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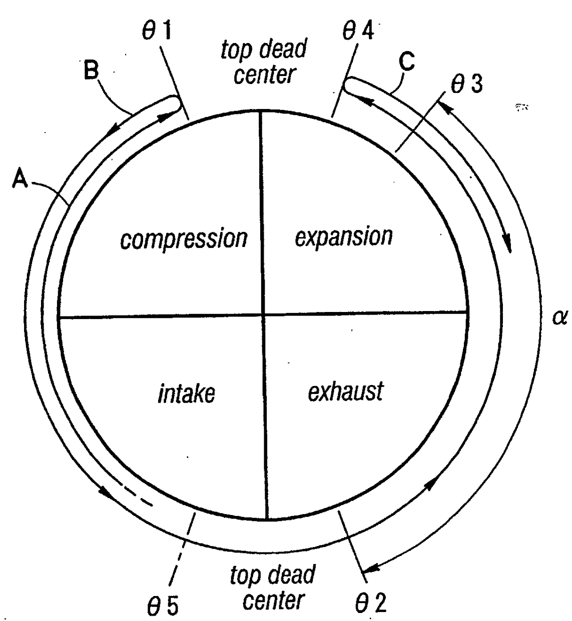
(54) **ENGINE STARTER**

(57) In an engine starter system adapted to crank an engine first in a reverse direction at least under a prescribed condition, and finally in a normal direction, a favorable swing cranking action can be achieved when necessary in a reliable manner. The rotational speed of the electric motor when rotating the crankshaft in the reverse direction is controlled so as to prevent the crankshaft from rotating in the reverse direction beyond the top dead center from the side of the expansion stroke. Thus, by controlling the rotational speed of the crankshaft, the crankshaft is prevented from rotating beyond the top dead center and made to stop at a position immediately before the top dead center. This provides a maximum spring back force of the compression pressure which assists the electric motor in rotating the crankshaft in the normal direction. This assist force, combined with a large approach run distance that can be obtained, ensures a reliable cranking of the engine while minimizing the size and power consumption of the electric motor.

Fig.7



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Description

TECHNICAL FIELD

[0001] The present invention relates to an engine starter system.

BACKGROUND OF THE INVENTION

[0002] Conventionally, in motor vehicles, an engine is cranked by an electric motor, and the electric motor is sometimes used also as an electric generator. By doing so, the electric motor serves both for cranking the engine and generating electricity, and the accessory equipment for the engine can be simplified.

[0003] In an engine starter system, because the position of the piston is indeterminate at the start of cranking the engine, the rated output of the starter motor needs to be high enough to be able to crank the engine even when the piston is at the beginning of a compression stroke and/or when the engine is cold and therefore involves a high level of viscous resistance. However, it is not desirable to increase the size of the starter motor.

[0004] A swing engine starter system is also known which cranks the engine in the normal direction after slightly turning the crankshaft in the reverse direction to ensure a successful cranking of the engine under any condition even when the rated output of the starter motor is relatively small. This swing action provides an approach run and allows the spring back force of a compression pressure to be utilized to help the cranking speed to reach an adequate level to overcome the compression stroke.

[0005] However, because the position at which the reverse drive starts is indeterminate, if the reversing rotation is effected over a large rotational angle and/or the friction loss is smaller than initially anticipated, the rotational speed (in the reverse direction) becomes so great that even when the supply of electric current is terminated at a position in the expansion stroke, the inertia force may be great enough to cause the crankshaft to rotate beyond the top dead center of the expansion stroke. Conversely, if the friction loss is great as is the case when the temperature is low, the cranking speed would not increase as anticipated, and the compression pressure of the expansion stroke may prevent a position in the expansion stroke to be reached. In such a case, because of the absence of the assist force of the compression pressure, the final normal cranking may not be able to rotate the crankshaft beyond the top dead center from the side of the compression stroke.

[0006] If the crankshaft is located at a position (in the expansion stroke) that would give an adequate approach run distance and an adequate assist force of the compression pressure from the beginning, the reverse drive may be omitted and the normal cranking can be directly started. This enables a quick cranking of the engine, and reduces the burden on the battery by minimizing the current required for the cranking. A rotary encoder or the like may be used for detecting the angular position of the crankshaft when starting the engine, but it leads to the rise in the cost of the system. A four stroke engine is typically provided with a reluctor attached to the side of the crankshaft (such as a flywheel). A magnetic sensor or the like detects the passage of the reluctor, and produces corresponding positive and negative pulse pairs in the exhaust stroke and compression stroke. The period between adjacent pulse pairs can be measured according to the preceding negative pulses, for instance.

[0007] However, because these periods have to be detected over a large rotational angle (360 degrees), the relationship between the lengths of periods may reverse at the time of an abrupt acceleration or deceleration or a misfire, and it is not always possible to distinguish between the exhaust stroke and compression stroke.

BRIEF SUMMARY OF THE INVENTION

[0008] In view of such problems of the prior art, a primary object of the present invention is to provide an engine starter system which can perform the swing start action in a reliable manner when necessary so that a reliable cranking action can be effected at all times.

[0009] A second object of the present invention is to provide an engine starter system which can start an engine quickly with a minimum consumption of electric power.

[0010] A third object of the present invention is to provide an engine starter system which allows the crankshaft angular position sensor used for such an engine starter system to be simplified and minimized in cost.

[0011] A fourth object of the present invention is to provide an engine starter system which is suitable for use with an idle stop system which requires frequent restarting of the engine.

[0012] A fifth object of the present invention is to provide an engine starter system which is suited to use an electric motor that serves also as an electric generator.

[0013] According to the present invention, such objects can be accomplished by providing an engine starter system adapted to crank an engine first in a reverse direction at least under a prescribed condition, and finally in a normal direction with an electric motor that is connected to a crankshaft of an engine, comprising: an electric motor connected to the crankshaft; a sensor for detecting an angular position of the crankshaft; and a controller for controlling a supply of electric current to the electric motor according an output signal of the sensor; the controller being adapted to store a crankshaft angle when the engine stopped previously, the normal final cranking being directly performed without the reverse cranking when the crankshaft angle stored in the controller is in a compression stroke or adjacent thereto from a side of an intake stroke.

