of the engine when the starter switch 133 is turned ON. Therefore, the motor 110 does not necessarily have to revolve backward when the ignition switch is turned ON. Alternatively, it may be so arranged that the motor 110 starts revolving backward when the starter switch 133 is tuned

ON. Still alternatively, it may be so arranged that the motor 110 revolves backward when the engine is stopped or the starter switch 133 is released (OFF) .

[0186] Then, as the engine start signal is input from the starter switch 133, the CPU 131 outputs a signal for causing the motor 110 to turn forward to the motor driver 136 in order to make the crankshaft 113 of the engine revolve forward from the exhaust stroke. At the time when the motor 110 starts turning, the field coil 129 is energized so as to intensify the field and raise the starting torque. Then, the rotational speed is raised gradually and when predetermined rotational speed level N1 is exceeded, the field coil 129 is deenergized and the performance of the motor that shows a large number of revolutions without load is selectively used. Thereafter, the rotational speed is raised further and when predetermined rotational speed level N2 is exceeded, the field coil 129 is energized so as to weaken the field and the performance of the motor is switched (FIG. 25). As a result, the rotational speed of the motor 110 can be efficiently increased so that it gets to a level higher than the level corresponding to the maximum number of revolutions per unit time that can be achieved by the performance of the motor before the switch. Thus, the crankshaft 113 is also driven to rotate at the possible highest rotational speed that can be achieved by means of the motor before the compression stroke and the inertial energy accumulated in the inertial mass of the rotary system is maximized when the engine enters the compression stroke.

[0187] Thus, as a result, the crankshaft 113 is driven, to rotate by the combined effect (thick solid line) of the inertial energy of the engine (dotted broken line) and the rotational energy of the starter motor (solid line) in the compression stroke as shown in (b) of FIG. 27. In other words, the crankshaft 113 is driven by the torque T_i due to the inertial energy produced as a result of the reduction in the number of revolutions of the crankshaft 113 and the drive torque T_m of the motor, which are added to each other to give rise to a torque sufficient to overcome the load of the initial compression stroke, or a ride over torque $T = T_m + T_i$, as the sum thereof.

[0188] If the rotational speed falls below both of the predetermined rotational speed levels N2, N1 as a result of the discharge of inertial energy that takes place when riding over the load of the compression stroke, the motor is made to show the performance corresponding to the actual rotational speed. Then, the motor torque can be raised again to make the engine ready for riding over the load.

[0189] In the engine to which this embodiment of motor according to the invention is applied, the drive torque of the motor is made $T_m \leq T/2$ when $T_m \leq T_i$ as seen from (b) in FIG. 27. In other words, the embodiment is designed to get over the load of the compression stroke mainly by means of the inertial energy subordinately by the motor energy and the engine can be made to start moving by means of a motor 110

whose largest torque (lock torque) is less than 1/2 of the ride over torque T necessary for getting over the load of the compression stroke. Additionally, as shown in (b) of FIG. 27, the motor 110 is designed to divide its drive energy into two parts and delivers them to the crankshaft 113 respectively during the approach run and during the time of riding over. Therefore, a motor with a relatively low output level according to the invention can be used to generate a large ride over torque if compared with conventional motors that are required to get over a large load in the compression stroke with a single delivery of energy.

[0190] If the engine does not start, the backward turn sequence down to the exhaust stroke of the attempt of restarting the engine immediately thereafter is automatically followed if the halt of the engine is detected while the ignition switch 134 is held ON. Therefore, when the starter switch 133 is turned ON for another time, the motor 110 immediately starts revolving forward without giving rise to any time lag. Additionally, the motor 110 is allowed to operate only when the brake is being operated and/or when the gear is found in the neutral position so that any unintended burst of the vehicle is inhibited.

[0191] Once the initial compression stroke is got through, inertial energy is accumulated thereafter and the load of any subsequent compression stroke can be easily surmounted. Then, the engine will start moving as the ignition coil 138 throws out sparks at predetermined timing.

[0192] As described above, in the case of FIG. 27, the piston is temporarily returned to the exhaust stroke before it is made to start moving in order to utilize the inertial energy of the crankshaft 113 so that the initial compression stroke can be got through with a torque smaller than that of any conventional motor of the type under consideration. Then, the motor can be downsized to reduce the manufacturing cost and the power consumption rate of the motor. Still additionally, if a starter according to the invention uses a magnet for the magnetic field system of the motor, the magnet is not required to show excessive magnetic force so that it is possible to reduce the rotational resistance of the motor and hence the specific fuel consumption of the engine without sacrificing the output power of the engine.

[0193] FIG. 28 is a schematic block diagram of the control circuit of a starter motor obtained by modifying Embodiment 5. FIG. 29 is a chart illustrating the starting motion of the starter motor of FIG. 28 in terms of the strokes of the engine. The performance of the motor 110 is also used selectively in a manner as described above.

[0194] In this case, while the crankshaft 113 is driven to revolve backward so as to make the engine temporarily move to the exhaust stroke at the time of engine start as illustrated in FIG. 27, the piston is made to move to the exhaust stroke by properly controlling the duration of energizing the motor 110 for backward revo-

lution and the duration of the subsequent suspension of energization without resorting to a camshaft sensor or some other sensor for detecting the piston position. Therefore, the detection signal of the motor temperature sensor 143 for detecting the temperature of the motor and that of the battery voltage sensor 144 for detecting the battery voltage are sent to the CPU 131.

[0195] When the starter switch 133 is turned ON while the ignition switch 134 is held ON, the CPU 131 issues a command to the motor driver 136 to energize and make it turn backward for a predetermined period of time in order to cause the crankshaft 113 to turn backward to the exhaust stroke. Additionally, after the energization for backward revolution, the energization of the motor 110 is suspended for a predetermined period of time to cause the crankshaft 113 to rotate simply by inertia. After the suspension of energization for the predetermined period of time, the motor 110 is energized to turn forward and cause the crankshaft 113 to revolve forward, thereby making the engine start moving.

[0196] While the motor 110 is made to turn backward when the starter switch 133 is turned ON in the above description, it may alternatively be so arranged that the motor 110 is made to turn backward when the ignition switch 134 is turned ON so that the motor 110 may be able to turn forward once the starter switch 133 is turned ON and, therefore, the engine may be made to start moving without any time lag. Therefore, the motor 110 does not necessarily have to revolve backward when the starter switch 133 is turned ON. Alternatively, it may be so arranged that the motor 110 starts revolving backward when the ignition switch 134 is turned ON.

[0197] The above starting motion generally follows one of the three patterns of motion as described below depending on the position at which the position is halted. They include the one that appears when the piston is located at the ordinary halt position before the compression stroke (pattern ①), the one that appears when the piston is located immediately before or after the top dead center between the exhaust stroke and the intake stroke (pattern ②) and the one that appears when the piston is located near the bottom dead center before the exhaust stroke (pattern ③).

[0198] Firstly, the starting motion that follows the pattern ① will be discussed. As the starter switch 133 is turned ON, the CPU 131 issues a command to make the motor 110 turn backward for t_1 seconds and the piston move from position A to position B. Thereafter, the energization of the motor 110 is suspended for t_2 seconds. However, the crankshaft 113 keeps on turning backward due to the inertial force obtained by the energization for t_1 seconds. Since the piston does not compress any gas from the intake stroke to the exhaust stroke and hence the load torque is small, the crankshaft 113 can easily keep on revolving by inertia. However, the inertial energy is consumed by the load torque to gradually reduce the rotational speed until the piston stops at position C.

[0199] The duration t_1 of energization for backward revolution is made longer than the time by which the piston can return to a position near the bottom dead center before the exhaust stroke due to the inertial force obtained by the energization. If the duration t_1 is too long, the rotational speed of the crankshaft 113 can become too high and generate too large inertial energy so that the explosion stroke can be got through during the time t_2 . Thus, the duration t_1 has to be so selected that the explosion stroke would not be got through while the crankshaft 113 is turning by inertia if the crankshaft 113 is driven to turn backward when the position is located at the bottom dead center before the compression stroke. Thus, the lower and higher limits of the duration t_1 of energization have to be defined so as to satisfy the above requirements.

[0200] After the time t_2 , the motor 110 is energized to turn forward. However, there may be occasions where the piston cannot get back to the exhaust stroke while it is turning by inertia if the time t_2 of suspension of energization is too short. Thus, the lower limit of the time t_2 is defined by taking this situation into consideration. The piston will successfully move from position B to position C in the exhaust stroke during the time t_2 if the above limits for the time t_2 and the duration t_1 are observed.

[0201] Note, while the piston is returned to position C in the exhaust stroke that is found within the range for starting forward turn in (d) of FIG. 29, it is desirable that the piston is moved back to a position near the bottom dead center before the start of the exhaust stroke that allows the piston to have the longest approach run. However, the position C in the exhaust stroke where the piston starts turning forward may include a position near the bottom dead center in the explosion stroke and a position near the top dead center in the intake stroke before or after the exhaust stroke.

[0202] When the time t_2 is over, the CPU 131 outputs a signal for causing the motor driver 136 to make the motor 110 revolve forward so that the engine may start moving from the exhaust stroke. Since the crankshaft 113 turns with a small load in the exhaust stroke and the intake stroke, the motor 110 will substantially gets to the largest number of revolutions per unit time that can taken place when it revolves without load before it gets into the compression stroke. In other words, the motor 110 will be in an almost saturated state. Therefore, the crankshaft 113 is also driven by the motor 110 to turn at the largest number of revolutions immediately before the compression stroke and the inertial energy stored in the inertial mass of the rotary system is maximized when the engine enters the compression stroke.

[0203] Thus, as a result, the crankshaft 113 is driven to rotate by the combined effect (thick solid line) of the inertial energy of the engine (dotted broken line) and the rotational energy of the starter motor (solid line) in the compression stroke as shown in (b) of FIG.29. In

other words the crankshaft 113 is driven by the torque T_i due to the inertial energy produced as a result of the reduction in the number of revolutions of the crankshaft 113 and the drive torque T_m of the motor, which are added to each other to give rise to a torque sufficient to overcome the load of the initial compression stroke, or a ride over torque $T = T_m + T_i$, as the sum thereof.

[0204] Then, in an engine to which this embodiment of motor according to the invention is applied, the drive torque of the motor is made $T_m \leq T/2$ when $T_m \leq T_i$ as seen from (b) in FIG. 29. In other words, the embodiment is designed to get over the load of the compression stroke mainly by means of the inertial energy subordinately by the motor energy and the engine can be made to start moving by means of a motor 110 whose largest torque (lock torque) is less than 1/2 of the ride over torque T necessary for getting over the load of the compression stroke. Additionally, as shown in (b) of FIG. 29, the motor 110 is designed to divide its drive energy into two parts and delivers them to the crankshaft 113 respectively during the approach run and during the time of riding over. Therefore, a motor with a relatively low output level according to the invention can be used to generate a large ride over torque if compared with conventional motors that are required to get over a large load in the compression stroke with a single delivery of energy.

[0205] Once the initial compression stroke is got through, inertial energy is accumulated thereafter and the load of any subsequent compression stroke can be easily surmounted. Then, the engine will start moving as the ignition coil 138 throws out sparks at predetermined timing.

[0206] Now, the starting motion that follows the pattern ② will be discussed below. The piston is located near the top dead center between the exhaust stroke and the intake stroke (position D) and then driven to turn backward from there to position E as the motor is energized for the time t_1 . Thereafter, the piston returns to the bottom dead center of the exhaust stroke by inertia and then enters the explosion stroke. However, the torque of the load of revolution increases due to the load of compression generated by the piston in the explosion stroke and the inertial energy is consumed quickly by the torque of the load to make the rotational speed falls and eventually cause the piston to completely halt (position F). At this time, the crankshaft 113 may be driven to turn forward slightly by the reaction force of compression produced by the piston but eventually stops at position G near the bottom dead center.

[0207] When the time t_2 is over, the engine piston is caused to start moving from the position G of the exhaust stroke. Then, the initial load of the compression stroke can be got through by the sum of the torque T_i due to the inertial energy obtained as a result of the approach run in the exhaust stroke and the intake stroke and the drive torque T_m as pointed out earlier.

[0208] Now, the starting motion that follows the pat-

tern ③ will be discussed below. In this instance, the piston is located near the bottom dead center before the exhaust stroke (position H) and then driven to turn backward. Since it enters the explosion stroke immediately after the start of the backward revolution, the torque of the load of revolution is generated by the piston due to the load of compression of the latter also immediately after the start of the backward revolution. Therefore, the number of revolutions per unit time of the crankshaft 113 is not raised remarkably nor any substantial inertial energy is generated. On the other hand, since the torque of the motor is selected to be less than 1/2 of the ride over torque T necessary for getting over the load of the compression stroke, the explosion stroke would not be got through by the backward revolution and the motor is locked and stops moving when the reaction force of compression produced by the piston and the motor torque are balanced by each other (position I).

[0209] When the time t_1 is over, the motor torque is lost as the motor has not been energized and the crankshaft 113 gradually starts revolving forward by the reaction force of the piston during the time t_2 and turns at an increasing rate. Subsequently, the reaction force of the piston is lost at or near the bottom dead center and thereafter the inertial energy of rotation is gradually consumed by the torque of the load of revolution so that the piston stops at position J before it enters into the intake stroke from the exhaust stroke. Then, in a manner as described above, the cranking motion starts from this position. Note, however, that the time t_2 has to be terminated before the piston enters the intake stroke by the reaction force because, otherwise, the piston can enter the intake stroke from the exhaust stroke during the time t_2 . In other words, the largest value of the time t_2 is defined by taking this situation into consideration.

[0210] Thus, as discussed above, the motor 110 is made to turn backward for the time t_1 set under the conditions described above by referring to the pattern ① before the engine is made to start moving. Then, the crankshaft 113 is made to turn by inertia, while the power supply is suspended for the time t_2 set under the conditions as discussed above by referring to the patterns ① and ③. Thereafter, the motor 110 is made to turn forward to temporarily bring the piston back to the exhaust stroke in order to make it possible to cause the engine to start moving. As discussed above, the motor 110 can reliably bring the piston back to the exhaust stroke by selecting appropriate values for the times t_1 and t_2 respectively. Thus, the engine can be reliably made to start moving from the exhaust stroke without providing a sensor for detecting the position of the piston such as a camshaft sensor so that the cost of the engine can be reduced for the reason of the absence of such sensors.

[0211] On the other hand, the extent (angle) of reverse turn can vary enormously as a function of the change in the performance of the motor due to fluctuations of the battery voltage and/or those of the tempera-

ture and/or the change in the torque of the load of revolution (friction) of the engine caused by the change in the oil viscosity also due to fluctuations of the temperature if appropriate values are selected respectively for the time t_1 and the time t_2 . In view of this fact, the ROM 141 is made to store a map for the time t_1 that carries values for the time t_1 obtained by using the temperature of the starter motor and the supply voltage as parameters and another map for the time t_2 that carries values for the time t_2 also obtained by using the temperature of the starter motor and the supply voltage as parameters so that appropriate values may be selected for t_1 and t_2 by referring to the respective maps. FIG. 30 is a schematic illustration of an example of a map of duration of energization for backward, FIG. 31 is a schematic illustration of an example of a map of duration of deenergization.

[0212] The output power of the motor 110 falls as the voltage of the battery falls so that the time required to store the rotational energy necessary for returning the piston to the right position increases. The oil viscosity rises as the temperature falls so that the time required to store the rotational energy necessary for moving the piston increases. Then, inertial energy will be consumed at a high rate when the piston is made to turn by inertia so that a large volume of inertial energy has to be stored. In FIG. 30, appropriate values are selected for the time t_1 by taking the temperature of the starter motor and the battery voltage into consideration, and it shows the relationship between the time t_1 and these factors as a map.

[0213] Also, the rotational speed of the crankshaft 113 falls quickly when the temperature is low because the rolling friction of the crankshaft 113 rises so that it takes time for the piston to return to the target position. Therefore, in FIG. 31, appropriate values are selected for the time t_2 by taking the temperature of the starter motor into consideration, and it shows the relationship between the time t_2 and the temperature as a map.

[0214] While the time t_2 is selected only as a function of the temperature of the starter motor in this case, the map may be made to additionally contain data on the battery voltage so that the crankshaft 113 can reliably return to the predetermined position by prolonging the time t_2 which is the time during which the crankshaft 113 turns by inertia in order to compensate the loss of inertial energy stored in the energization process for backward revolution caused by a fall of the battery.

[0215] Then, the CPU 131 obtains the motor temperature T_s from the motor temperature sensor 143 and the battery voltage V from the battery voltage sensor 144 and determines both the times t_1 and t_2 on the basis of these values by referring to the map for the time t_1 and the map for the time t_2 . As a result, both the times t_1 and t_2 are compensated in terms of temperature and fluctuations of the voltage so that the piston can reliably be made to return to the exhaust stroke regardless of any changes in the environmental factors.

[0216] While the ROM 141 stores the maps of FIGS. 30 and 31 to be used for selecting appropriate values for the time t_1 and the time t_2 in the above description, it may alternatively be so arranged that the CPU 131 comprises a means for computationally determining the time t_1 from the motor temperature T_s and the battery voltage V , and a means for computationally determining the time t_2 from the temperature so that it can computationally determine those values. Then, the approximate expressions as shown below can be used for determining the time t_1 and time t_2 from the motor temperature and the battery voltage.

$$t_1 = 0.18 + (12 - V) \times 0.02 + T_s$$

$$t_2 = 0.12 + T_s \times 0.01$$

[0217] While the times t_1 and t_2 are determined by using the temperature of the motor 110 in the above description, the temperature that can be used as parameter is not limited to that of the motor and that of the engine cooling water, that of the engine oil or that of the ambient air may alternatively be used. Still alternatively, any of the above temperatures may be used as parameters in addition to the temperature of the motor 110 when preparing a map and an approximate expression. While the backward revolution and the revolution by inertia are controlled by means of time in the above description, it is also possible to control them by detecting the rotational angle of the motor 110. Then, the rotational angle of the motor 110 is recognized on the basis of the pulse signal from the commutation position sensor 125 shown (c) of FIG. 29 and the motor is energized for backward revolution and then the energization is suspended in such a way that the motor turns by the predetermined angle.

[0218] FIG. 32 is a schematic diagram of the functional blocks of the engine start control section of another CPU 131 that can be used for controlling the starting motion illustrated in FIG. 29.

[0219] It will be appreciated that the starting motion is controlled by means of a control circuit as in FIGS. 26 and 28. As shown in FIG. 32, the CPU 131 has a motor rotational speed computing means 151 for computationally determining the rotational speed of the motor 110 on the basis of a pulse signal indicating the commutation position input from the commutation position sensor 125 and a motor rotational angle computing means 152 for computationally determining the rotational angle of the motor 110 also on the basis of the pulse signal. It also has an extent of backward turn correcting means 153 and an extent of inertial turn correcting means 154 adapted to respectively receive the time t_1 of energization for backward revolution and the time t_2 of suspension of energization, which will be discussed hereinafter, and correct them on the basis of the rotational speed and the rotational angle of the motor 110. Additionally, the CPU 131 has a means 155 for directing

energization of the motor for backward revolution to the motor driver 136 and a means 156 for directing suspension of energization of the motor respectively on the basis of the time t_1 and the time t_2 selected by the means 153 and 154. Finally, the CPU 131 also has a means 157 for directing a start of forward turn of the motor to cause the engine to start moving after the time t_2 .