[0014] Thus, a cranking can be accomplished quickly while saving the consumption of electric power so that a compact and energy saving design for the electric motor is enabled. Because the electric motor may consist of a motor having a relatively small rated output, the motor may be adapted to be used also an electric generator. If desired, a brushless motor may be used for the electric motor, and serve also as an AC generator.

[0015] It is therefore important to detect the angular position of the crankshaft when the engine is turned off in optimizing the control of the restarting operation. The crankshaft angle can be detected in any of a number of possible ways, but it is desirable to be able to do so by using an inexpensive sensor.

[0016] For instance, the crankshaft angle sensor may comprise an ignition timing sensor which is adapted to produce a pair of pulses one after the other at a prescribed angular interval, a point at which each pulse pair are produced being identified as being in the compression stroke or in an exhaust stroke by comparing the angular interval with that of a preceding pulse pair. Such an ignition timing sensor may consist of a common pulser ignition timing sensor using a reluctor.

[0017] Also, the crankshaft angular position sensor may comprise an ignition timing sensor for producing an ignition timing reference pulse, and an angle signal sensor for producing a pulse for each incremental rotational angle at a higher resolution, a position of the crankshaft being determined by detecting a period of a prescribed number of angle signal pulses following a prescribed number of angle signal pulses following a production of an ignition timing reference pulse, and detecting a change in the period. The angle signal sensor may consist of a sensor using teeth of a simple gear as reluctors, or a commutating signal sensor if the electric motor consists of a brushless motor.

[0018] Typically, an ignition timing sensor produces a pulse representing an absolute angular position for each revolution of the crankshaft while an angle signal sensor produces pulses representing relative angular changes at a higher resolution. Therefore, by combining them, it is possible to determine the absolute angle of the crankshaft at a high resolution. The engine stroke can also be identified because the period of the angle signal pulses extends in the compression stroke. The top dead center between the compression and expansion strokes can be determined as corresponding to a point at which the period of the pulse output of the angle signal sensor changes from an increasing state to a decreasing state.

[0019] If the crankshaft angular position sensor comprises an angle signal sensor adapted to provide a plurality of pulses for each revolution of the crankshaft at a regular angular interval except for an uneven section, and an angular position of the crankshaft is determined according to a pulse output of the angle signal sensor, a single sensor can provide the absolute angle of the crankshaft at a high resolution.

[0020] If the controller is adapted to control a rotational speed of the electric motor when rotating the crankshaft in the reverse direction so as to prevent the crankshaft from rotating in the reverse direction beyond the top dead center from the side of the expansion stroke, the crankshaft can be stopped before the top dead center is reached, preferably as immediately before the top dead center as possible, without rotating beyond the top dead center. Therefore, a substantial spring back force of the compression pressure can be made available as an assist force for the final normal drive, and combined with a large approach distance that can be obtained, ensures a reliable cranking action. This also contributes to a compact and power-saving design of the electric motor.

[0021] For instance, the controller may be adapted to control a rotational speed of the electric motor when rotating the crankshaft in the reverse direction below a prescribed upper limit. In such a case, as a rational design consideration, the upper limit of the rotational speed may be defined so as to be smaller than $(2EP0/I)^{1/2}$ where EP0 is the sum of the maximum compression energy of the engine piston and the engine friction loss energy, and I is the moment of inertia of the crankshaft system. From a practical view point, a favorable speed control can be achieved by having the rotational speed of the electric motor when rotating the crankshaft in the reverse direction equal to or greater than $(1/4)\ (2EP0/I)^{1/2}$.

[0022] Because the cranking property of an engine is strongly affected by the battery voltage and engine temperature, the upper limit of the rotational speed may be varied in dependence on at least one of the battery voltage and the engine temperature.

[0023] As a safety net, a forced reversing position may be defined in the expansion stroke near the top dead center thereof, and the crankshaft may be forcibly rotated in the normal direction when the crankshaft has reached the forced reversing position. Also, the reverse drive may be terminated and the crankshaft may be forcibly rotated in the normal direction when the crankshaft has failed to start rotating in the normal direction within a prescribed time period from the time the reverse drive started.

[0024] As an alternate method of speed control, a rotating speed detecting position may be defined in an intermediate point of the expansion stroke, and the crankshaft may be forcibly rotated in the normal direction when the crankshaft has reached the rotating speed detecting position and a rotational speed of the crankshaft is higher than a prescribed rotational speed limit at this position. This allows the control circuit to be simplified.

[0025] Additionally, a reverse drive terminate position may be defined in the expansion stroke, and the reverse drive may be terminated when the crankshaft has reached the reverse drive terminate position after reversing the expansion stroke, the crankshaft being forcibly rotated in the normal direction when a compression pressure has become dominant over an inertia force that has been causing the crankshaft to continue rotating in the reverse direction, and the crankshaft has started rotating in the normal direction. This prevents a waste of power consumption by the electric motor can be controlled, and a smooth operation is enabled.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Now the present invention is described in the following with reference to the appended drawings, in which:

Figure 1 is a schematic diagram of an engine starter system embodying the present invention;
Figure 2 is a fragmentary sectional side view of the engine starter system;
Figure 3 is a fragmentally end view partly in section as seen in the direction indicated by arrows III-III in Figure 2;
Figure 4 is a simplified circuit diagram of the engine starter system embodying the present invention;
Figure 5 is a time chart showing a mode of operation of the engine starter system including a preliminary normal cranking of a four stroke engine according to the present invention;
Figure 6 is a time chart showing the commutating signal of the electric motor (brushless motor);
Figure 7 is a diagram showing the change in the strokes of the four stroke engine corresponding to the control procedure illustrated in Figure 5;
Figure 8 is a time chart corresponding to the control procedure illustrated in Figure 5;
Figure 9 is a diagram showing an embodiment of the control procedure during the reverse drive embodying the present invention;
Figure 10 is a diagram showing another embodiment of the control procedure during the reverse drive embodying the present invention;
Figure 11 is a diagram showing yet another embodiment of the control procedure during the reverse drive embodying the present invention;
Figure 12 is a diagram showing yet another embodiment of the control procedure during the reverse drive embodying the present invention;
Figure 13 is a diagram showing yet another embodiment of the control procedure during the reverse drive embodying the present invention;
Figure 14 is a time chart showing a mode of operation of the engine starter system not including a preliminary normal cranking of a four stroke engine according to the present invention;
Figure 15 is a diagram showing the change in the strokes of the four stroke engine corresponding to the control procedure illustrated in Figure 14;
Figure 16 is a time chart corresponding to the control procedure illustrated in Figure 14;
Figure 17 is a time chart showing several embodiments of the procedure for identifying the compression stroke according to the present invention;
Figure 18 is a simplified diagram showing an electric motor provided with a plurality of reluctors; and
Figure 19 is a time chart showing a control mode based on a pulse train obtained from the electric motor illustrated in Figure 19.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] Figure 1 is a schematic diagram showing an engine starter system embodying the present invention. As shown in Figure 1, this starter system includes an electric motor (generator) 1 which is coaxially and directly connected to a crankshaft 2 of an engine ENG, and is adapted not only to crank the engine but also to function as an electric generator during the operation of the engine. A controller ECU controls the electric motor 1 as well as the engine ENG by receiving signals from an ignition switch IG and a starter switch ST.