[0220] Firstly, the starting motion that follows the pattern ① shown in FIG. 29 will be discussed. As the starter switch 133 is turned ON under the condition that the ignition switch 134 is turned ON, the motor 110 turn backward for t_1 seconds by means of a command issued from the means 155 for directing energization of the motor for backward revolution of the CPU 131 and the piston move from position A to position B. Thereafter, the energization of the motor 110 is suspended for t_2 seconds by a command issued from the means 156 for directing suspension of energization of the motor. However, the crankshaft 113 keeps on turning backward due to the inertial force obtained by the energization for t_1 seconds. Since the piston does not compress any gas from the intake stroke to the exhaust stroke and hence the load torque is small, the crankshaft 113 can easily keep on revolving by inertia. However, the inertial energy is consumed by the load torque to gradually reduce the rotational speed until the piston stops at position C.

[0221] The CPU 131 constantly monitors the rotational speed and the rotational angle of the motor 110 by way of the motor rotational speed computing means 151 and the motor rotational angle computing means 152, using the pulse signal indicating the commutation position from the commutation position sensor 125. More specifically, it computationally determines the rotational speed of the motor on the basis of the number of pulses and the pulse intervals of the pulse signal indicating the commutation position as counted in during the time of energization and also the rotational angle on the basis of the accumulated number of the pulses. It also computationally determines the rate of change of the rotational speed (dv/dt) of the motor 110 on the basis of the pulse signal indicating the commutation position. On the other hand, the ROM 141 stores the reference value X_r for the rate of change of the rotational speed and the target rotational speed N_r of the motor 110 to be achieved during the time t_1 . The extent of backward turn correcting means 153 recognizes the friction of the engine on the basis of the increasing rotational speed and feeds it back for controlling the rotational motion of the motor 110.

[0222] More specifically, the extent of backward turn correcting means 153 compares the rate of change of the rotational speed as determined by observing the rotational motion of the motor 110 with the above reference value X_r . If the rate of change of the rotational speed is lower than the reference value and hence the rate of change of the rotational speed is low, the time

required for the motor 110 to get to the target rotational speed will be longer than the estimated time, the means 153 judges that the load of rotation of the crankshaft 113 is greater than the expected value. If the operation is left uncorrected, the friction of the engine will be greater than the estimated value during the time of rotation by inertia so that the piston may not be able to return to the expected position. Therefore, the means 153 raises the target rotational speed N_r to increase the inertial energy to be stored in the crankshaft 113 so that the piston may be able to return to the exhaust stroke as expected.

[0223] If, on the other hand, the rate of change of the rotational speed exceeds the reference value, hence the rate of change of the rotational speed is high, the time required for the motor 110 to get to the target rotational speed will be shorter than the estimated time, the means 153 judges that the load of rotation of the crankshaft 113 is smaller than the expected value. If the operation is left uncorrected, the friction of the engine will be smaller than the estimated value during the time of rotation by inertia so that the piston may pass by the expected position. Therefore, the means 153 lowers the target rotational speed N_r to decrease the inertial energy to be stored in the crankshaft 113 so that the piston may be able to return to the exhaust stroke as expected.

[0224] The extent of backward turn correcting means 153 also monitors the rotational speed of the motor itself to recognize the inertial energy of rotation. More specifically, when the rotational speed gets to the target value N_r , it judges that inertial energy is stored by the predetermined amount if the current time is before the end of the time t_1 . Then, it carries out a correcting operation of reducing the time t_1 and causes the means 155 for directing energization of the motor for backward revolution to suspend the energization of the motor 110. When, on the other hand, the rotational speed does not get to the target value N_r , the means 153 judges that inertial energy is not sufficiently stored if the current time is at the end of the time t_1 . Then, it carries out a correcting operation of extending the time t_1 and causes the means 155 to continue the energization of the motor 110.

[0225] On the other hand, the ROM 141 also stores the reference angle θ_r for backward revolution of the motor 110 and, during the rotation by inertia, the extent of inertial turn correcting means 154 compares the angle of backward revolution as a function of the time of energization for backward revolution and the reference angle θ_r . In this embodiment, an angle of 180° is selected for the reference angle θ_r because the piston will probably be in the exhaust stroke with that angle if the backward revolution is started from the bottom dead center that is the possible remotest position before entering the compression stroke. Therefore, the means 154 of the CPU 131 judges if the rotational angle of the motor 110 has exceeded 180° or not and hence if the

input pulse signal of the commutation position is good for 180° or not.

If it is determined by the means 154 that the rotational angle exceeds 180°, it judges that the piston has returned to the exhaust stroke and hence the objective of the suspension of energization is achieved so that it determines to terminate the energization if the current time is before the end of the time t_2 . Then, it notifies the means 156 for directing suspension of energization of the motor that the energization is terminated and issues a command to the means 157 for directing a start of forward turn of the motor to make the latter start driving the motor 110 to rotate immediately once the starter switch 133 is turned ON.

[0226] If, on the other hand, it is determined by the means 154 that the pulse signal of the motor 110 shows a period greater than the predetermined value at the time when the rotational angle is less than 180° so that the rotational speed of the motor undergoes a predetermined level (e.g., speed 0=halt), it judges that the piston has not returned to the exhaust stroke. Then, it judges that the objective of the suspension of energization is not achieved and temporarily stops the suspension of energization to make the motor turn backward for a short period of time even if the current time is in the time t_2 . Differently stated, it notifies the means 156 that the time of suspension of energization is temporarily stopped and, at the same time, orders the means 155 to energize the motor so as to make it turn backward for a short period of time. After the short period of energizing the motor for backward revolution, the time t_2 is started once again and terminate it when the total rotational angle exceeds 180°.

[0227] When the time t_2 is over as mentioned above, the means 157 for directing a start of forward turn of the motor of the CPU 131 outputs a signal for causing the motor driver 136 to make the motor 110 revolve forward so that the engine may start moving from the exhaust stroke. Since the crankshaft 113 turns with a small load in the exhaust stroke and the intake stroke, the motor 110 will substantially gets to the largest number of revolutions per unit time that can taken place when it revolves without load before it gets into the compression stroke. In other words, the motor 110 will be in an almost saturated state. Therefore, the crankshaft 113 is also driven by the motor 110 to turn at the largest number of revolutions immediately before the compression stroke and the inertial energy stored in the inertial mass of the rotary system is maximized when the engine enters the compression stroke.

[0228] Now, the starting motion that follows the pattern ② will be discussed below. The piston is located near the top dead center between the exhaust stroke and the intake stroke (position D) and then driven to turn backward from there to position E as the motor is energized for the time t_1 . Thereafter, the piston returns to the bottom dead center of the exhaust stroke by inertia and then enters the explosion stroke. However, the torque of

the load of revolution increases due to the load of compression generated by the piston in the explosion stroke and the inertial energy is consumed quickly by the torque of the load to make the rotational speed falls and eventually cause the piston to completely halt (position F).

[0229] At this time, the pulse signal of the motor 110 indicating the commutation position shows a period that rapidly increases to by turn rapidly increase the rate of change of the rotational speed (the rate of decreasing speed) of the motor 110 until the latter exceeds the upper limit value X_{max} . Upon recognizing that the rate of change of the rotational speed exceeds the upper limit value X_{max} , the extent of inertial turn correcting means 154 judges that the piston passes by the bottom dead center before the exhaust stroke and enters the explosion stroke to start receiving the compression resistance of the engine. As a result, the piston enters a region where the extent of the approach run can be maximized and inertial energy can be maximally infused into the crankshaft 113. In other words, it is detected that the piston has got to the region suited to start turning forward.

[0230] Then, the means 154 terminates the time t_2 . It then notifies the means 156 of the fact and issues a command for making the motor 110 start turning forward immediately. While the crankshaft 113 may be returned forward slightly by the reaction force of the compression of the piston at this time, the piston halts at position G near the bottom dead center.

[0231] Then, as the time t_2 is terminated and an engine start signal is input from the starter switch 133, the engine is made to start moving from the condition where the piston is located at position G of the exhaust stroke. As a result, the initial load of the compression stroke can be got through by the sum of the torque T_i due to the inertial energy obtained as a result of the approach run in the exhaust stroke and the intake stroke and the drive torque T_m as pointed out earlier.

[0232] Now, the starting motion that follows the pattern ③ will be discussed below. In this instance, the piston is located near the bottom dead center before the exhaust stroke (position H) and then driven to turn backward. Since it enters the explosion stroke immediately after the start of the backward revolution, the torque of the load of revolution is generated by the piston due to the load of compression of the latter also immediately after the start of the backward revolution. Therefore, the number of revolutions per unit time of the crankshaft 113 is not raised remarkably nor any substantial inertial energy is generated. On the other hand, since the torque of the motor 110 is selected to be less than 1/2 of the ride over torque T necessary for getting over the load of the compression stroke, the explosion stroke would not be got through by the backward revolution and the motor is locked and stops moving when the reaction force of compression produced by the piston and the motor torque are balanced by each other (posi-

tion I).

[0233] Then, the period of the pulse signal that is once reduced by energization as a result of the operation of the motor 110 increases to become longer than the predetermined value so that the rotational speed falls below the predetermined lower limit value V_{min} . Upon recognizing that the rotational speed falls below the predetermined lower limit value V_{min} , the extent of backward turn correcting means 153 judges that the piston passes by the bottom dead center of the explosion stroke and compression torque begins to be generated. In other words, it judges that the objective of the backward revolution is achieved and immediately terminates the time t_1 .

[0234] When the time t_1 is terminated, the motor torque is lost as the motor has not been energized and the crankshaft 113 gradually starts revolving forward by the reaction force of the piston during the time t_2 and turns at an increasing rate. Subsequently, the reaction force of the piston is lost at or near the bottom dead center and thereafter the inertial energy of rotation is gradually consumed by the torque of the load of revolution so that the piston stops at position J before it enters into the intake stroke from the exhaust stroke. If the torque of the load of revolution is small, the piston can enter the intake stroke from the exhaust stroke during the time t_2 due to rotation by inertia so that the time t_2 has to be terminated before the piston enters the intake stroke. Therefore, the energization for forward revolution has to be started before the commutation pulse of the motor 110 exceeds the extent corresponding to 180° at maximum even before the termination of the time t_2 . Then, in a manner as described above, the cranking motion starts from this position. Note, if the starter switch 133 is turned ON during the time t_2 , the motor 110 is made to turn forward immediately even if the time t_2 is not over.

[0235] Thus, as described above, the motor 110 is made to turn backward for the time t_1 before the engine starts moving and then it is deenergized for the time t_2 to allow the crankshaft 113 to turn by inertia. Thereafter, the motor 110 is made to turn forward. At this time, the motor 110 computationally determines the rotational speed, the rate of change of the rotational speed and the rotational angle of the motor on the basis of the pulse signal indicating the commutation position and estimates the piston position to feed back and control the times t_1 and t_2 . Thus, the engine can be reliably made to start moving from the exhaust stroke without providing a sensor for detecting the position of the piston such as a camshaft sensor so that the cost of the engine can be reduced for the reason of the absence of such sensors.

[0236] FIG. 33 is a chart illustrating the starting motion of another starter motor obtained by modifying Embodiment 5.

[0237] In this case, when making the engine to start moving from position Pa in the ordinary stop zone P

shown in (c) of FIG. 33, the crankshaft 113 is firstly made to turn backward in order to pass through the intake stroke and the exhaust stroke and get into the explosion stroke. Therefore, the gas remaining in the combustion chamber is compressed by the backward turn in the explosion stroke under the condition in which both the intake valve and the exhaust valve are closed so that energy for forward revolution is accumulated in the combustion chamber as a result of the compression. The doubly dotted broken line in (b) of FIG. 33 indicates the accumulated energy. Note that, when the engine is made to start moving, it can be turned backward in a manner as described above not only when the piston is in the ordinary stop zone P but also when the piston is at pause in the intake stroke or the exhaust stroke.

[0238] The crankshaft 113 is turned forward by the motor 110 after it is tuned backward to the tuning point, or the position Qa from which it is turned forward, of starting zone Q for forward revolution in the explosion stroke. At this time, the energy for forward revolution accumulated in the compressed gas in the combustion chamber is discharged to the rotary system of the crankshaft 113 including the flywheel. Thus, the rotary system is fed with the energy discharged as a result of the compression and the rotational energy delivered from the motor 110.

[0239] In (b) of FIG. 33, the changing energy fed to the crankshaft 113 from the motor 110 that is turning forward is indicated by a solid line, while the changing inertial energy stored in the rotary system is indicated by a dotted broken line. As seen from FIG. 33, inertial energy is rapidly accumulated in the rotary system in the initial stages of the forward revolution due to the discharge of gas energy that takes place as a result of the reaction of the compression and the accumulated inertial energy is increased gradually from the explosion stroke to the compression stroke by the rotational force of the motor 110. Therefore, in the compression stroke, the sum of the inertial energy accumulated in the rotary system and the energy of the motor 110 is fed to the crankshaft 113 as indicated by a thick solid line in FIG. 33. In other words, the crankshaft 113 is driven by the inertial energy that is discharged as the number of revolution decreases and consumed in the compression stroke and the torque of the motor 110, and the maximum ride-over torque T is the sum of the largest value T_i of the discharged energy of the inertial torque and the largest value T_m of the torque of the motor 110, which is sufficient for getting through the initial compression stroke.

[0240] FIG. 34 (a) shows the change in the piston position, (b) shows the change in the number of revolutions of the crankshaft, (c) shows the energy change, (d) shows the change in the motor output energy and (e) shows the change in the ride-over energy.

[0241] In this case, the motor 110 is tuned backward into the explosion stroke of the piston to compress the gas in the combustion chamber when the internal

combustion engine is made to start moving so that energy is accumulated for forward revolution by the reaction of the compression and the rotational energy of the motor 110 is added to the accumulated energy and consequently inertial energy may be accumulated in the rotary system of the crankshaft 113. Then, energy for getting through the compression stroke is formed by not only the energy generated by the motor 110 but also the reaction energy of the compression. With this arrangement, the motor 110 may be significantly down-sized.

[0242] When the crankshaft is turned backward to the explosion stroke, the signal from the camshaft sensor 132 may be used for detecting the stop position Pa of the crankshaft 113 and the position Qa for forward revolution. Additionally, it may be so arranged that the motor 110 is made to turn backward from the halt position for a predetermined period of time and subsequently the piston is returned to the explosion stroke by inertia. Alternatively, the engine may be driven back to the explosion stroke by the motor 110.

[0243] Since a pulse signal can be taken out from the commutation position sensor 125 as shown in (d) of FIG. 33 when the motor 110 is turning backward or forward, it may be so arranged that the turning point from backward revolution to forward revolution is detected by detecting the pulse signal. The turning point may be detected by counting the number of pulses when the motor 110 is changing the sense of turning. Alternatively, the speed of the motor may be detected by detecting the pulse intervals. In any case, the turning point can be reliably detected by feeding back the outcome of the above detection to the control section.

[0244] When the speed of the motor is detected by detecting the pulse intervals, there may be cases where the rotational resistance of the engine is large and the piston cannot return to the predetermined position if it takes more time than expected for the speed to get to the predetermined level. Therefore, it is necessary to provide and operate a feedback and control system in order to raise the target value of the speed. If, on the other hand, the speed gets to the predetermined level too early, the rotational resistance of the engine can be small and the piston may pass by the predetermined position. Then, it is necessary to operate the feedback and control system in order to lower the target value of the speed.

[0245] It may alternatively be so arranged that the motor is energized until the rotational speed of the rotary system get to the target value and subsequently deenergized once the target value is reached if it is possible to detect the rotational inertial energy of the rotary system.

[0246] When the piston get through the intake stroke and moves into the explosion stroke from the exhaust stroke, it is exposed to compression resistance when it passes through the bottom dead center and moves upward. Then, the speed increases gradually after the turning point and then becomes reduced.

Thus, the pulse intervals are shortened as a result of the speed increase and then prolonged as a result of the speed reduction. Therefore, it is also possible to detect the time when the explosion stroke is reached by detecting the change in the pulse intervals. If the piston is made to return to the explosion stroke by inertia without energizing the motor, the rate of increase of the pulse intervals, or the rate of speed reduction, rapidly changes. Therefore, it is possible to detect the time when the explosion stroke is reached by detecting the change in the rate of increase of the pulse intervals.

[0247] Now, the sequence of operation of making the engine start moving will be described. As the ignition switch 134 is turned ON, the CPU 131 firstly recognizes the current position of the piston on the basis of the detection signal of the camshaft sensor 132. In other words, the CPU 131 recognizes the current position of the piston and causes the piston to turn backward to the explosion stroke by means of the signal from the camshaft sensor 132.

[0248] If a camshaft sensor 132 is provided and the piston is at rest at a position outside the ordinary stop zone P, the position can be detected from the detection signal of the camshaft sensor 132. The CPU 131 determines that the piston is to be returned to the explosion stroke on the basis of the detection signal and issues a command to the motor driver 136 to temporarily turn backward the motor 110 and making the crankshaft 113 also turn backward to the explosion stroke. If a camshaft sensor 132 is provided, it outputs an H signal indicating that the piston has reached the explosion stroke so that it is possible to detect that the piston has turned backward and got to the position Qa in the explosion stroke from which it starts turning forward. Then, the CPU 131 makes the motor 110 stop its backward revolution and immediately start turning forward.

[0249] Then, as an engine start signal is input by the starter switch 133, the CPU 131 issues a signal to the motor driver 136 to make the motor 110 turn forward and starts the engine in the explosion stroke. In this case, since the crankshaft 113 turns with a small load in the exhaust stroke and the intake stroke, the motor 110 will substantially gets to the largest number of revolutions that can taken place when it revolves without load and will be in an almost saturated state before it gets into the compression stroke. In other words, the motor 110 will be in an almost saturated state. Therefore, the crankshaft 113 is also driven by the motor 110 to turn at the largest number of revolutions immediately before the compression stroke and the inertial energy stored in the inertial mass of the rotary system is maximized when the engine enters the compression stroke.

[0250] Thus, as a result, the crankshaft 113 is driven to rotate by the combined effect (thick solid line) of the inertial energy of the engine (dotted broken line) and the rotational energy of the starter motor (solid line) in the compression stroke as shown in (b) of FIG. 33. Additionally, as shown in (b) of FIG. 33, the motor 110 is

designed to divide its drive energy into two parts and delivers them to the crankshaft 113 respectively during the approach run and during the time of riding over. Therefore, a motor with a relatively low output level according to the invention can be used to generate a large ride over torque if compared with conventional motors that are required to get over a large load in the compression stroke with a single delivery of energy.

[0251] As described above, the energy generated as a result of the reaction to the compression is accumulated in the engine if the piston is temporarily returned to the explosion stroke before the engine start so that the accumulate energy is transformed into inertial energy of the crankshaft 113 as it is discharged. Then, the initial compression stroke can be got through by means of a motor showing a motor torque lower than any conventional motors of the type under consideration because the inertial energy of the rotary system is effectively utilized.

[0252] While the piston is turned firstly backward from the halt position and then forward when the engine is made to start moving in the above description, it may alternatively be so arranged that crankshaft 113 is made to firstly turn forward until it gets to midway in the compression stroke, more specifically immediately before the top dead center of the compression stroke for instance, and subsequently backward to the explosion stroke. Then, the gas remaining in the combustion chamber can be compressed in the compression stroke to accumulate energy so that the crankshaft may be turned backward by discharging the energy of the compressed gas and using the discharged energy along with the energy supplied by the motor.

[0253] The above described method of accumulating the energy generated by turning the crankshaft 113 forward and compressing the gas in the engine and then causing the crankshaft 113 to turn backward by discharging the accumulated energy at the time of engine start is particularly effective for 2-stroke cycle engines, because in the 2-cycle engine, both the intake valve and the exhaust valve, or the scavenging valve are held open simultaneously between the explosion stroke and the compression stroke and the stretch between the explosion stroke and the compression stroke is short relative to its counterpart of the 4-stroke engine so that it is not possible to provide a sufficiently long approach.