[0028] An exemplary structure of the electric motor 1 is now described in the following with reference to Figures 2 and 3. As shown in the drawings, an outer rotor 3 having the shape of a shallow cup and serving also as a flywheel is coaxially attached to the crankshaft 2 of the engine ENG, and includes a prescribed number of arcuate magnet pieces 4 that are attached to the inner circumferential surface of the outer rotor 3 in such a manner that the magnetic poles of the magnet pieces 4 alternate between N and S along the circumferential direction.

[0029] The electric motor 1 is additionally provided with an inner stator 5 which is coaxially disposed with respect to the outer rotor 3 and cooperates with the latter. The inner stator 5 is provided with a same number of stator cores 7 as the magnet pieces 4 which are disposed radially with respect to the crankshaft 2 inside the peripheral wall of the outer rotor 3 opposite the magnetic poles of the magnet pieces 4, and stator coils 6 which are wound around the corresponding stator cores 7. The inner stator 5 is fixedly attached to an end surface of the engine ENG with threaded bolts 11. Each stator coil 6 is connected to a drive device such as an FET in a motor driver circuit 14 for driving the electric motor 1 according to an electric motor control signal from a CPU provided in the controller ECU as shown in Figure 4 also. The electric motor of this ACG starter system consists of a brushless motor, and the motor driver circuit 14 include a pair of FETs for each of the U, V and W phases to drive the corresponding phase into high and low states. An intermediate node between each pair of the FETs is connected to the stator coil 6 of the corresponding phase.

[0030] To the outer circumferential surface of the outer peripheral wall of the outer rotor 3 is attached a reluctor 8 consisting of a magnetic member. A pulser (magnetic detection coil) 9 is fixedly attached to an end surface of the engine ENG via a bracket 10 which is integrally formed with the pulser 9 with a threaded bolt 12 so as to oppose the outer peripheral surface of the peripheral wall of the outer rotor 3. The pulser 9 forms an ignition timing sensor in cooperation with the reluctor 8 by detecting magnetic changes as the reluctor 8 passes the pulser 9. Three Hall devices 13 are provided in the inner stator 5 of the electric motor 1 to form a commutating position sensor. The outer rotor 3 is provided with an annular sensor magnet 15 serving as an object of detection around a boss projecting toward the engine main body. The Hall devices 13 are placed on suitable locations of the inner stator 5 via a positioning case so as to detect the positional changes in the magnetic poles of the sensor magnet 15. The Hall devices 13 are arranged at a regular interval along the circumferential direction so as to correspond to the U, V and W phases as shown in Figure 3.

[0031] Referring to Figure 1 and 4, the controller ECU monitors the engine temperature TE and the battery voltage BT. According to the monitored values, a preliminary action can be started by selecting a control action which is both efficient and appropriate according to a data table stored in ROM in advance. The engine temperature TE may include the cooling water temperature in a water cooled engine, the ambient temperature inside the engine room, the temperature of the electric motor (electric generator) 1, the temperature of the controller ECU when it is mounted inside the engine room, or any data that would give a measure of the temperature of any part of the engine.

[0032] The mode of cranking the engine with this engine starter system is described in the following. As the electric motor 1 consists of a three phase brushless motor in this embodiment, the Hall devices 13 are arranges so as to detect the timings of the rise (L→H) and fall (H→L) of each of the U, V and W phases as shown in Figure 6, and the rotational angle can be detected by an increment of 10 degrees according to the combinations of the states of the three phases. As there are six possible combinations of these states, the same combination repeats itself for every 60 degrees. Therefore, this sensor can detect relative angular changes, but cannot measure the absolute angular position by itself.

[0033] Because the engine consists of a four stroke engine, for each two revolutions or for each rotation of 720 degrees, the compression, expansion, exhaust and intake strokes take place as illustrated in Figure 7. The pulser 9 detects the passage of the reluctor 8 at a position (θ1) slightly before the top dead center between the compression and expansion strokes, and at a position (θ2) slightly before the top dead center between the exhaust and intake strokes or at a position separated from position θ1 by 360 degrees. Positions θ1 and θ2 are referred to as "ignition timing reference position" and "angle computing reference position" in the following description. Because the reluctor 8 has a certain width, the pulser 9 produces pulses of mutually opposite polarities as the leading edge and trailing edge of the reluctor 8 passe the pulser 9. Therefore, the pulser 9 can determine the absolute angular position, but can determine only one point out of 360 degrees, and cannot distinguish between the compression stroke and exhaust stroke.

[0034] When the engine ENG is stationary, it can be estimated that that the crankshaft is somewhere in the exhaust or intake stroke, but cannot be determined for certain under normal condition. Therefore, when an attempt is made to successfully crank the engine by rotating the crankshaft in the reverse direction before finally cranking the engine in the normal direction (swing start action), it cannot be determined how far back the crankshaft should be rotated in the reverse direction. In other words, depending on the position of the crankshaft before cranking the engine, the reverse drive may not able to rotate the crankshaft in the reverse direction to a sufficient extent to provide an adequate approach run distance and adequate swing action when finally cranking the engine in the normal direction due to the compression resistance that is encountered when reversing the expansion stroke. It is also possible for the reverse drive to rotate the crankshaft beyond the top dead center from the side of the expansion stroke. Therefore, in the illustrated embodiment, prior to the final cranking action, the crankshaft is rotated in the normal direction (preliminary normal drive), when necessary, to such an extent as not to go beyond the top dead center between the compression and expansion strokes so that the swing start action can be effected with an adequate approach run distance for the reverse drive.

[0035] According to the starter system of the present invention, the ignition switch IG is turned on at first, and the starter switch ST is then turned on to crank the engine by supplying electric current to the electric motor. At this time, as shown in Figure 5, as soon as the ignition switch IG is turned on, the electric motor 1 is rotated in the normal direction in an intermittent manner as a first preliminary normal drive. The duration of each intermittent operation T1 may be 50 ms, for instance. This action takes place in an automatic manner as the vehicle operator turns on the ignition switch IG and then turn on the starter switch ST.

[0036] During this first normal drive operation, the crankshaft 2 is turned to an angle which is immediately before the top dead center of a compression stroke of a four-stroke engine as shown in arrow A in Figures 7 and 8. Such a control action can be effected by noting the possibility of computing the rotational speed from the commutating position signal or the count of rotational angle. When the rotational speed has dropped to zero during the non-drive period of the intermittent operation, it can be judged that the piston has risen to a point close to the top dead center, and the resulting rise in the compression pressure has resisted any further rise of the piston. The normal drive is therefore terminated. The intermittent operation is conducted for the purpose that the crankshaft 2 can be rotated to a position substantially coinciding with a ignition timing reference position (a certain angle before the top dead center which is used for the ignition timing control) θ1 but not to the extent to reach the top dead center (by producing a torque that would not overcome the compression resistance).

[0037] Then, the starter switch ST is turned on to drive the electric motor 1 in the reverse direction (arrow B in Figures 7 and 8). At this time, the pulser 9 detects the passage of the reluctor 8 (angle computing reference position θ2) during the exhaust stroke of the illustrated four-stroke engine, and produces a signal similar to that is produced at the ignition timing reference position θ1. The rotational angle is counted anew from this angle computing reference position θ2. When the count from the angle computing reference position θ2 reaches an angle α, the drive of the electric motor 1 in the reverse direction is terminated. This position which is behind the angle computing reference position θ2 by the angle α is defined as a reverse drive terminate position θ3. Even after the reverse drive of the electric motor 1 has been terminated, the crankshaft continues to rotate by a certain angle under the inertia force. However, the spring back force of the compression pressure eventually becomes dominant over this inertia force as the expansion stroke is reversed, and the crankshaft comes to a stop. This position is defined as a reversing position θ4. Once this reversing position θ4 is reached, the normal drive of the electric motor 1 is started (arrow C in Figure 7). This saves the consumption of electric power as compared to the case where the normal drive is started as soon as the reverse drive is terminated.

[0038] The reversing of the expansion stroke produces a rise in the compressive pressure which produces an assist force that tends to push back the piston. This assist force, combined with an adequate approach run distance, increases the rotational speed of the electric motor 1 in the normal direction. This provides an adequate torque for getting over the top dead center from the side of the compression stroke in the normal direction, and allows the need for the output of the electric motor of the starter system to be minimized.

[0039] Referring to Figure 9, the mode of operation of the starter system of the present invention is now described in the following. Figure 9 shows a case in which the engine is initially cranked in the reverse direction. Upon receiving a signal from the starter switch ST, the crankshaft 2 is turned in the reverse direction, and under normal temperature condition the cylinder pressure rises as the angular motion of the crankshaft 2 reverses the expansion stroke. When a rotational angle detecting position θd (BTDC 600 degrees) defined in an intermediate part of the expansion stroke (near the point from which the compression pressure starts increasing) is reached, the supply of electric current to the electric motor 1 is terminated. Thereafter, the inertia force maintains the reversing of the expansion stroke, and as soon as the rotation of the crankshaft ceases as a result of the opposition by the compression pressure, the rotation in the normal direction owing to the compression pressure starts, and the normal drive of the electric motor 1 is started at the same time. Thus, the normal drive is assisted by the spring back force of the compression pressure so that the cranking torque can be effectively increased without increasing the actual output of the electric motor 1.

[0040] To prevent the rotational angle of the crankshaft 2 from getting over the top dead center from the side of the expansion stroke, as required by the present invention, if necessary, the electric motor 1 may be subjected to a regenerative braking action by monitoring the rotational speed after the upper limit rotational speed NH has been reached, and turning on all of the FETs on the low side of the motor driver circuit 14 so as to control the deceleration level to be greater than a prescribed level.

[0041] To control the rotational speed in a simple manner, in the illustrated embodiment, a constant speed control is started as soon as the upper limit rotational speed NH has been reached. In this case, as shown by the double-dot chain-dot line in the drawing, a constant speed control is started as soon as the upper limit rotational speed NH has been reached, and the supply of electric current to the electric motor 1 is terminated as soon as the rotational speed detecting position θd has been reached. Therefore, even when the friction loss is extremely small, the excessive rise in the rotational speed can be controlled, and inadvertently getting over the top dead center of the expansion stroke can be avoided.

[0042] By defining the rotational speed detecting position θd and the upper limit rotational speed NH in such a manner as to prevent the crankshaft 2 from getting over the top dead center from the side of the expansion stroke, the crankshaft can be stopped before the top dead center, preferably as immediately before the top dead center as possible, as shown in the drawing. Thereby, a substantial compression spring back force can be obtained, and this provides a substantial assist to the normal drive so that the electric motor can be designed in a compact manner and the power consumption can be minimized.

[0043] The rotational speed of the crankshaft 2 should be controlled in such a manner that the upper limit rotational speed is less than $(2EP0/I)^{1/2}$ where EP0 is the sum of the maximum compression energy of the engine piston and the engine friction loss energy, and I is the moment of inertia of the crankshaft system. The rotational speed of the crankshaft 2 should be also controlled in such a manner that the upper limit rotational speed is equal to or greater than $(1/4)(2EPO/I)^{1/2}$. This allows the rotational speed control to be conducted in a rational manner.