[0254] FIG. 35 is a chart of the starting, where the crankshaft 113 is turned firstly forward to compress the gas in the combustion chamber and then backward by utilizing the compression energy at the time of causing the engine to start moving. FIG. 36 is a chart illustrating the energy change in the case of FIG. 35. Thus, by adding a forward turning motion before the backward tuning motion, the 2-stroke engine can be made to start moving by means of a small motor 110.

[0255] The present invention is by no means limited to the above embodiments, which may be modified or

altered appropriately without departing from the scope of the present invention.

[0256] For example, while the above embodiments are described mainly in terms of the engine of a motor bicycle, the present invention can equally be applied to the engine of a four-wheeled automobile. It is applicable not only to an engine having a single cylinder but also to an engine having a plurality of cylinders. Additionally, while the motor is directly linked to the crankshaft of the engine in the above description of the embodiments, the present invention is also applicable to a starter motor of the type that is adapted to drive the crankshaft by way of a gear or an electromagnetic clutch. Still additionally, in terms of the type of motor, a starter motor according to the present invention is not limited to the outer rotor type and may be of the inner rotor type.

[0257] Thus, according to the invention, the starter motor is driven to revolution forward while the piston is located in the exhaust stroke when the engine is made to start moving so that inertial energy is accumulated in the crankshaft in both the exhaust stroke and the intake stroke and the compression stroke can be got through by the effect of combining the accumulated inertial energy and the rotational energy of the starter motor. Therefore, the rotational energy required to get through the compression stroke can be reduced to make it possible to down-size and reduce the cost of the motor.

[0258] If magnets are used for the field system, it is no longer necessary to make the magnetic force of the magnets excessively strong and hence the rotational resistance can be reduced to improve the economy of fuel consumption and prevent the engine from lowering its output.

[0259] Additionally, with a starter motor to be used with an internal combustion engine according to the invention, the motor is made to turn backward in order to temporarily move the piston into the explosion stroke so that, if the piston is at rest at a position in other than the exhaust stroke, the internal combustion engine can be made to start moving under the condition where the piston is reliably located in the exhaust stroke.

[0260] Still additionally, the starter motor is made to turn backward by energizing it for a predetermined period of time for backward revolution and then the energization of the starter motor is suspended for another predetermined period of time in order to place the piston in the exhaust stroke before the starter motor is made to turn forward to cause the engine to start moving. Thus, the engine can be made to start moving with the piston reliably located in the exhaust stroke without using any sensor for detecting the piston position so that the cost of the engine starting system can be reduced.

[0261] Furthermore, according to the invention, the duration of energization for backward revolution and that of suspension of energization are determined respectively by using a map of duration of energization for backward revolution and a map of duration of deen-

energization. Thus, temperature changes and voltage fluctuations can be compensated for the duration of energization for backward revolution and that of suspension of energization so that the piston can be reliably moved back to the exhaust stroke regardless of environmental changes.

[0262] With a control device according to the invention, the starter motor is tuned backward for time t_1 of energization for backward revolution and then the crankshaft is made to turn by inertia for time t_2 of suspension of energization before the motor is made to turn forward. With this arrangement, the rotational speed, the rate of change of the rotational speed and the rotational angle of the motor are computationally determined on the basis of the pulse signal indicating the commutation position of the starter motor and the time t_1 of energization for backward revolution and the time t_2 of suspension of energization are fed back to the control device properly depending on the computed values so that the piston can be reliably moved back to the exhaust stroke without using any sensor for detecting the piston position. Thus, the cost of the engine starting system can be reduced because it is no longer necessary to use sensors such as a camshaft sensor.

[0263] Furthermore, with a starter for an internal combustion engine according to the invention, the gas in the combustion chamber is compressed by turning the starter motor backward and moving the piston to the explosion stroke and the reaction force of the compressed gas trying to expand is utilized for driving the crankshaft to turn forward in order to increase the inertial energy accumulated in the rotary system for forward revolution. Then, the initial compression stroke is got through by the effect of combining the inertial energy and the energy from the starter motor to consequently reduce the rotational energy to be fed to the starter

Claims

1. A starter of an internal combustion engine comprising:
 - a starter motor linked to a crankshaft of the internal combustion engine having the exhaust stroke as starting position and having an output torque smaller than the maximum load of rotation of the internal combustion engine; and
 - a control means for getting through the compression stroke with the combined effect of the inertial energy of revolution of said crankshaft and the rotational energy of said starter motor.
2. A starter of an internal combustion engine according to claim 1, wherein
 - said control means is adapted to make said starter motor turn backward in order to return to the exhaust stroke.

3. A starter of an internal combustion engine comprising:

- a starter motor linked to a crankshaft of the internal combustion engine; and
- a control means adapted to place the piston of said internal combustion engine in the exhaust stroke by making said starter motor turn backward during a predetermined time of energization and subsequently making said crankshaft turn by inertia during a predetermined time of suspension of energization and thereafter make said starter motor turn forward so as to cause said internal combustion engine to start moving.

4. A starter motor of an internal combustion engine according to claim 3, further comprising:

- a memory means storing a map of duration of energization for backward revolution defined by using at least either the temperature or the supply voltage as parameter and a map of duration of suspension of energization defined by using the temperature as parameter.

5. A starter motor of an internal combustion engine according to claim 3, wherein

- said control means includes a means for computing the time of energization of the motor for backward revolution adapted to determine the time of energization of the motor for backward revolution from the temperature and the supply voltage and a means for computing the time of suspension of energization of the motor adapted to determine the time of suspension of energization from the temperature.

6. A start control device of an internal combustion engine comprising:

- a motor rotational speed computing means for computationally determining the rotational speed of the starter motor linked to the crankshaft of the internal combustion engine on the basis of the rotary pulse signal output as a result of the revolution of said starter motor;
- a motor rotational angle computing means for computationally determining the rotational angle of said starter motor also on the basis of the said rotary pulse signal;
- a means for directing energization of said starter motor for backward revolution for a predetermined period of time;
- an extent of backward turn correcting means for correcting the time of energization for backward revolution on the basis of the rotational

- speed of said starter motor;
 a means for directing suspension of energiza-
 tion of the motor adapted to suspend the ener-
 gization of said starter motor for a
 predetermined period of time after driving said
 crankshaft to turn backward, cause said crank-
 shaft to turn by inertia and place the piston of
 said internal combustion engine in the exhaust
 stroke;
 an extent of inertial turn correcting means for
 correcting the extent of revolution by inertia of
 said crankshaft on the basis of the rotational
 speed and the rotational angle of said starter
 motor; and
 a means for directing a start of forward revolu-
 tion of the motor adapted to make said starter
 motor turn forward from the state of said piston
 as located in the exhaust stroke and causes
 said internal combustion engine to start moving
 after the termination of said time of suspension
 of energization.
7. A start control device of an internal combustion
 engine according to claim 6, wherein
- said extent of backward turn correcting means
 compares the rate of change of the rotational
 speed of said starter motor as computationally
 determined from the rotational speed thereof
 with a predetermined reference value and
 raises the target rotational speed of said starter
 motor to increase the inertial energy of said
 crankshaft if the rate of change is smaller than
 the reference value, but lowers the target rota-
 tional speed of said starter motor to decrease
 the inertial energy of said crankshaft if the rate
 of change is greater than the reference.
8. A start control device of an internal combustion
 engine according to claim 6 or 7, wherein
- said extent of backward turn correcting means
 suspends the energization of said starter motor
 when the rotational speed of said starter motor
 gets to a target value even within said time of
 energization for backward revolution, but
 extends said time of energization for backward
 revolution and continues the energization of
 said starter motor when the rotational speed of
 said starter motor does not gets to the target
 value within said time of energization for back-
 ward revolution.
9. A start control device of an internal combustion
 engine according to any of claims 6 through 8,
 wherein
- said extent of backward turn correcting means

terminates the energization of said starter
 motor within said time of energization for back-
 ward revolution when the rotational speed of
 said starter motor falls below a predetermined
 lower limit within said time of energization for
 backward revolution.

10. A start control device of an internal combustion
 engine according to any of claims 6 through 9,
 wherein

said extent of inertial turn correcting means ter-
 minates said time of suspension of energiza-
 tion and makes said starter motor turn forward
 by said means for directing a start of forward
 turn of the motor even within said time of sus-
 pension of energization when the rotational
 angle of said starter motor due to energization
 exceeds a predetermined backward turn refer-
 ence angle, but terminates said time of suspen-
 sion of energization and makes said starter
 motor turn backward again by said means for
 directing energization of the motor for back-
 ward revolution even within said time of sus-
 pension of energization when the rotational
 speed of said starter motor falls below a prede-
 termined value while the rotational angle
 undergoes said predetermined backward turn
 reference angle.

11. A start control device of an internal combustion
 engine according to any of claims 6 through 10,
 wherein

said extent of inertial turn correcting means ter-
 minates said time of suspension of energiza-
 tion and makes said starter motor turn forward
 by said means for directing a start of forward
 turn of the motor even within said time of sus-
 pension of energization when the rate of
 decrease of rotational speed as computationally
 determined from the rotational speed of
 said starter motor exceeds a predetermined
 upper limit value.

12. A starter of an internal combustion engine compris-
 ing:

a starter motor linked to the crankshaft of the
 internal combustion engine;
 a commutation position detection means
 adapted to output a pulse signal representing
 the detected commutation position of said
 starter motor; and
 a control means adapted to control said starter
 motor so as to make said internal combustion
 engine get through the compression stroke by
 causing the piston of said internal combustion

engine to turn backward to the explosion stroke and compress the gas in the combustion chamber in order to accumulate energy for forward revolution due to the reaction of the compression and then accumulate inertial energy in the rotary system surrounding said crankshaft by the effect of combining said energy and the rotational energy due to said starter motor;

said control means being also adapted to detect the sense of rotation of said crankshaft on the basis of the change in the pulse intervals of the pulse signal output from said commutation position detecting means when making said starter motor turn backward.

13. A starter of an internal combustion engine according to claim 12, wherein

said control means judges that the piston gets to the explosion stroke when the pulse intervals of the pulse signal output from said commutation position detecting means exceeds a predetermined value.

14. A starter of an internal combustion engine comprising:

a starter motor linked to the crankshaft of the internal combustion engine;
a crank angle sensor for detecting the angle of said crankshaft; and
a control means adapted to control said starter motor so as to make said internal combustion engine get through the compression stroke by causing the piston of said internal combustion engine to turn backward to the explosion stroke and compress the gas in the combustion chamber in order to accumulate energy for forward revolution due to the reaction of the compression and then accumulate inertial energy in the rotary system surrounding said crankshaft by the effect of combining said energy and the rotational energy due to said starter motor;
said control means being also adapted to detect if said piston gets to the explosion stroke or not on the basis of the crank angle detected by said crank angle sensor when making said starter motor turn backward.

15. A starter of an internal combustion engine according to claim 14, wherein

said control means determines the start of energization for turning said crankshaft forward on the basis of the crank angle detected by said crank angle sensor.

16. A starter of an internal combustion engine comprising:

ing:

a starter motor linked to the crankshaft of the internal combustion engine;
a camshaft sensor for detecting the cam position of said internal combustion engine; and
a control means adapted to control said starter motor so as to make said internal combustion engine get through the compression stroke by causing the piston of said internal combustion engine to turn backward to the explosion stroke and compress the gas in the combustion chamber in order to accumulate energy for forward revolution due to the reaction of the compression and then accumulate inertial energy in the rotary system surrounding said crankshaft by the effect of combining said energy and the rotational energy due to said starter motor;
said control means being also adapted to detect if said piston gets to the explosion stroke or not on the basis of the signal from said camshaft sensor when making said starter motor turn backward.

17. A starter of an internal combustion engine according to claim 14, wherein

said control means determines the start of energization for turning said crankshaft forward on the basis of the crank angle detected by said camshaft sensor.

18. A starter of an internal combustion engine according to any of claims 12 through 17, wherein

said control means energizes said starter motor for forward revolution after allowing said crankshaft to turn by inertia for a predetermined period of time after the termination of the energization of said starter motor for backward revolution.

19. A starter of an internal combustion engine according to any of claims 12 through 18, wherein

said control means starts energizing said starter motor when it detects that the sense of revolution of said crankshaft is switched to forward revolution by the reaction force of the compression in the explosion stroke.

20. A starter of an internal combustion engine according to any of claims 12 through 19, wherein

said starter motor is made to turn the piston forward to the compression stroke before it is turned backward to the explosion stroke.

21. An internal combustion engine designed to get through the compression stroke by the effect of combining the inertial energy of rotation of the crankshaft and the rotational energy of the starter motor when the internal combustion engine is made to start moving; 5

said starter motor being linked to the crankshaft of said internal combustion engine and its performance is selectively used depending on its rotational speed. 10

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Fig. 1

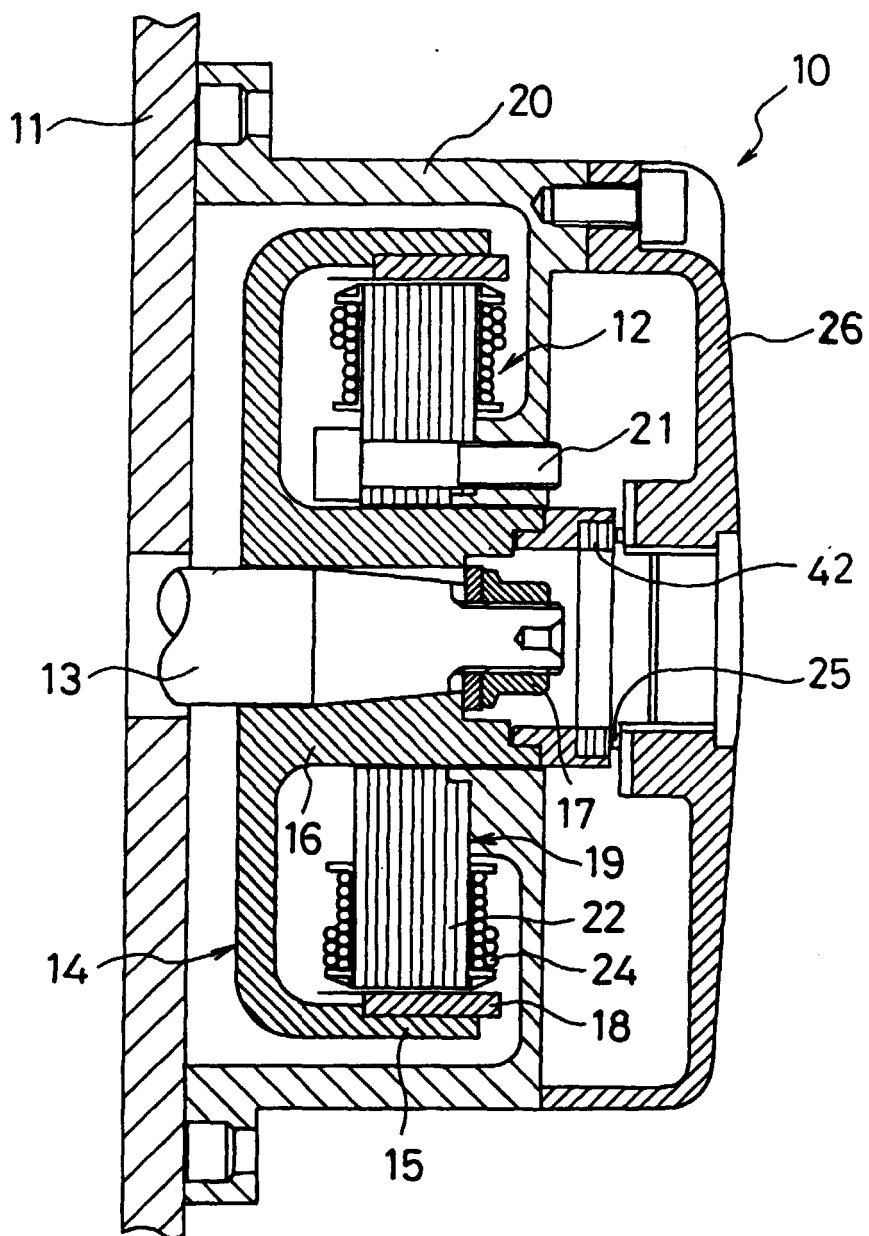


Fig. 2

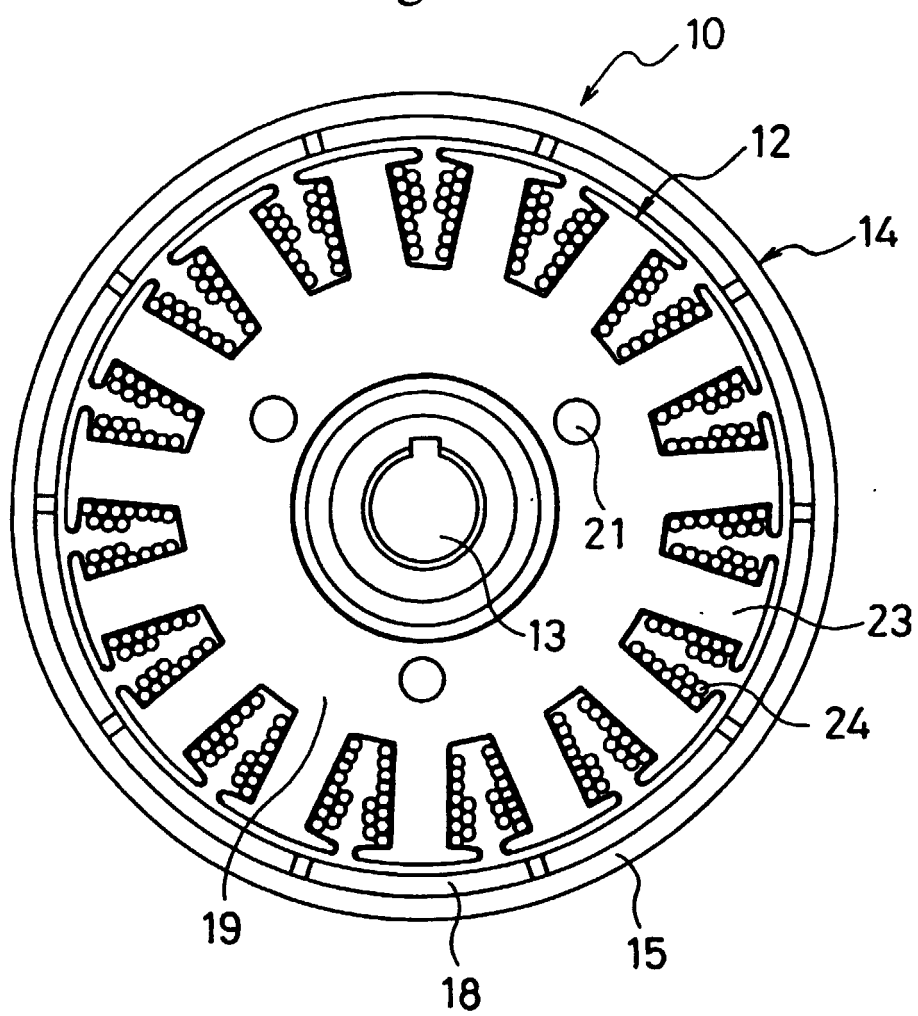


Fig. 3

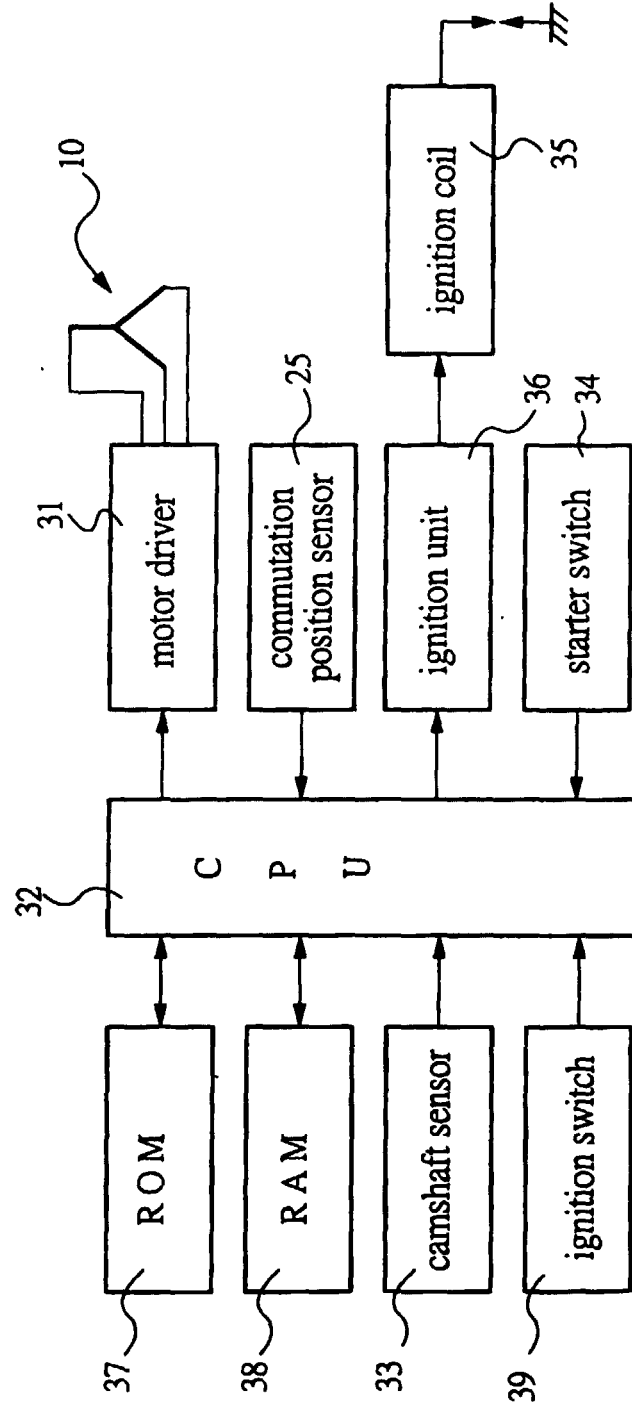


Fig. 4

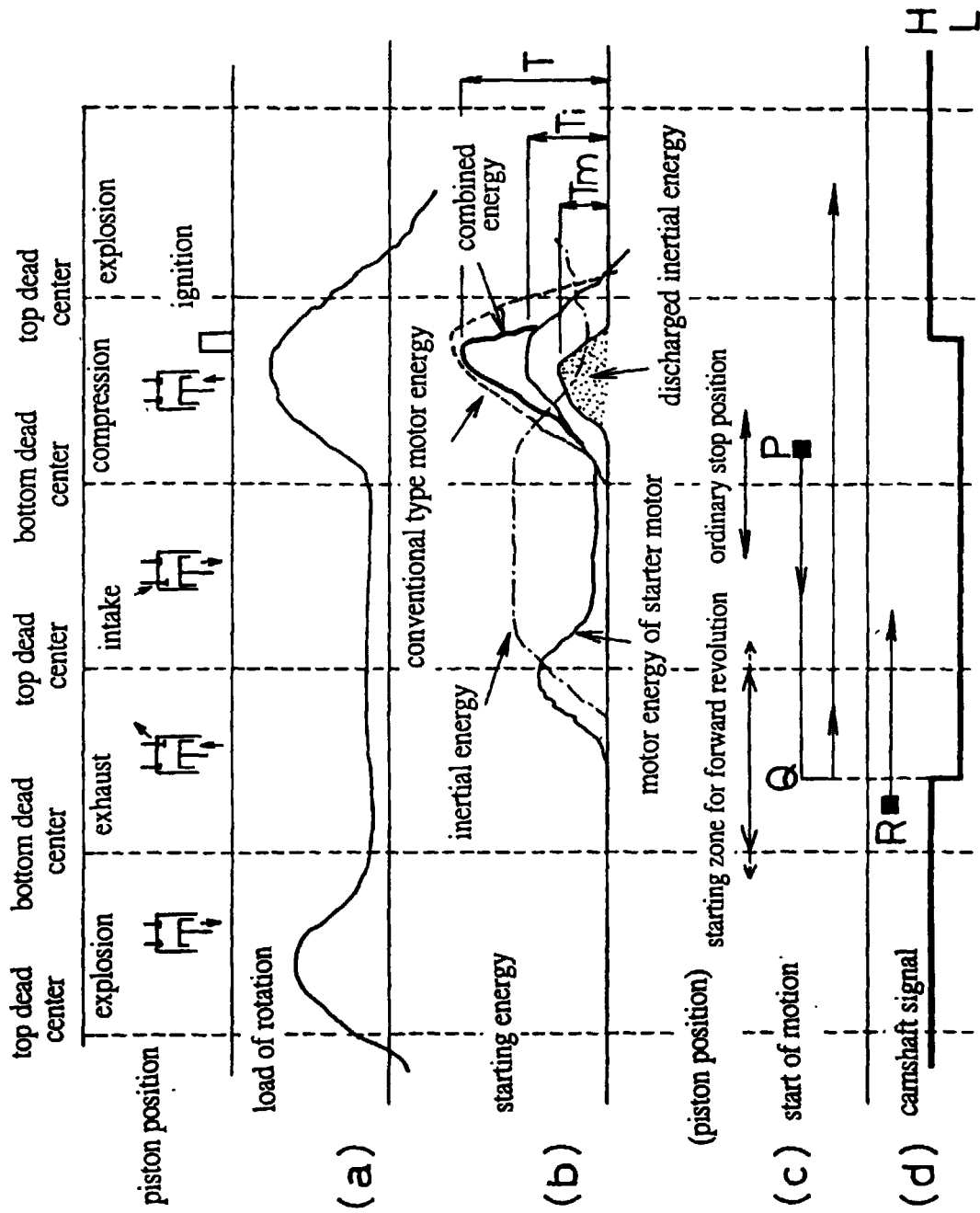


Fig. 5

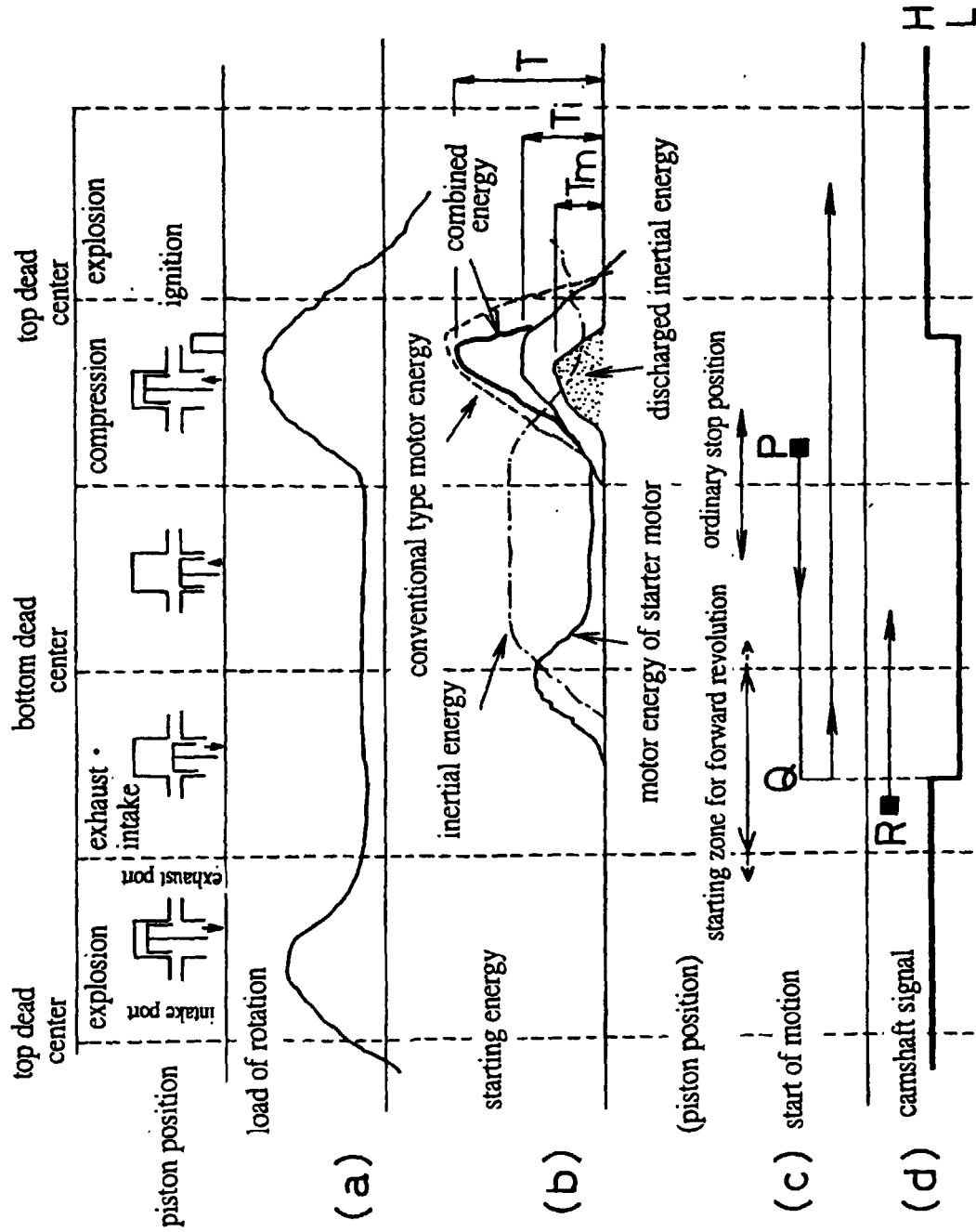


Fig. 6

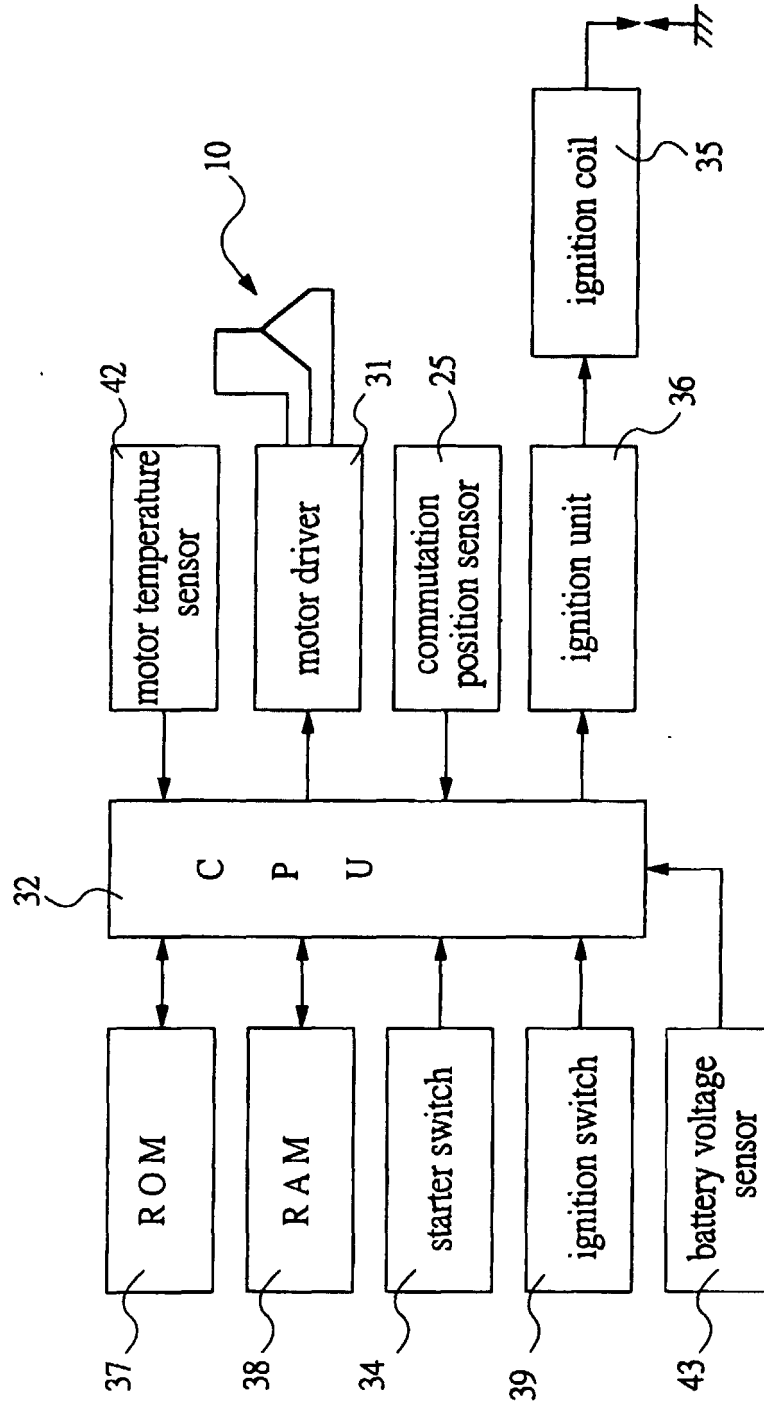


Fig. 7

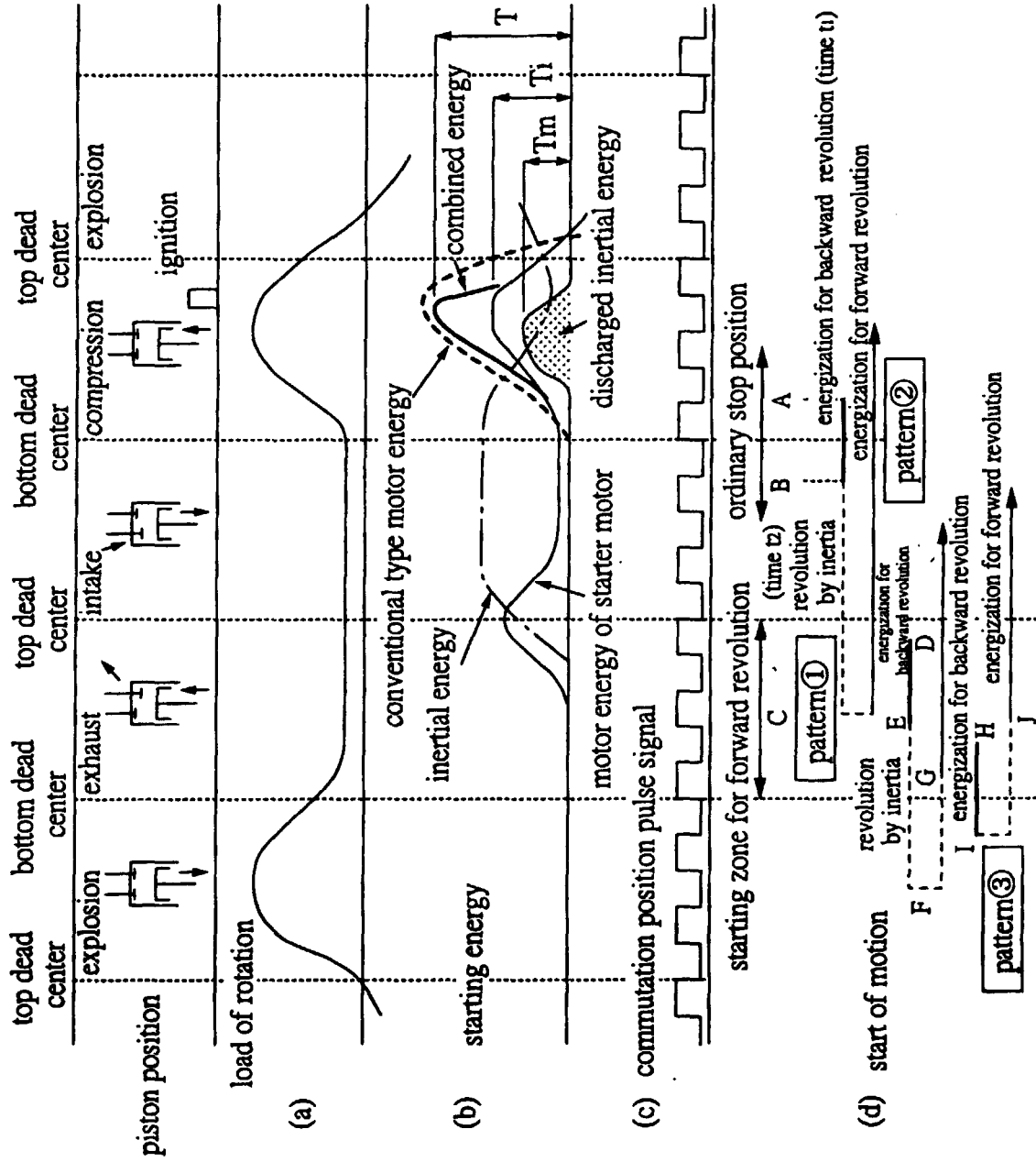


Fig. 8

MAP1 (time of energization for backward revolution) unit : second

	starter motor temperature (°C)					
battery voltage (V)	-20	0	20	40	80	100
12	0.20	0.18	0.16	0.14	0.12	0.10
11	0.22	0.20	0.18	0.16	0.14	0.12
10	0.24	0.22	0.20	0.18	0.16	0.14
9	0.26	0.24	0.22	0.20	0.18	0.16
8	0.28	0.26	0.24	0.22	0.20	0.18
7	0.30	0.28	0.26	0.24	0.22	0.20

Fig. 9

MAP2 (time of suspension of energization)

starter motor temperature (°C)	-10	0	20	40	80	100
time (second)	0.14	0.12	0.10	0.08	0.06	0.04