[0044] The upper limit rotational speed may be varied in dependence on at least one of a battery voltage and an engine temperature. For instance, a detection signal such as that indicating an engine temperature (which may consist of a cooling water temperature, a temperature of the electric motor 1, or a temperature of a controller ECU) is fed to a controller ECU as shown in Figure 1, and the upper limit rotational speed in lowered (NH1) when the engine temperature is high and the friction loss is therefore low while the upper limit rotational speed in raised (NH2) when the engine temperature is low and the friction loss is therefore high as shown in Figure 10. The limit may not be selected from two possible values, but may be varied continually between the lower upper limit rotational speed (NH1) and higher upper limit rotational speed (NH2) depending on the temperature.

[0045] Thereby, the point H of reversing the direction of rotating the crankshaft 2 can be kept at a substantially fixed point as shown in Figure 10 without regard to the engine temperature so as to provide an adequate compression pressure spring back force at all times. As shown in Figure 1, the parameter is not limited to an engine temperature, but may also consist of a battery voltage. In the latter case, the upper limit rotational speed should be higher when the battery voltage is low, and the upper limit rotational speed should be lower when the battery voltage is high. It is also possible to determine the upper limit rotational speed in dependence on both an engine temperature and a battery voltage.

[0046] According to yet another embodiment of the present invention, as shown in Figure 11, a forced reversing position θh is defined near the top dead center of the expansion stroke, and the crankshaft 2 is forcedly turned in the normal direction upon reaching the forced reversing position θh. In this case, there is no need to define the upper limit rotational speed NH or to conduct a constant speed control, and the control circuit can be simplified. Even when the rotational speed has increased to a level that would cause the crankshaft to rotate beyond the top dead center in absence of the forced reversal of the cranking motion as indicated by the chain-dot line, the forced reversal of the cranking direction can be effected without fail as illustrated in Figure 11.

[0047] According to yet another embodiment of the present invention, a rotational speed detecting position θs is defined in an intermediate point of the expansion stroke (which may coincide with θd in the illustrated embodiment) as shown in Figure 12, and the crankshaft 2 is forcedly turned in the normal direction when the rotational speed of the crankshaft 2 at the rotational speed detecting position θs is found to be greater than a rotational speed upper limit N_{max}. More specifically, similarly as the other illustrated embodiments, the reverse drive of the crankshaft ceases at the rotational speed detecting position θs as indicated by the double-dot chain-dot line in the drawing, and the normal drive of the crankshaft starts as soon as the spring back of the compression pressure has overcome the inertia force under normal condition. However, when the rotational speed of the crankshaft at the rotational speed detecting position θs is found to be greater than the rotational speed upper limit N_{max}, the cranking of the engine in the reverse direction is braked by the normal drive, and the engine is then cranked in the normal direction without causing the crankshaft to rotate beyond the top dead center in spite of the excessive rotational speed.

[0048] According to yet another embodiment of the present invention, as shown in Figure 13, a drive of the electric motor 1 in the reverse direction is terminated when it is detected that the crankshaft 2 has passed a reverse compression start position θd at which a compression is started as the crankshaft 2 is rotated in the reverse direction in the expansion stroke, and the crankshaft 2 is then forcedly rotated in the normal direction upon detecting the reversing of the rotational motion of the crankshaft into the normal direction as the reverse rotation under an inertia force is overcome by a progressively increasing compression pressure. By so doing, the drive in the normal direction is started immediately after the reversing of the rotation of the crankshaft into the normal direction has taken place so that the loss in the approach run time and approach run distance can be eliminated, and the reversing of the drive direction can be effected both efficiently and promptly.

[0049] According to yet another embodiment of the present invention, as shown in Figure 11, when the rotational speed is low (as indicated by the imaginary line in Figure 11), the crankshaft 2 comes to a stop without reaching the forced reversing position θh. To be able to promptly start the drive in the normal direction even in such a case, a timer is started from the start of the drive in the reverse direction, and if the forced reversing position θh fails to be reached within a prescribed time period, the drive in the normal direction is forcedly started. Similarly, in the cases of Figures 12 and 13, when the reversing of the rotation of the crankshaft is not detected within the prescribed time period, the drive in the normal direction is forcedly started. By so doing, even when the condition for starting the reverse drive is not met, the drive in the normal direction is started without fail, and the cranking of the engine can be effected.

[0050] Figures 14 to 16 show a cranking control without involving the preliminary normal cranking for a four stroke engine embodying the present invention. According to this engine starter system, the ignition switch IG is first turned on to supply electric current to the system. Then, by turning on the starter switch ST, electric current is supplied to the electric motor 1 to crank the engine. In this case, by turning on the starter switch ST, the electric motor is rotated in the reverse direction (as indicated by arrow B in Figures 15 and 16). At this time, the pulser 9 detects the passage of the reluctor 8 (angle computing position θ2) during the exhaust stroke of the illustrated four-stroke engine, and produces a signal similar to that is produced at the ignition timing reference position θ1. The rotational angle is counted anew from this angle computing position θ2. When this count has reached angle α, the drive of the electric motor 1 in the reverse direction is terminated. This position which is behind the ignition timing reference position θ1 by the angle α is defined as a reverse drive terminate position θ3. Even after the reverse drive of the electric motor 1 has been terminated, the crankshaft continues to rotate over a certain rotational angle, but eventually comes to a stop as the spring back force of the compression pressure which builds up as the expansion stroke is reversed becomes predominant over the inertia force. This position is defined as a reversing position θ4. Once the crankshaft 2 has reached the reversing position θ4, the normal drive of the electric motor 1 begins (arrow C in Figures 15 and 16). By so doing the consumption of electric power can be reduced as compared to the case where the normal drive is started immediately after the reverse drive has been terminated.

[0051] The reversing of the expansion stroke produces a rise in the compressive pressure, and this provides a spring back force that assists the normal drive of the electric motor 1. This assist force, combined with an adequate approach run distance that is obtained, increases the rotational speed of the electric motor, and provides an adequate torque for the crankshaft to rotate in the normal direction well beyond the top dead center from the side of the compression stroke so that the electric motor for the engine starter system is required to have a relatively small rated output.