Fig. 10

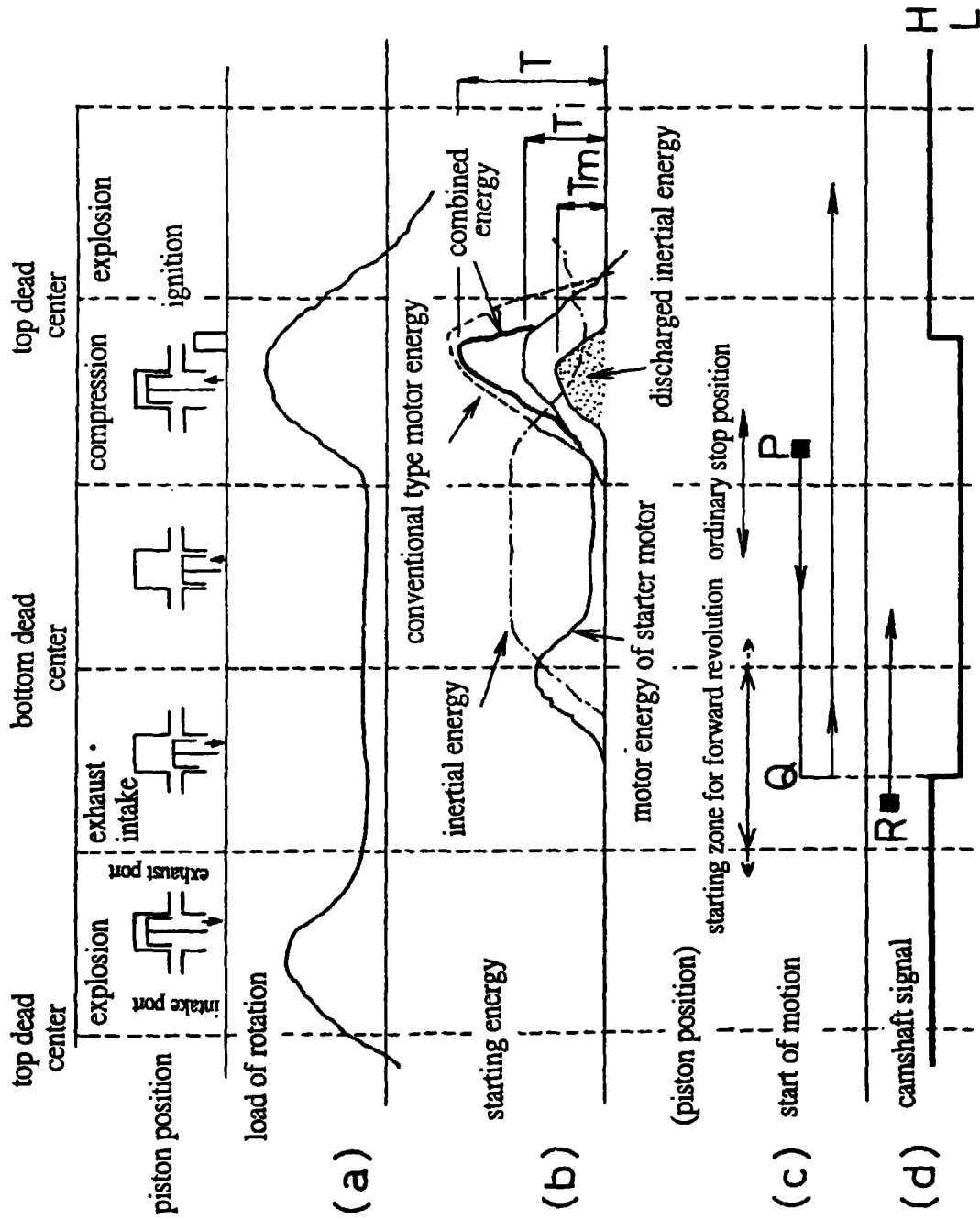


Fig. 11

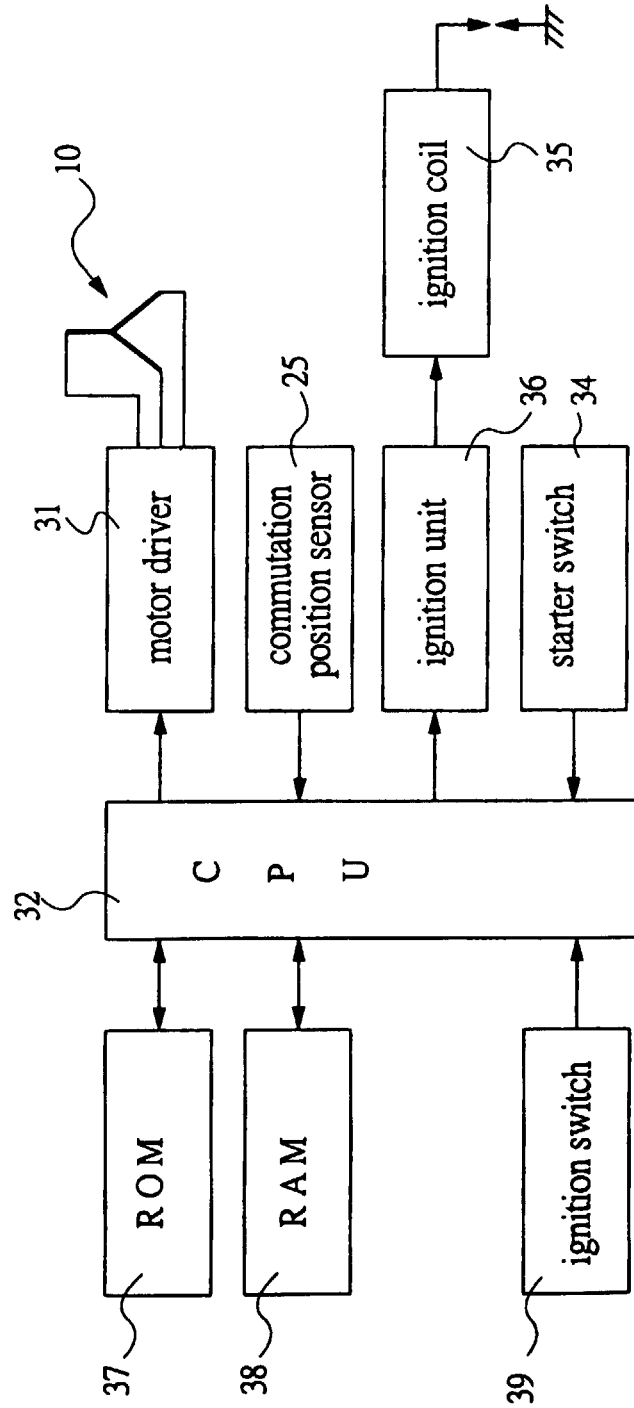


Fig. 12

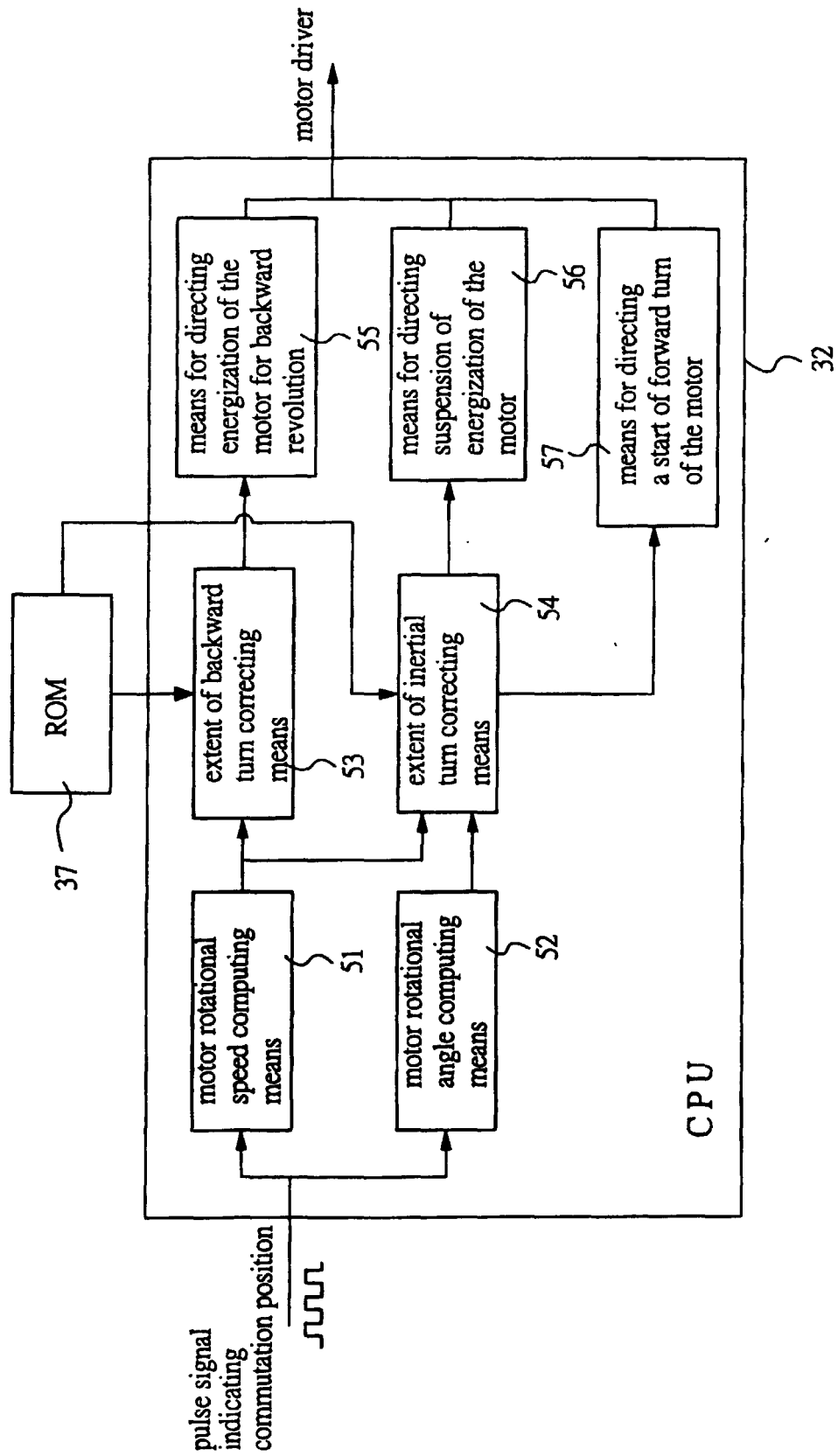


Fig. 13

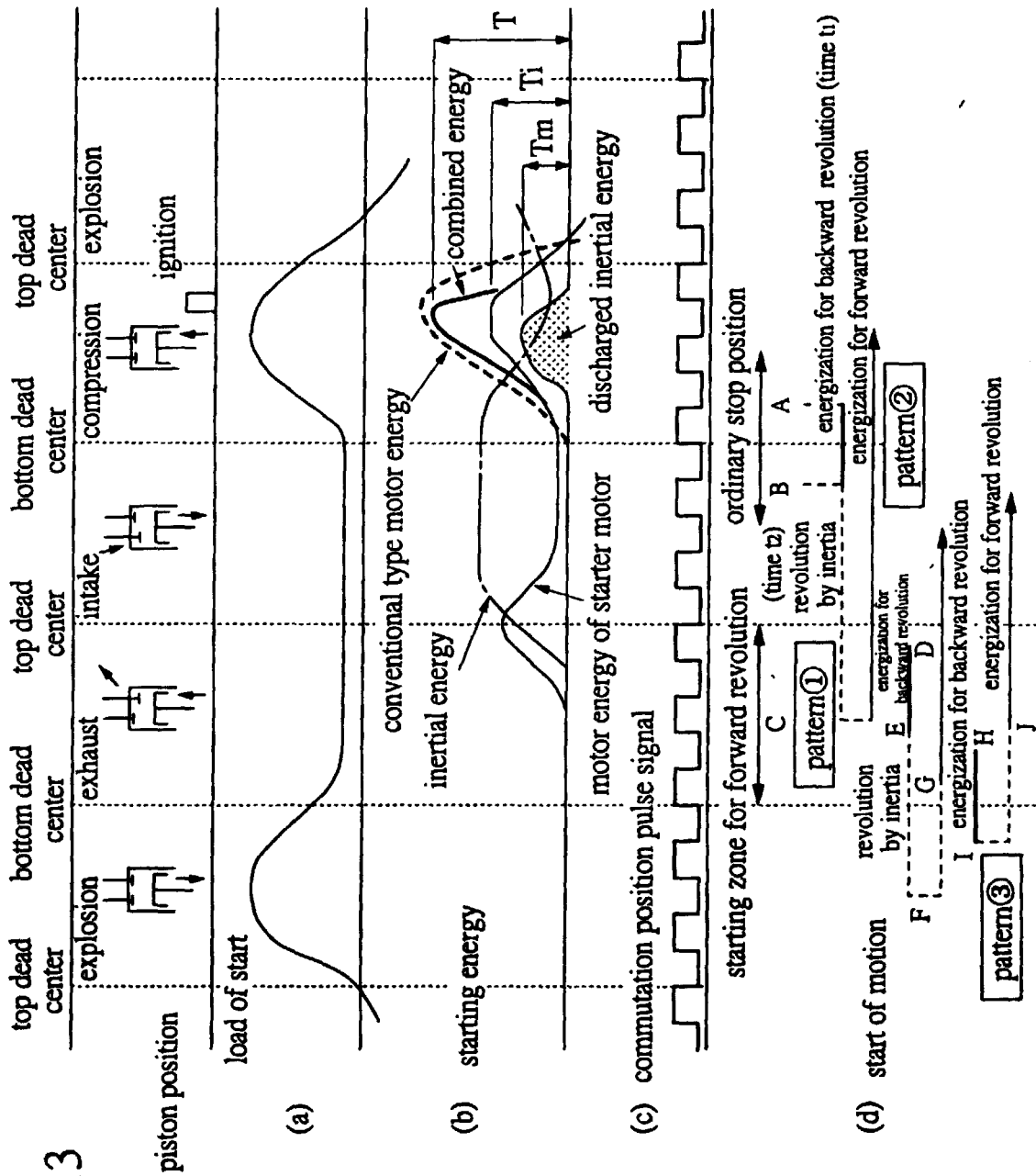


Fig. 14

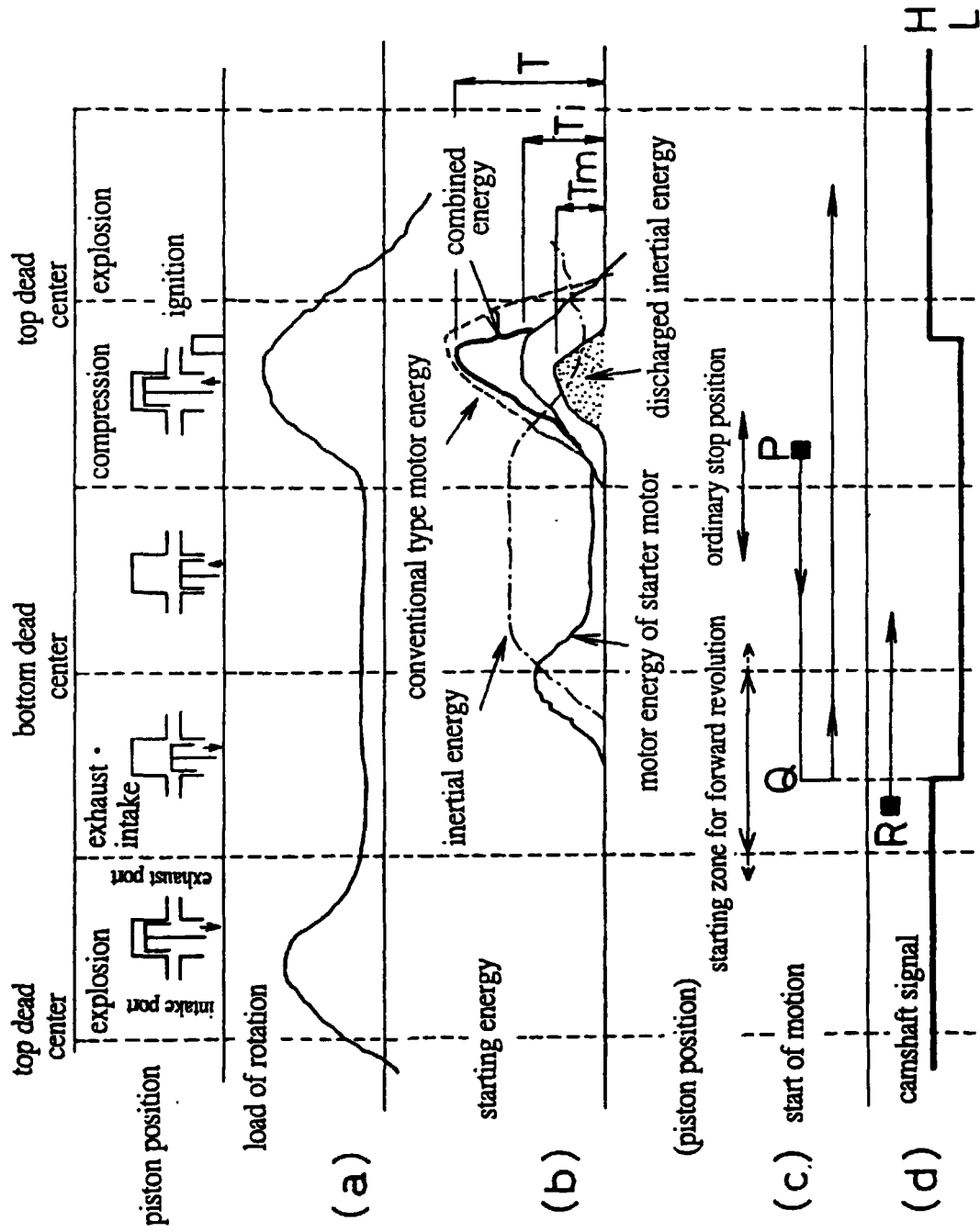


Fig. 15

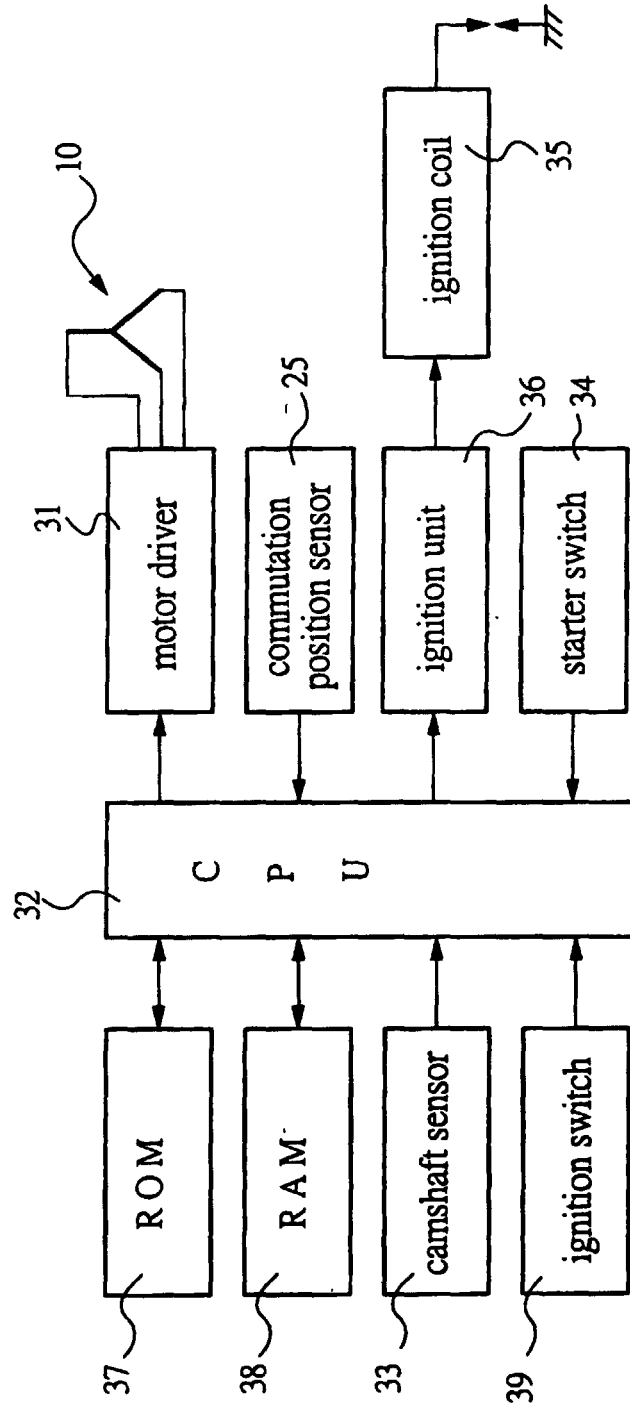


Fig. 16

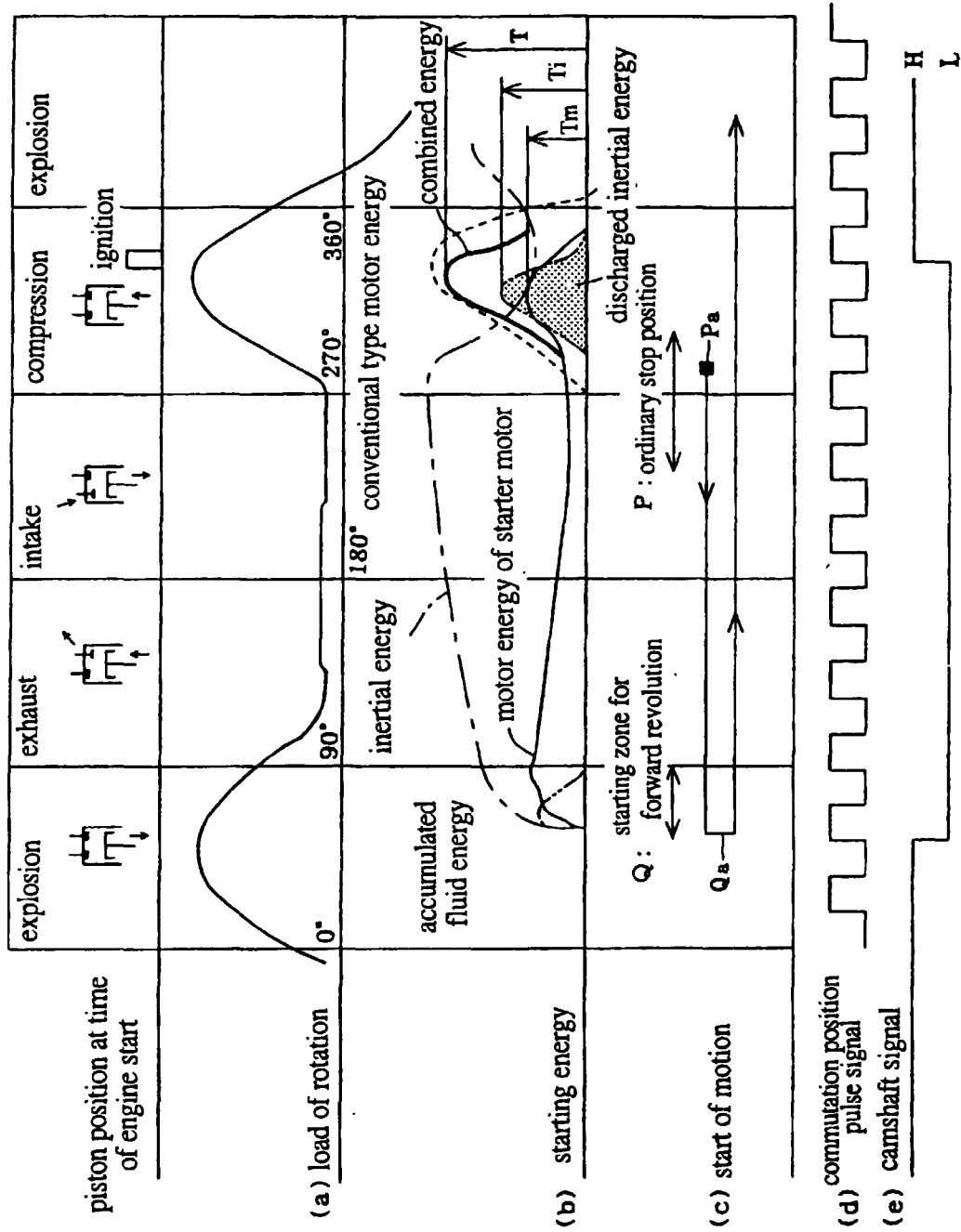


Fig. 17

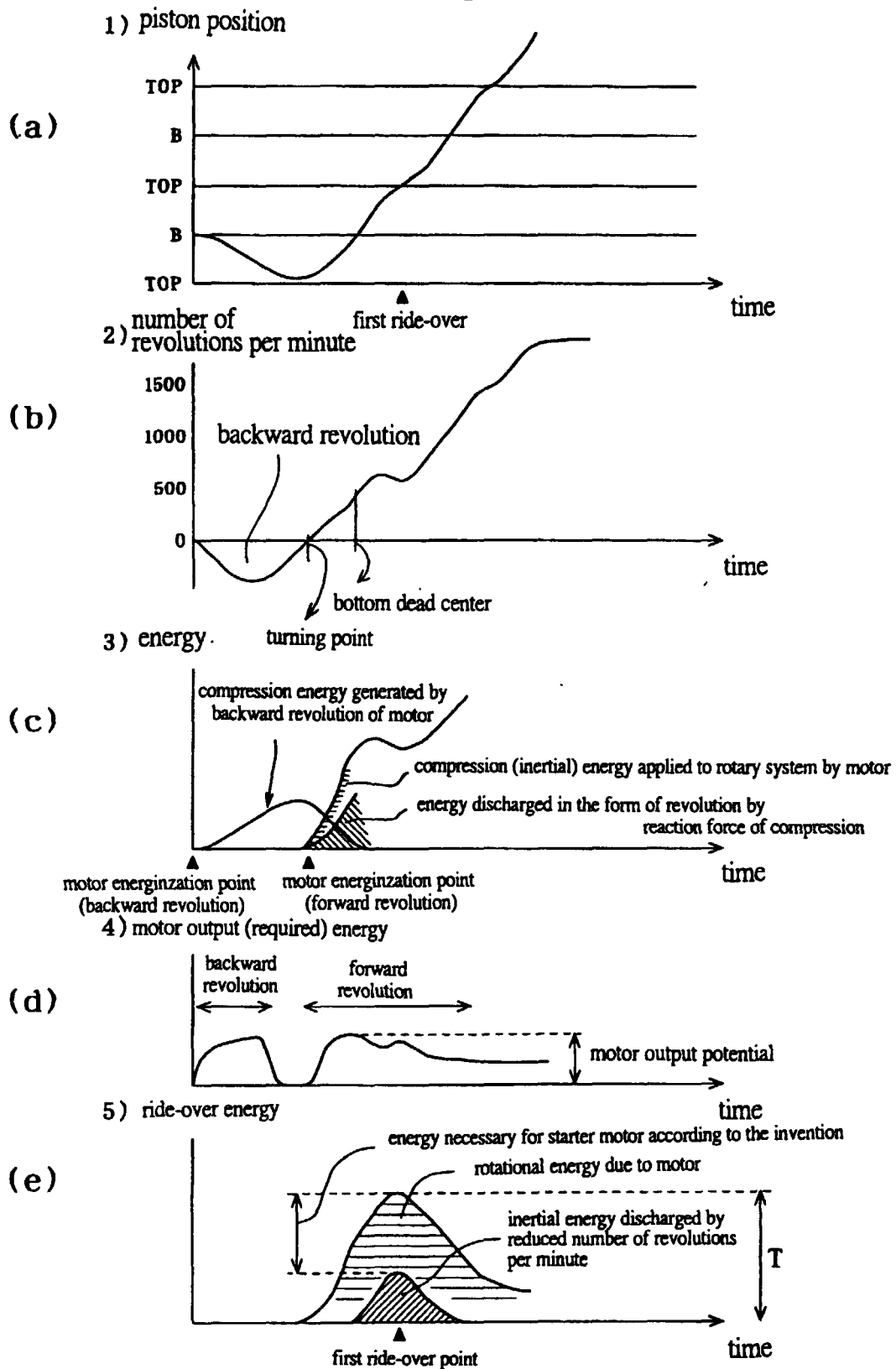


Fig. 18

energy accumulation process

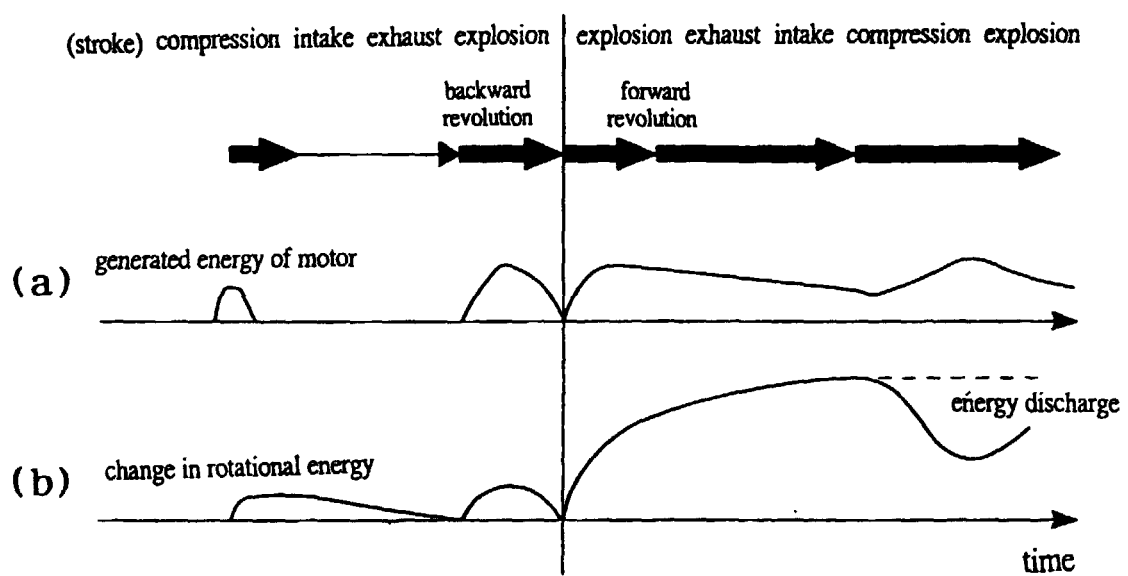


Fig. 19

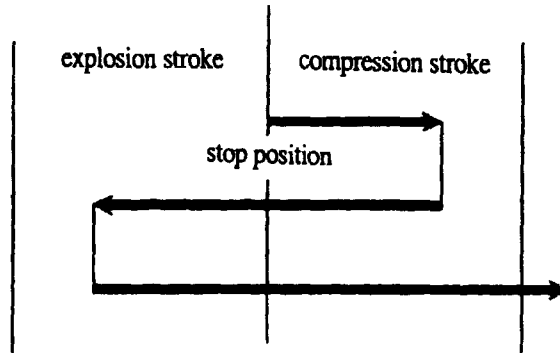


Fig. 20

energy accumulation process

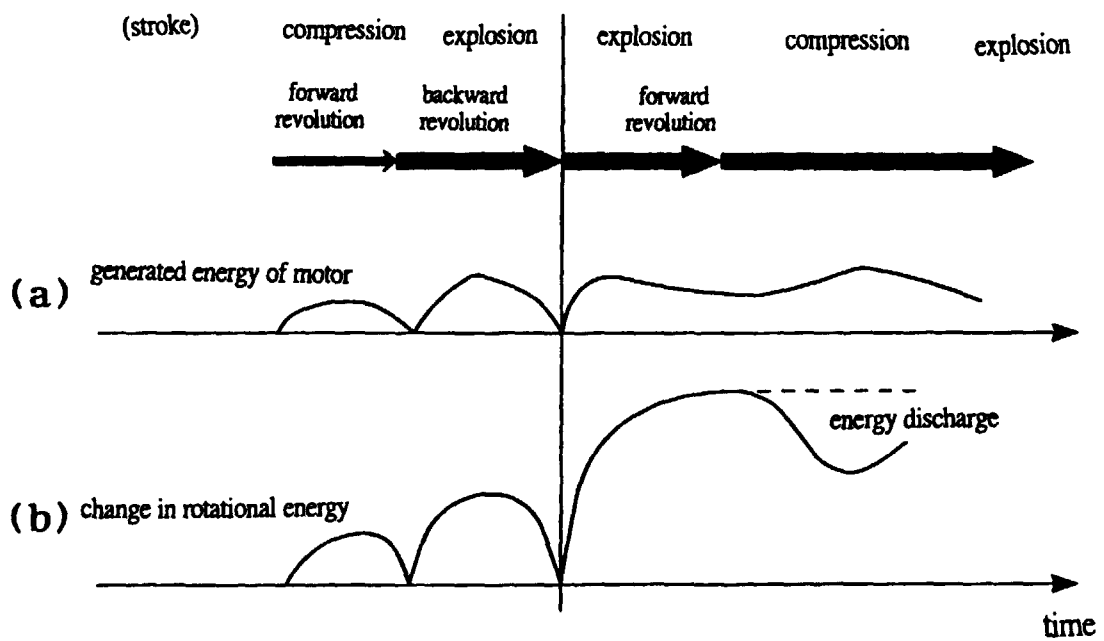


Fig. 21

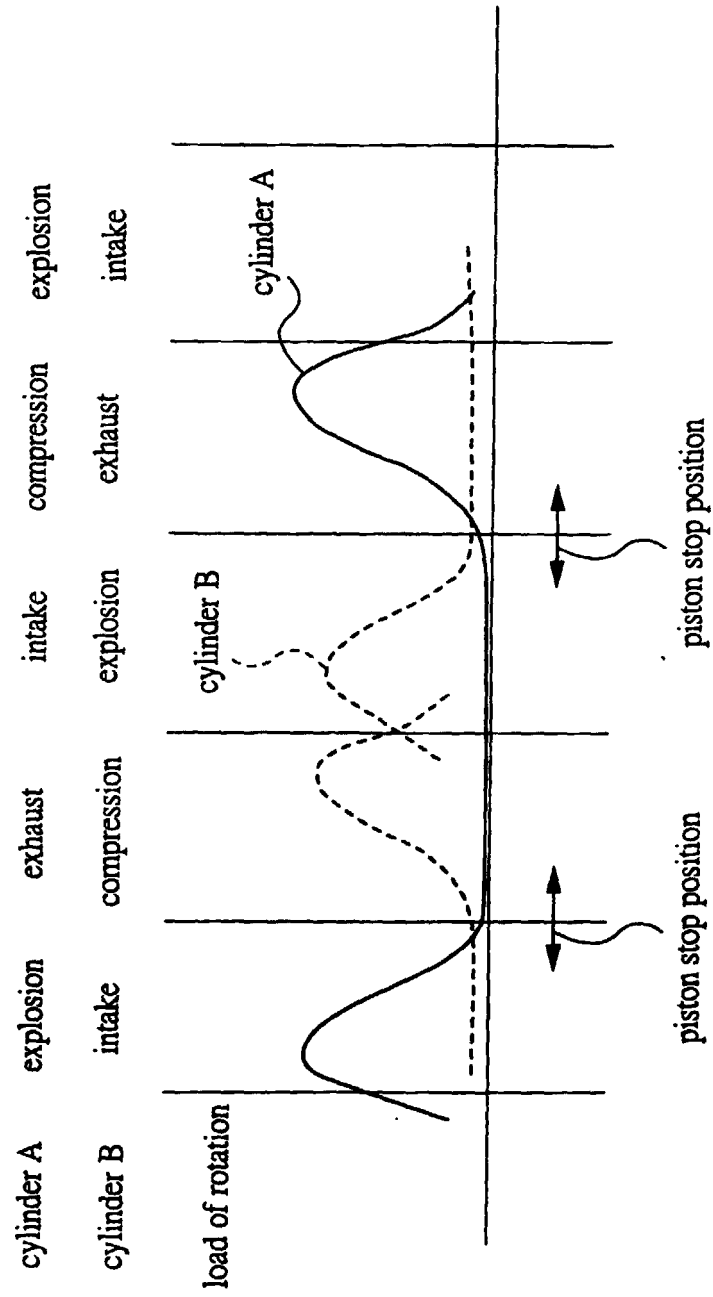


Fig. 22

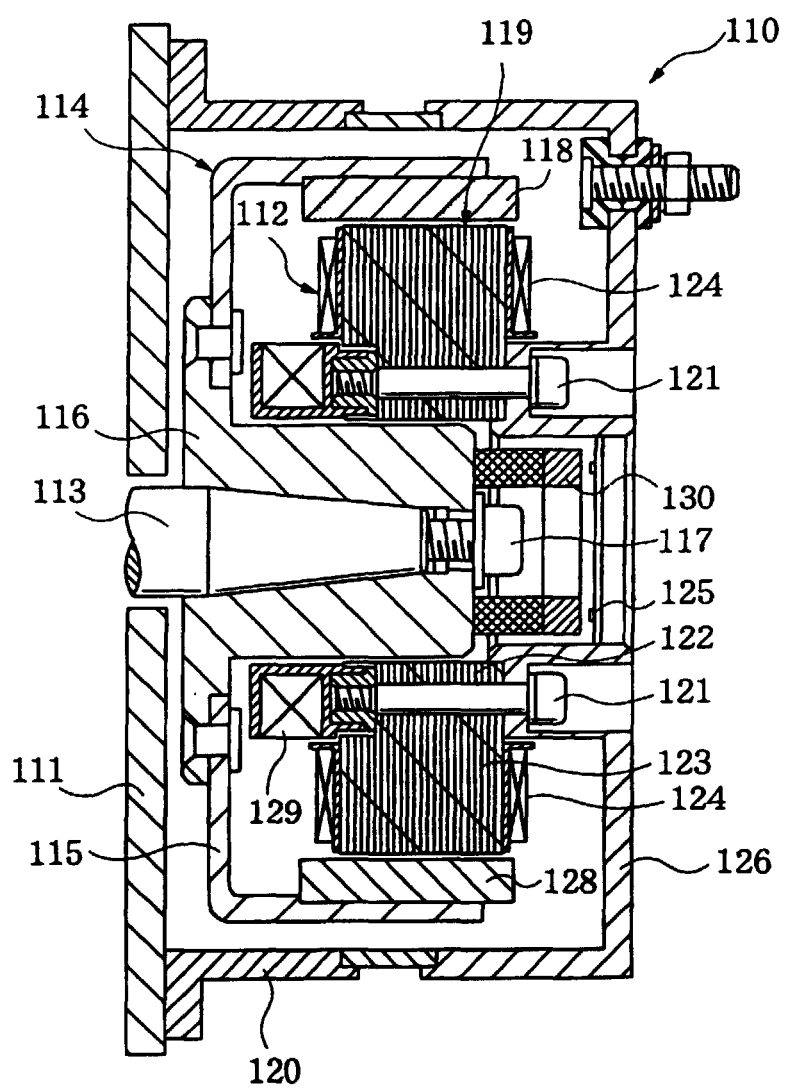


Fig. 23

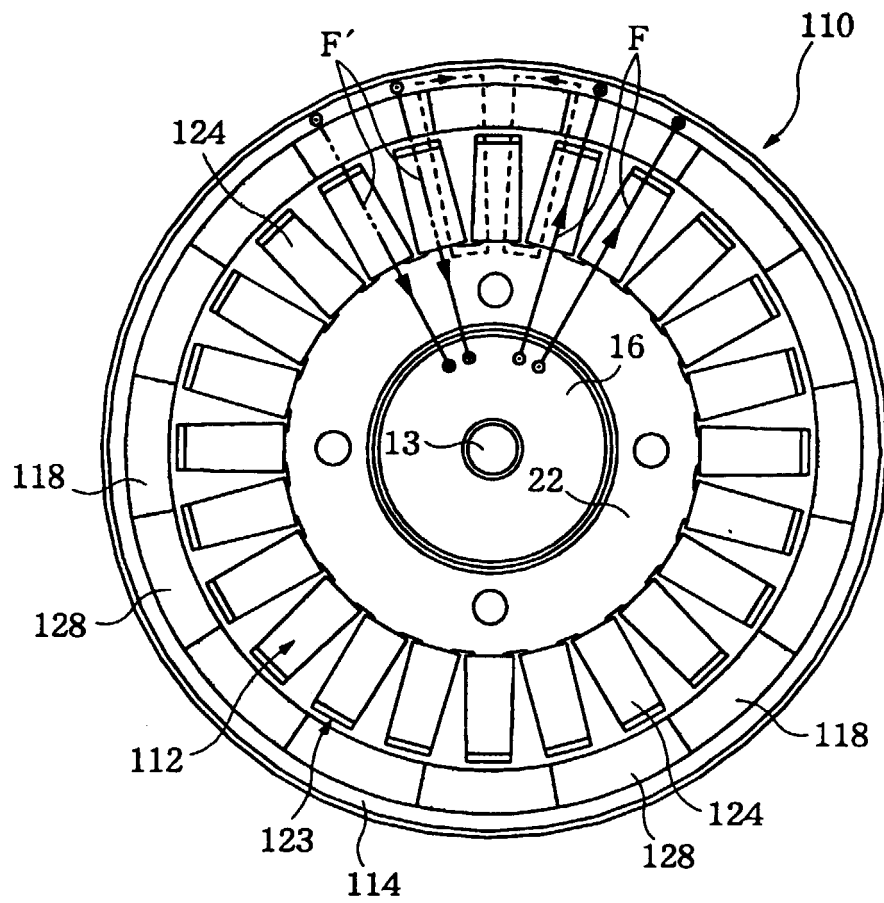


Fig. 24