[0052] When performing such a swing cranking control, it is important to know the angular position of the crankshaft. It is thus preferable to store the position of the crankshaft when the engine was stopped previously, and to perform the swing cranking control based on the stored crankshaft angular position. For instance, when the crankshaft is located in the compression stroke or at an adjacent point on the side of the intake stroke, the cranking may be performed in the reverse direction before the final cranking in the normal direction is performed. On the other hand, when the crankshaft is located in the expansion stroke or at an adjacent point on the side of the exhaust stroke, the cranking may be performed directly in the normal direction without involving any reverse drive.

[0053] A mode of identifying the position of the crankshaft according to the present invention is described in the following with reference to Figure 17. As shown in Figure 17, the pulser detection signal by the pulser 9 is produced in both the compression stroke and exhaust stroke. Because the reluctor 8 has a certain width, the pulser detection signal consists of a pair of pulses having opposite polarity that are produced at the leading edge and trailing edge of the reluctor 8. According to the present invention, the periods (between adjacent pulses which may be either positive or negative) tc1, tc2, tc3, ... of the pulser detection signal in the compression stroke and those th1, th2, th3, ...in the exhaust stroke are compared. These periods are inversely proportional to the rotational speed of the crankshaft. Based on the change in these periods, the local changes in the rotational speed of the crankshaft can be monitored.

[0054] Because the rotational speed sharply drops immediately before the top dead center of the compression stroke, by comparing the periods of consecutive two or three pairs of pulses, it is possible to determine that the pulse pair having a longer period corresponds to the compression stroke. In the illustrated embodiment, the period th2 of the pulse pair in the exhaust stroke is shorter than the period tc3 of the pulse pair of the immediately following compression stroke tc3 (th2 < tc3). Therefore, the pulse pair having the longer period tc2 can be determined as having occurred in the compression stroke.

[0055] When three consecutive pulse pairs are compared and th1 < tc2 > th2, the period tc2 corresponds to the compression stroke. If tc2 > th2 < tc3, the periods tc2 and tc3 correspond to the compression stroke.

[0056] According to yet another embodiment of the present invention, as shown in Figure 17, using a positive or negative pulse (a negative pulse in the illustrated embodiment) of the pulse detection signal as a reference, the period θc1, θh1, θc2, θh2 and θc3 of a prescribed number (two in the illustrated embodiment) of pulse detection signals is compared for each incremental angle (each individual angle signal in the illustrated embodiment). The angle signal pulse may consist of the commutating signal of a brushless motor based on the changes in the state of the U, V and W phases, and may produce a pulse for each increment of 10 degrees as the crankshaft rotates, for instance. By so doing, it is also possible to determined that the period θc2 corresponds to the compression stroke because θh2 < θc3 by the comparison of two consecutive angle signal pulses. Because θh1 < θc2 > θh2 and θc2 > θh2 < θc3 by the comparison of three consecutive angle signal pulses, it can be determined that θc2 and θc3 correspond to the compression stroke.

[0057] Yet another embodiment of the present invention is described in the following. According to this embodiment, the increase and decrease of the period of the angle signals is monitored. More specifically, the rotational speed progressively diminishes in the compression stroke due to the increase in the pressure in the cylinder as the piston rises toward the top dead center while the rotational speed rapidly increases due to the rise in the combustion pressure after passing the top dead center so that there is a sharp change in the period of the angle signals before and after the top dead center. Therefore, the top dead center of the compression and expansion strokes can be detected from the point at which the period of the angle signals has started to diminish. Therefore, the angular position of the crankshaft 2 can be determined from the angle signals using the top dead center as a reference, and the cranking control can be optimized from the knowledge of the position in the engine strokes. This is particularly advantageous when an idle stop arrangement is adopted, and frequent restarting of the engine is required. For instance, if the engine is in the compression stroke when it came to a stop, the engine may be rotated in the reverse direction before being finally rotated in the normal direction as discussed earlier.

[0058] If the engine is stationary in the expansion stroke or in a vicinity thereof, an adequate approach run distance is available for the electric motor to start cranking the engine directly in the normal direction, and an adequate acceleration to rotate the crankshaft beyond the top dead center of the compression stroke can be achieved. This prevents a waste in the consumption of electric current that would be caused by unnecessary reliance on the swing cranking process, and reduces the burden on the battery even when the idle stop operation is repeated for a large number of times.

[0059] If the commutating signal (see Figure 6) of the brushless motor (electric motor 1) is used also for providing the angle signals, the need for a separate rotational angle detecting means is eliminated, and both the simplification and cost-reduction of the engine starter system can be achieved. However, as such a rotational angle detecting means, it is possible to form a gear around the flywheel and detect the passage of the teeth of the gear with a magnetic sensor. In such as a case, the angular increment can be selected at will, and this contributes to the optimum design for each particular model.

[0060] The timing of the pulser detection signal in terms of the angle preceding the top dead center can be known from the position of the reluctor 8, and it is therefore possible to identify the top dead center of the compression stroke at the accuracy of the increment of the angle signal if the compression stroke can be identified. The absolute angle can be thus determined by counting the angle signals (by the increment of 10 degrees in the illustrated embodiment) using the top dead center as a reference, and the obtained absolute angle can be used by the controller ECU in supplying the ignition signal P and fuel injection signal F as shown in Figures 1 and 4. Therefore, the need for a separate angle detection sensor for such control is eliminated, and the overall structure of the engine can be simplified.

[0061] As an alternate method of detecting the position of the crankshaft 2 by detecting the angle signals, it is also possible to compare total periods of a number of consecutive angle signals ($n\theta 1$ and $n\theta 2$ in Figure 17) each of which represents a prescribed incremental angle. In the illustrated embodiment, the total period $n\theta 1$ corresponding to the exhaust stroke and the total period $n\theta 2$ are compared with each other, and the total period $n\theta 2$ is determined as corresponding to the compression stroke because $n\theta 1 < n\theta 2$.

[0062] It is also possible to compare average periods of a number of consecutive angle signals ($A\theta 1$ and $A\theta 2$ in Figure 9) each of which represents a prescribed incremental angle. In this case also, the average period $A\theta 1$ is determined as corresponding to the compression stroke because $A\theta 1 < A\theta 2$. In either of these embodiments, the subsequent cranking control is similar to those of the previous embodiments.

[0063] The illustrated embodiments were directed to four-stroke engines, but the present invention is also applicable to two-stroke engines if a similar reluctor is provided on the side of the bottom dead center.

[0064] The present invention can be favorably applied to engines equipped with electronic fuel injection systems which are adapted to detect a plurality of pulses for each revolution of the crankshaft for the control of the fuel injection timing. For instance, as shown in Figure 18, a plurality of reluctors 8a to 8k may be fixedly attached to the outer circumferential surface of the peripheral wall of the outer rotor 3. The reluctors 8a to 8k are arranged at a regular interval, except for that a gap corresponding to an additional reluctor is provided between the reluctors 8k and 8a. By detecting the passage of these reluctors 8a to 8k, similar pulses are produced by a number corresponding to the number of the reluctors 8a to 8k for reach revolution of the crankshaft 2 as shown in Figure 19.

[0065] From the positional relationship between the gap and the top dead center, it is possible to determine the absolute angle of the crankshaft each time a pulse is produced. Therefore, the pulse corresponding to the ignition timing reference position can be identified as being the pulse indicated by P1 in Figure 19, and the fuel injection reference position can be identified as being the pulse indicated by F1 in Figure 19. Because the fuel injection timing varies depending on the change in the rotational speed as indicated by arrow D in the drawing, a large number of pulses are produced so as to control the fuel injection timing with a required resolution.

[0066] In the illustrated embodiment, the ignition timing reference position pulse P1 of all the pulses can be used in place of the ignition timing reference position $\theta 1$. It is also possible to use the N-th pulse Pn from the pulse P1 as the reference. In either case, by comparing the period in relation to the rotational angle, a similar determination process can be effected.

[0067] Although the present invention has been described in terms of preferred embodiments thereof, it is obvious to a person skilled in the art that various alterations and modifications are possible without departing from the scope of the present invention which is set forth in the appended claims.

Claims

1. An engine starter system adapted to crank an engine first in a reverse direction at least under a prescribed condition, and finally in a normal direction with an electric motor that is connected to a crankshaft of an engine, comprising:

an electric motor connected to the crankshaft;
a sensor for detecting an angular position of said crankshaft; and
a controller for controlling a supply of electric current to said electric motor according an out-

put signal of said sensor;
said controller being adapted to store a crankshaft angle when the engine stopped previously, said normal final cranking being directly performed without said reverse cranking when said crankshaft angle stored in said controller is in a compression stroke or adjacent thereto from a side of an intake stroke.

2. An engine starter system according to claim 1, wherein said crankshaft angle sensor comprises an ignition timing sensor which is adapted to produce a pair of pulses one after the other at a prescribed angular interval, a point at which each pulse pair are produced being identified as being in the compression stroke or in an exhaust stroke by comparing said angular interval with that of a preceding pulse pair.

3. An engine starter system according to claim 1, wherein said crankshaft angular position sensor comprises an ignition timing sensor for producing an ignition timing reference pulse, and an angle signal sensor for producing a pulse for each incremental rotational angle at a higher resolution, a position of said crankshaft being determined by detecting a period of a prescribed number of angle signal pulses following a prescribed number of angle signal pulses following a production of an ignition timing reference pulse, and detecting a change in the period.

4. An engine starter system according to claim 3, wherein said electric motor comprises a brushless motor, and said angle signal sensor comprises a commutating position sensor of said brushless motor.

5. An engine starter system according to claim 3, wherein an angular position of said crankshaft at which said reverse drive is taken over by said final normal drive is determined from an output of said angle signal sensor using an output of said ignition timing sensor produced in the compression stroke or exhaust stroke of said engine as a reference.

6. An engine starter system according to claim 3, wherein said crankshaft angular position sensor comprises an angle signal sensor adapted to provide a plurality of pulses for each revolution of said crankshaft at a regular angular interval except for an uneven section, and an angular position of said crankshaft is determined according to a pulse output of said angle signal sensor.

7. An engine starter system according to claim 1, wherein said crankshaft angular position sensor comprises an angle signal sensor adapted to provide a plurality of pulses for each revolution of said crankshaft at a regular angular interval, and a top dead center between the compression and expansion strokes is determined as corresponding to a point at which the period of said the pulse output of said angle signal sensor changes from an increasing state to a decreasing state.

8. An engine starter system according to claim 1, wherein said controller is adapted to control a rotational speed of said electric motor when rotating said crankshaft in the reverse direction so as to prevent said crankshaft from rotating in the reverse direction beyond the top dead center from the side of the expansion stroke.

9. An engine starter system according to claim 1, wherein said controller is adapted to control a rotational speed of said electric motor when rotating said crankshaft in the reverse direction below a prescribed upper limit.

10. An engine starter system according to claim 9, wherein the upper limit of the rotational speed is defined so as to be smaller than $(2EPO/I)^{1/2}$ where EP0 is the sum of the maximum compression energy of the engine piston and the engine friction loss energy, and I is the moment of inertia of the crankshaft system.

11. An engine starter system according to claim 9, wherein the upper limit of the rotational speed is varied in dependence on at least one of a battery voltage and an engine temperature.

12. An engine starter system according to claim 8, wherein a forced reversing position is defined in the expansion stroke near the top dead center thereof, and said crankshaft is forcibly rotated in the normal direction when said crankshaft has reached said forced reversing position.

13. An engine starter system according to claim 8, wherein a rotating speed detecting position is defined in an intermediate point of the expansion stroke, and said crankshaft is forcibly rotated in the normal direction when said crankshaft has reached said rotating speed detecting position and a rotational speed of said crankshaft is higher than a prescribed rotational speed limit.

14. An engine starter system according to claim 8, wherein a reverse drive terminate position is defined in the expansion stroke, and said reverse drive is terminated when said crankshaft has reached said reverse drive terminate position after reversing said expansion stroke, said crankshaft being forcibly rotated in the normal direction when a compression pressure has become dominant over an inertia force causing said crankshaft to continue rotating in the reverse direction, and said crankshaft has started rotating in the normal direction.

15. An engine starter system according to claim 8, wherein said reverse drive is terminated and said crankshaft is forcibly rotated in the normal direction when said crankshaft has failed to start rotating in the normal direction within a prescribed time period from the time said reverse drive started.