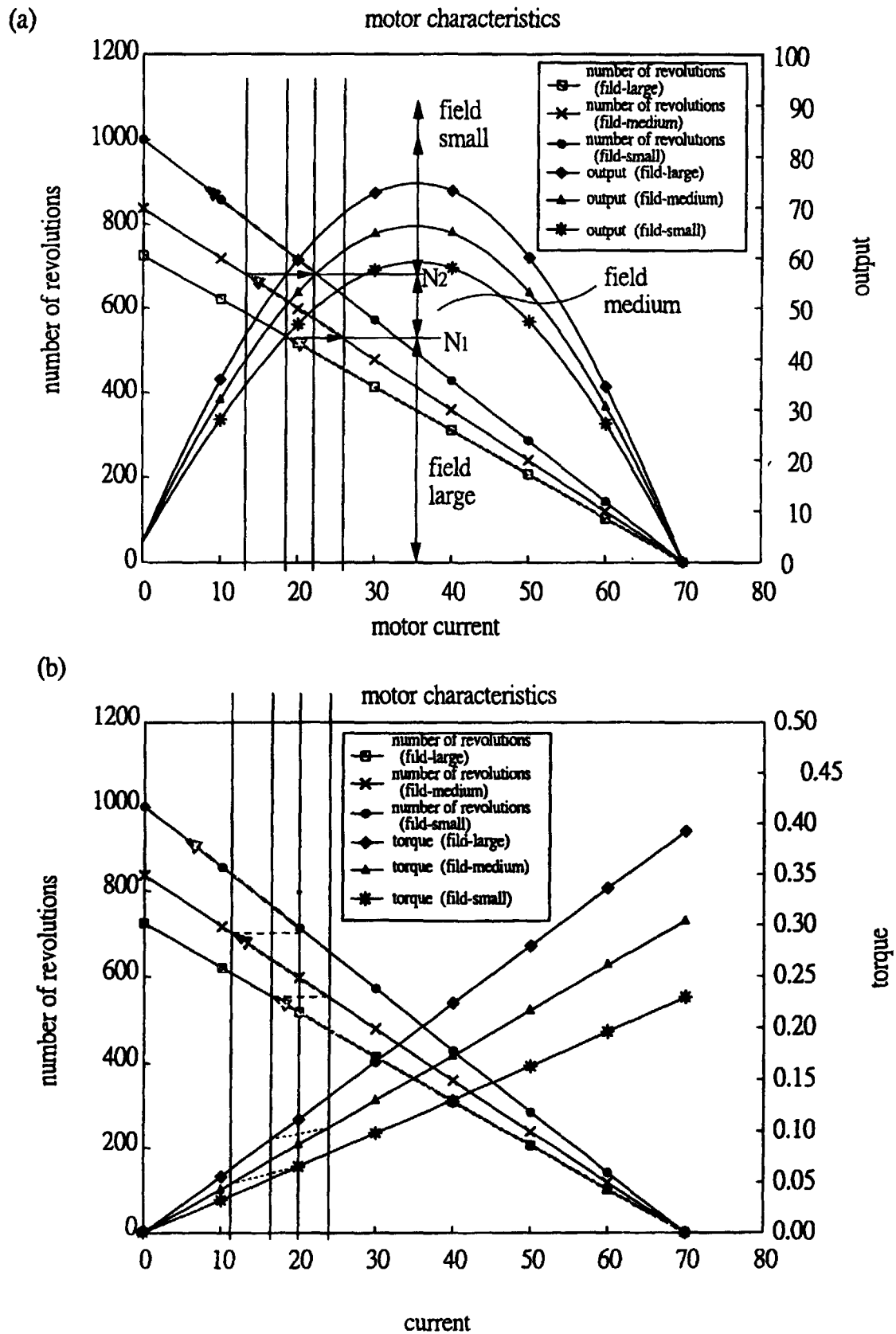


Fig. 25

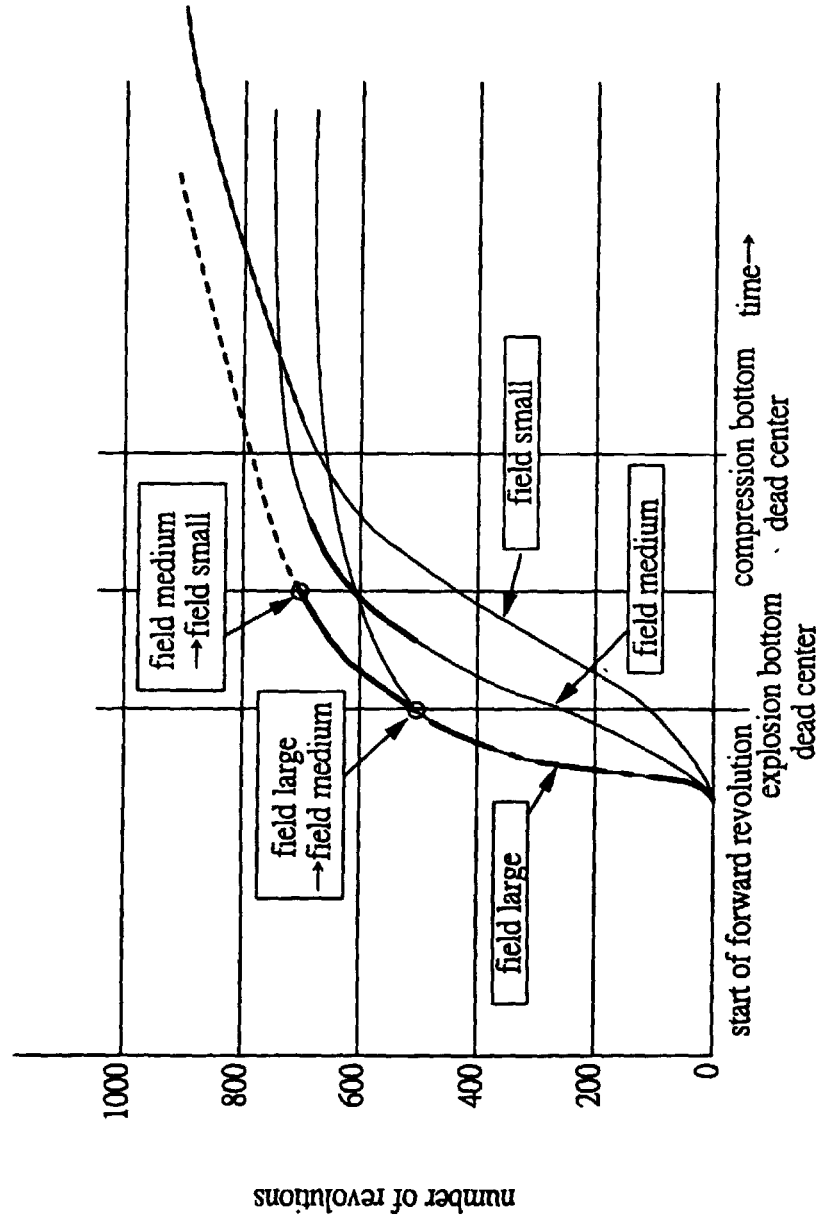


Fig. 26

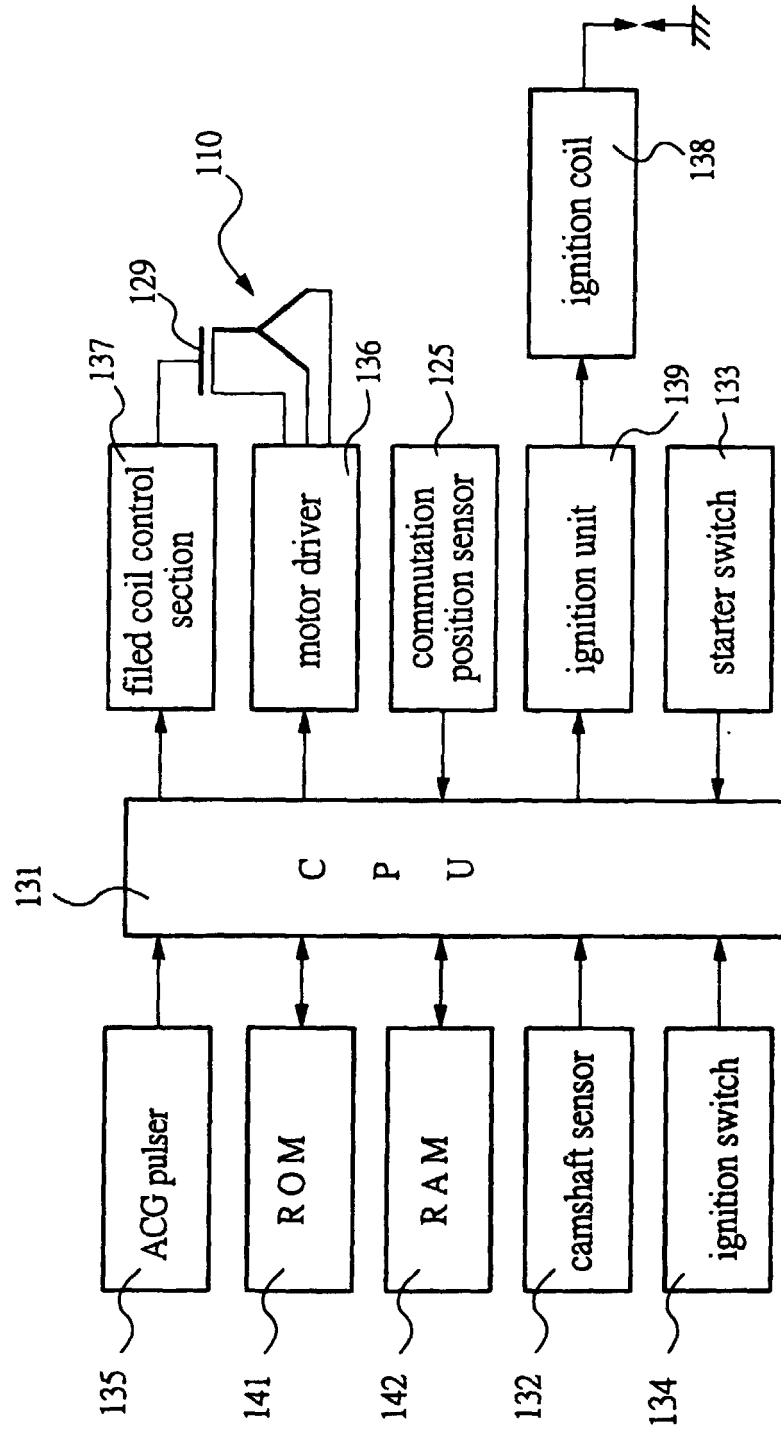


Fig. 27

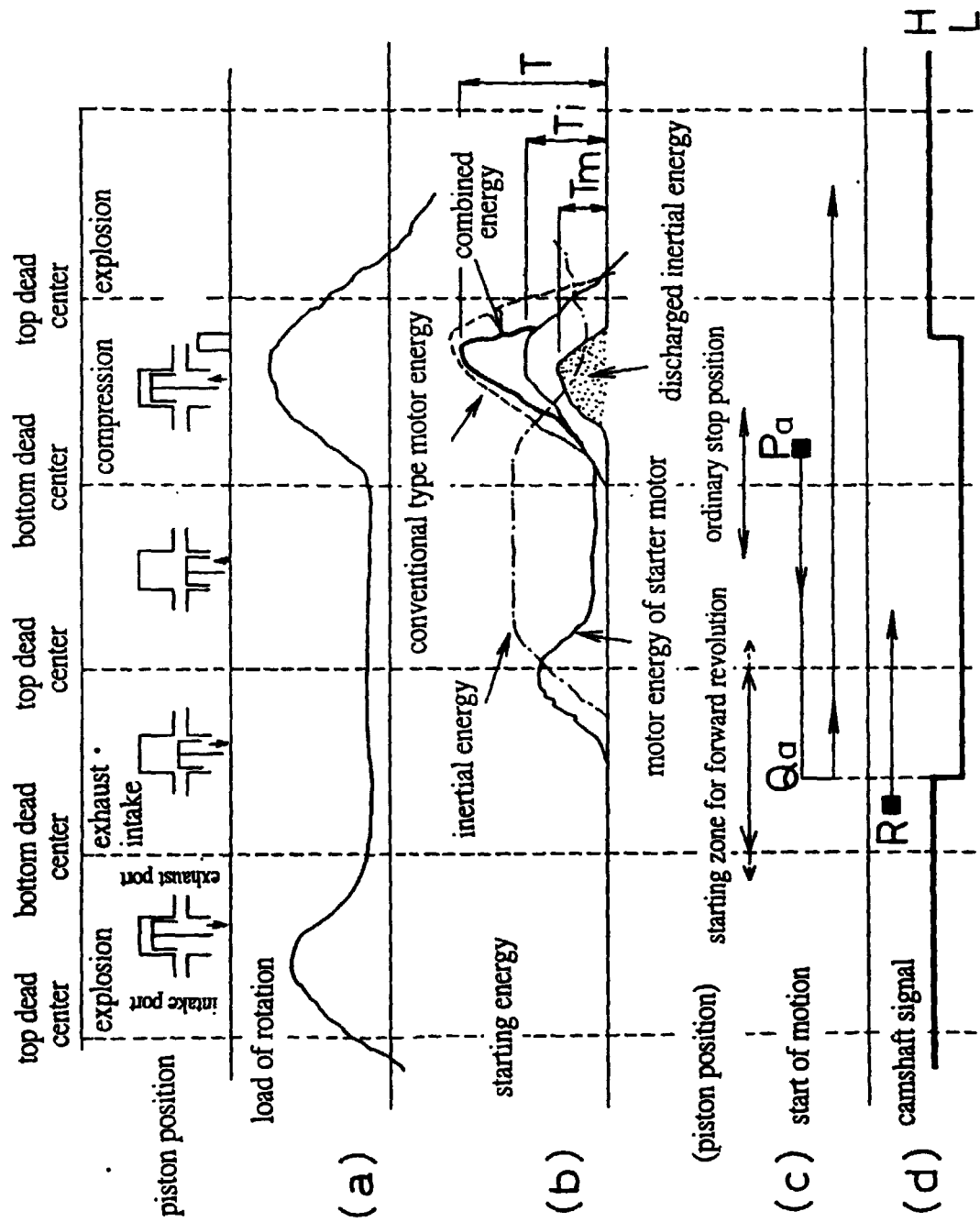


Fig. 28

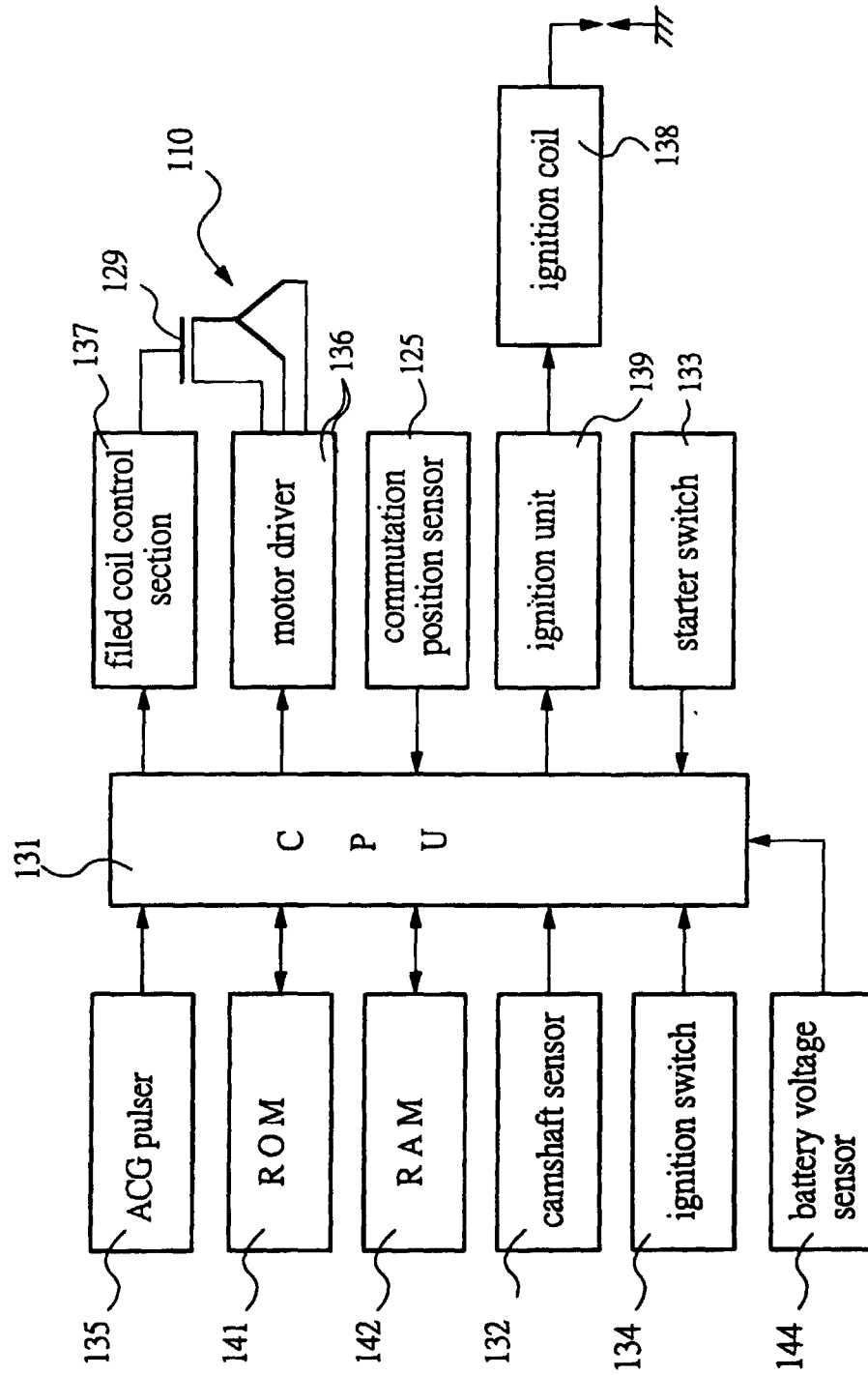


Fig. 29

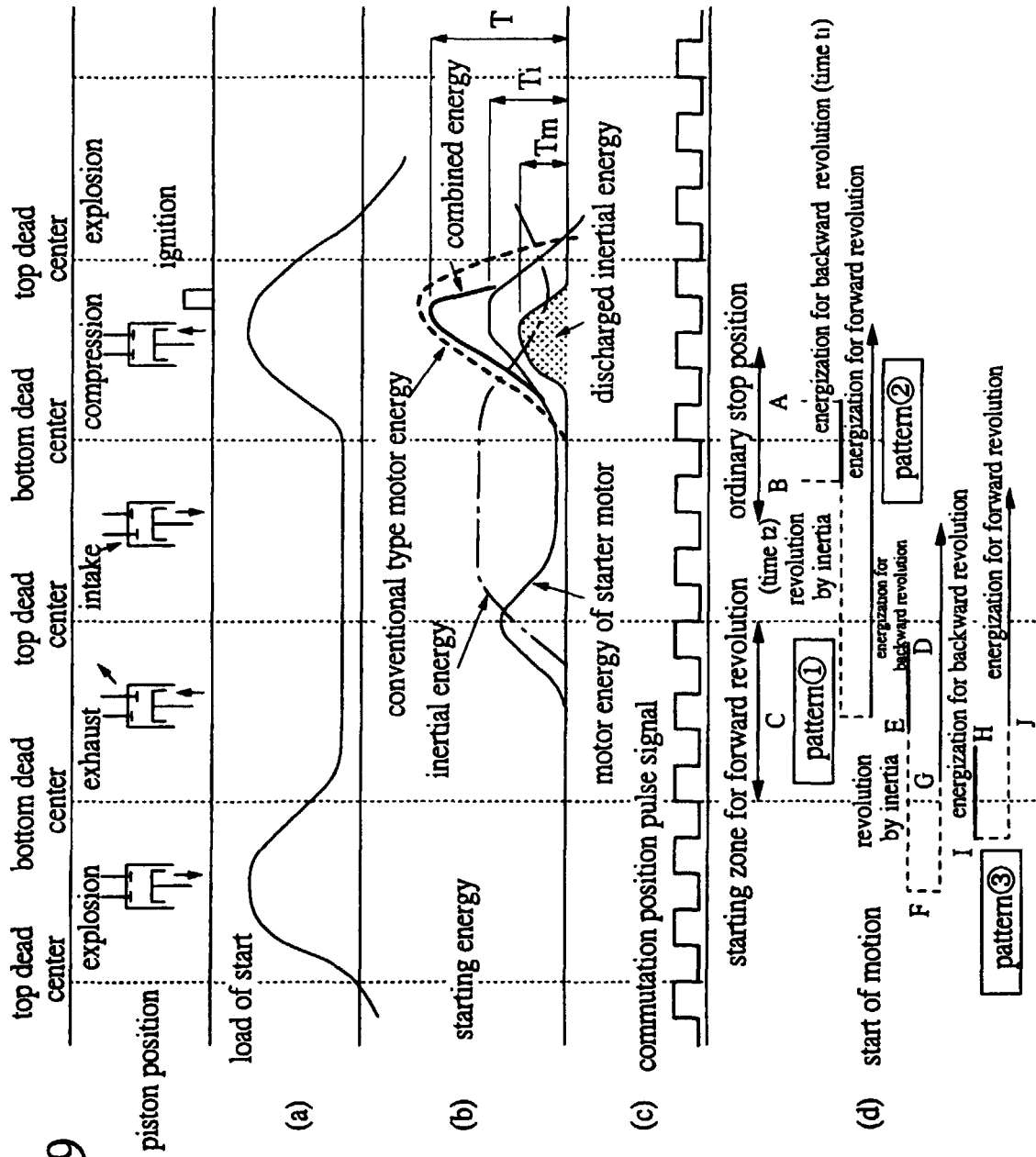


Fig. 30

MAP1 (time of energization for backward revolution) unit : second

	starter motor temperature (°C)					
battery voltage (V)	-20	0	20	40	80	100
12	0.20	0.18	0.16	0.14	0.12	0.10
11	0.22	0.20	0.18	0.16	0.14	0.12
10	0.24	0.22	0.20	0.18	0.16	0.14
9	0.26	0.24	0.22	0.20	0.18	0.16
8	0.28	0.26	0.24	0.22	0.20	0.18
7	0.30	0.28	0.26	0.24	0.22	0.20

Fig. 31

MAP2 (time of suspension of energization)

starter motor temperature (°C)	-10	0	20	40	80	100
time (second)	0.14	0.12	0.10	0.08	0.06	0.04

Fig. 32

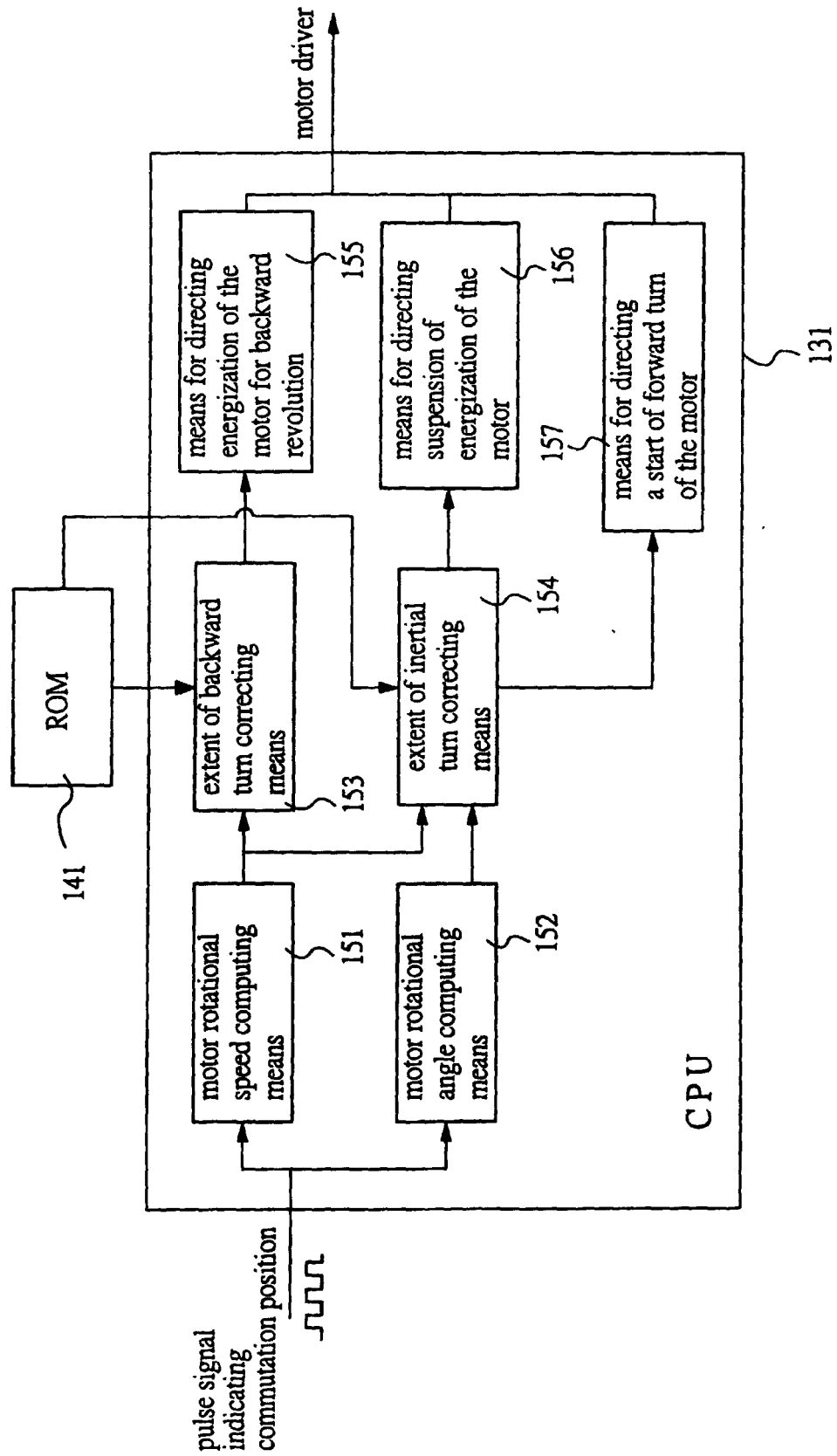


Fig. 33

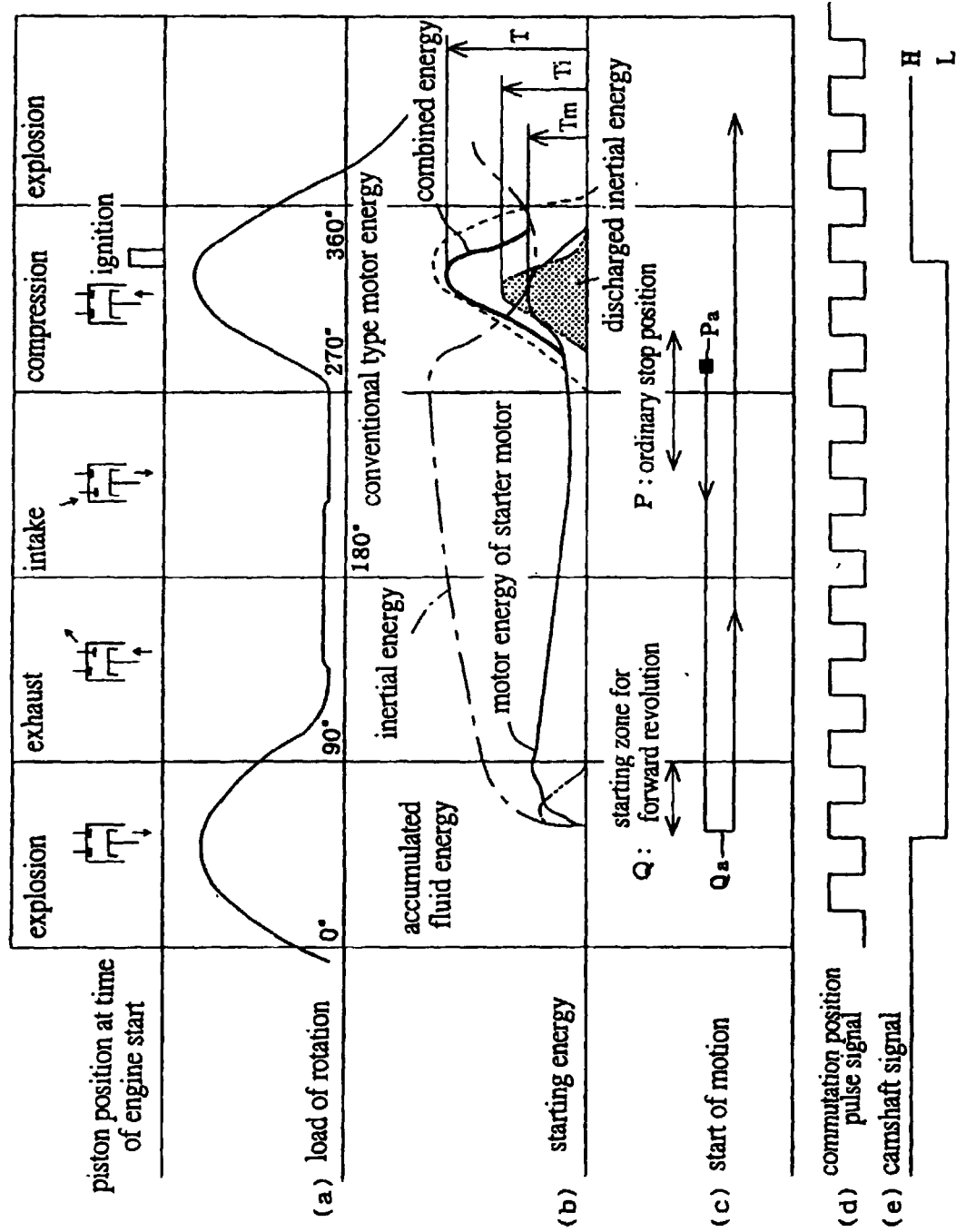


Fig. 34

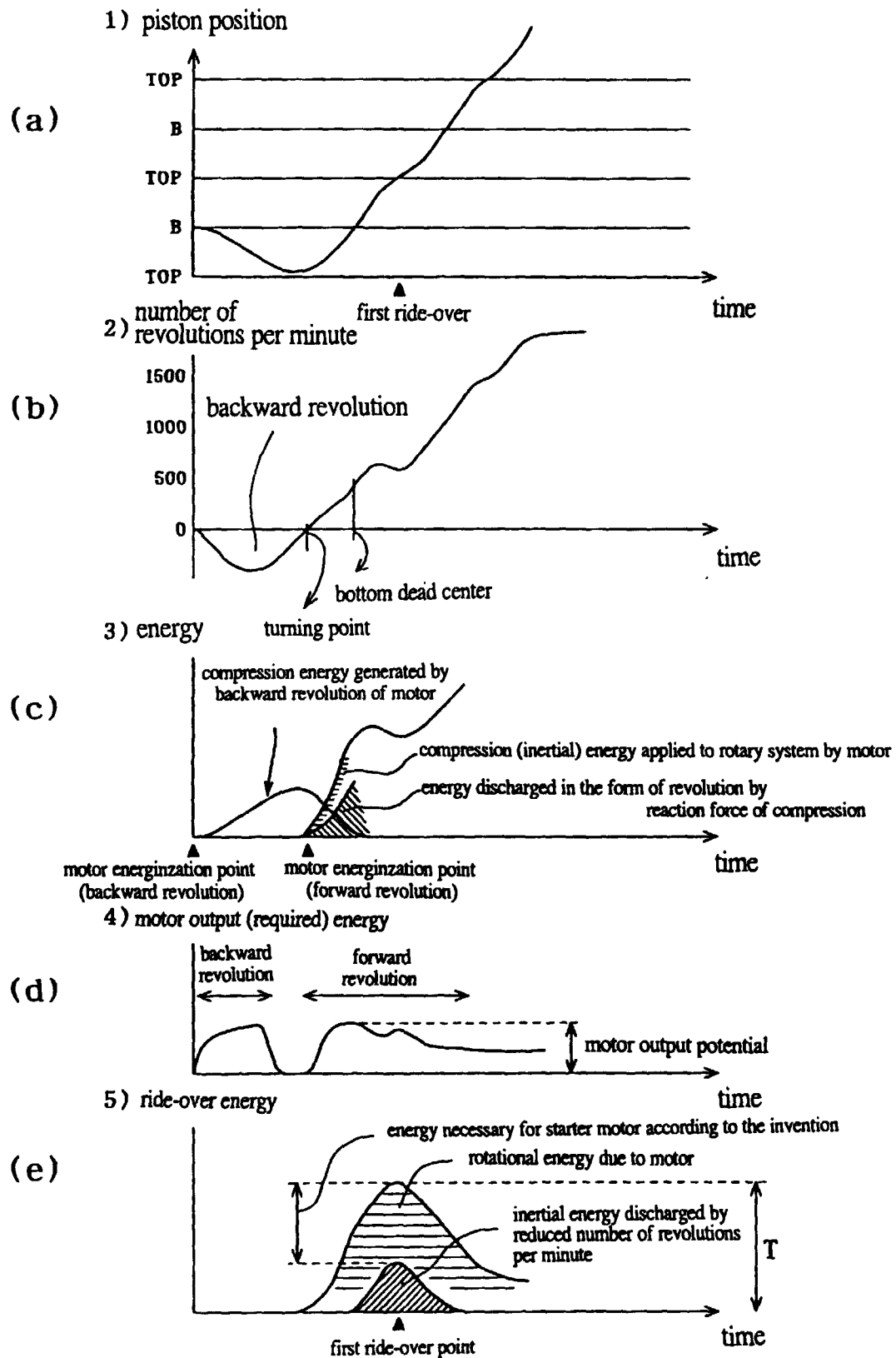


Fig. 35

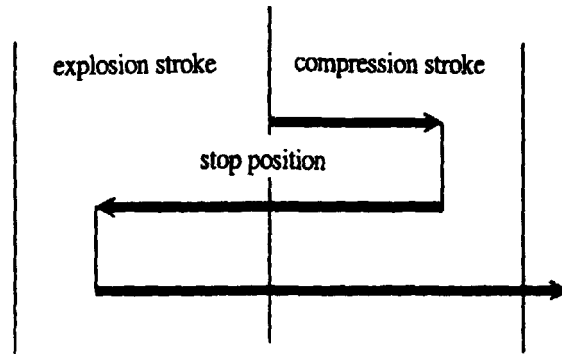
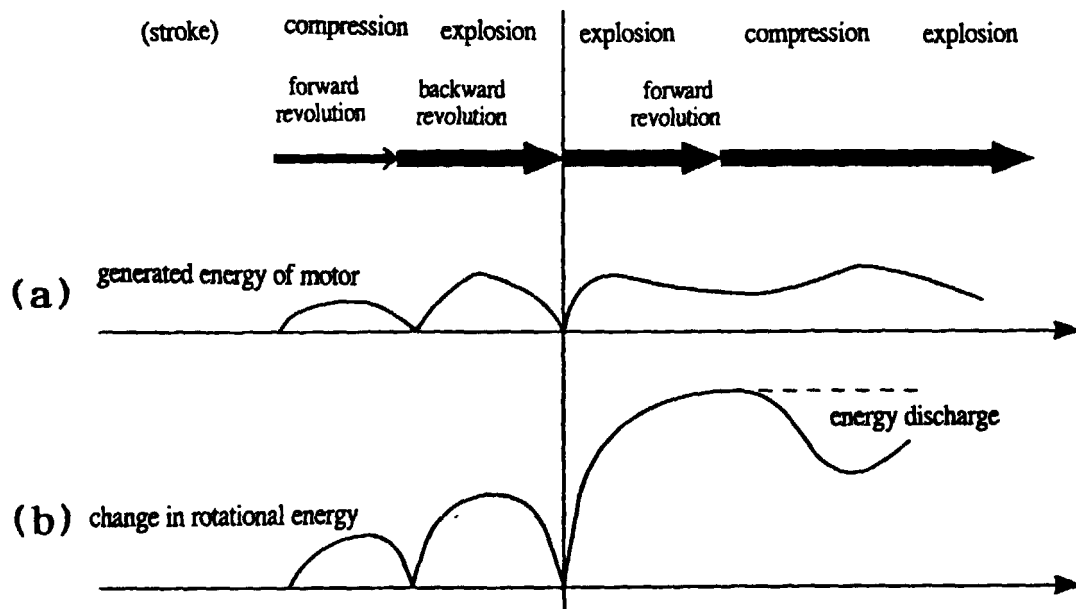


Fig. 36

energy accumulation process



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP99/06902

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl.⁷ F02N11/08

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)
Int.Cl.⁷ F02N11/00, F02N5/04Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1926-1996 Jitsuyo Shinan Toroku Koho 1996-2000
Kokai Jitsuyo Shinan Koho 1971-2000 Toroku Jitsuyo Shinan Koho 1994-2000

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	JP, 02-286874, A (Mitsubishi Motors Corporation), 27 November, 1990 (27.11.90) (Family: none)	1, 21
A	JP, 09-151833, A (SUZUKI MOTOR CORPORATION), 10 June, 1997 (10.06.97) (Family: none)	1-21

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

* Special categories of cited documents:

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"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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

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"Y" 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

"Z" document member of the same patent family

Date of the actual completion of the international search
09 March, 2000 (09.03.00)Date of mailing of the international search report
21 March, 2000 (21.03.00)Name and mailing address of the ISA/
Japanese Patent Office

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Form PCT/ISA/210 (second sheet) (July 1992)