Fig.1

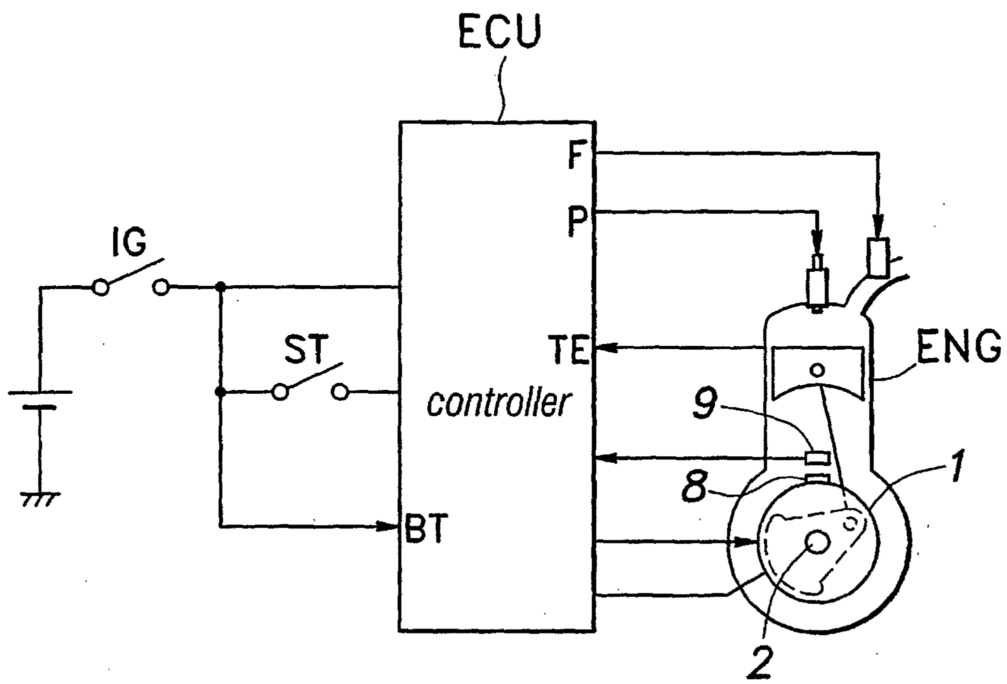


Fig.2

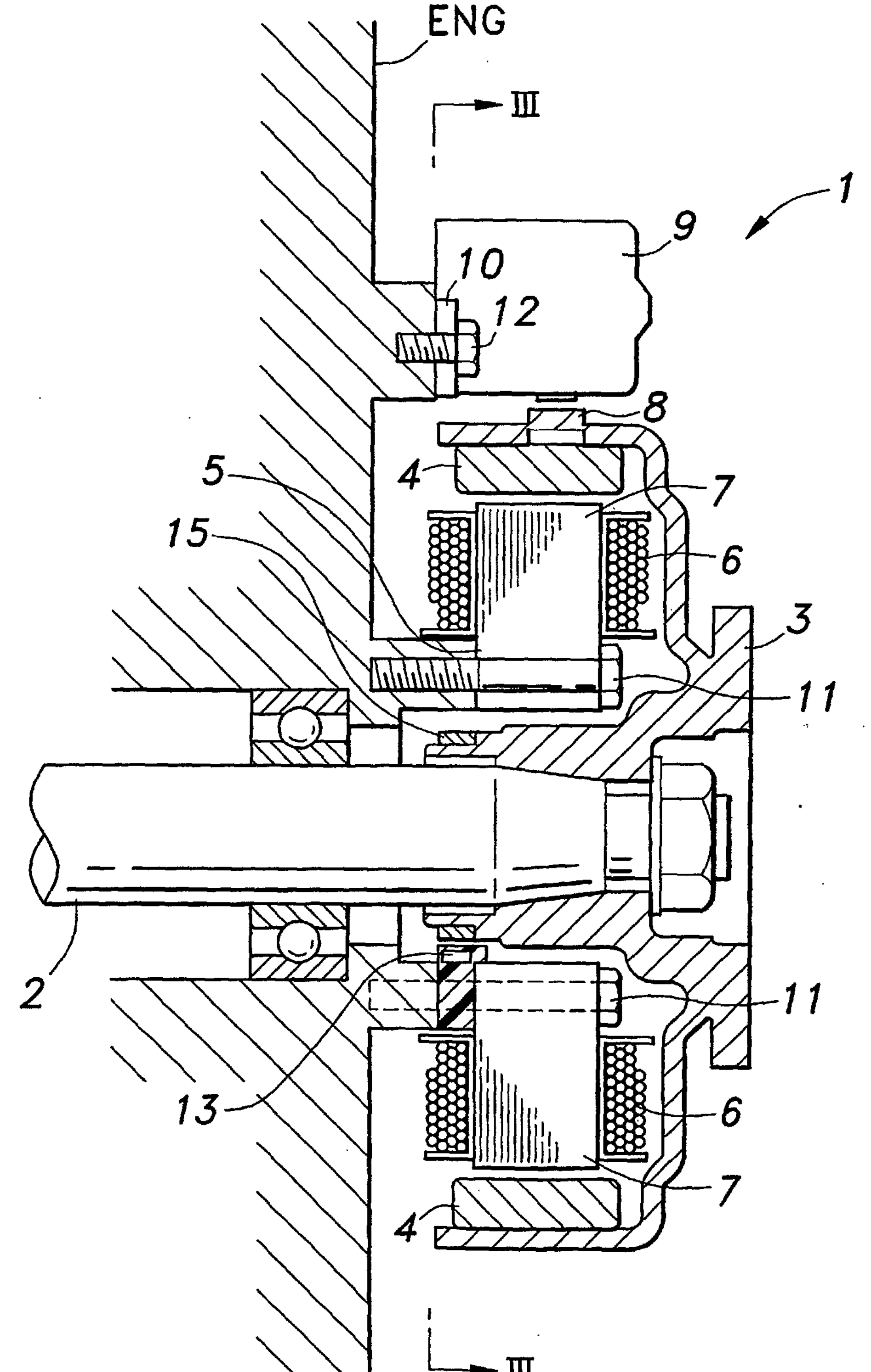


Fig.3

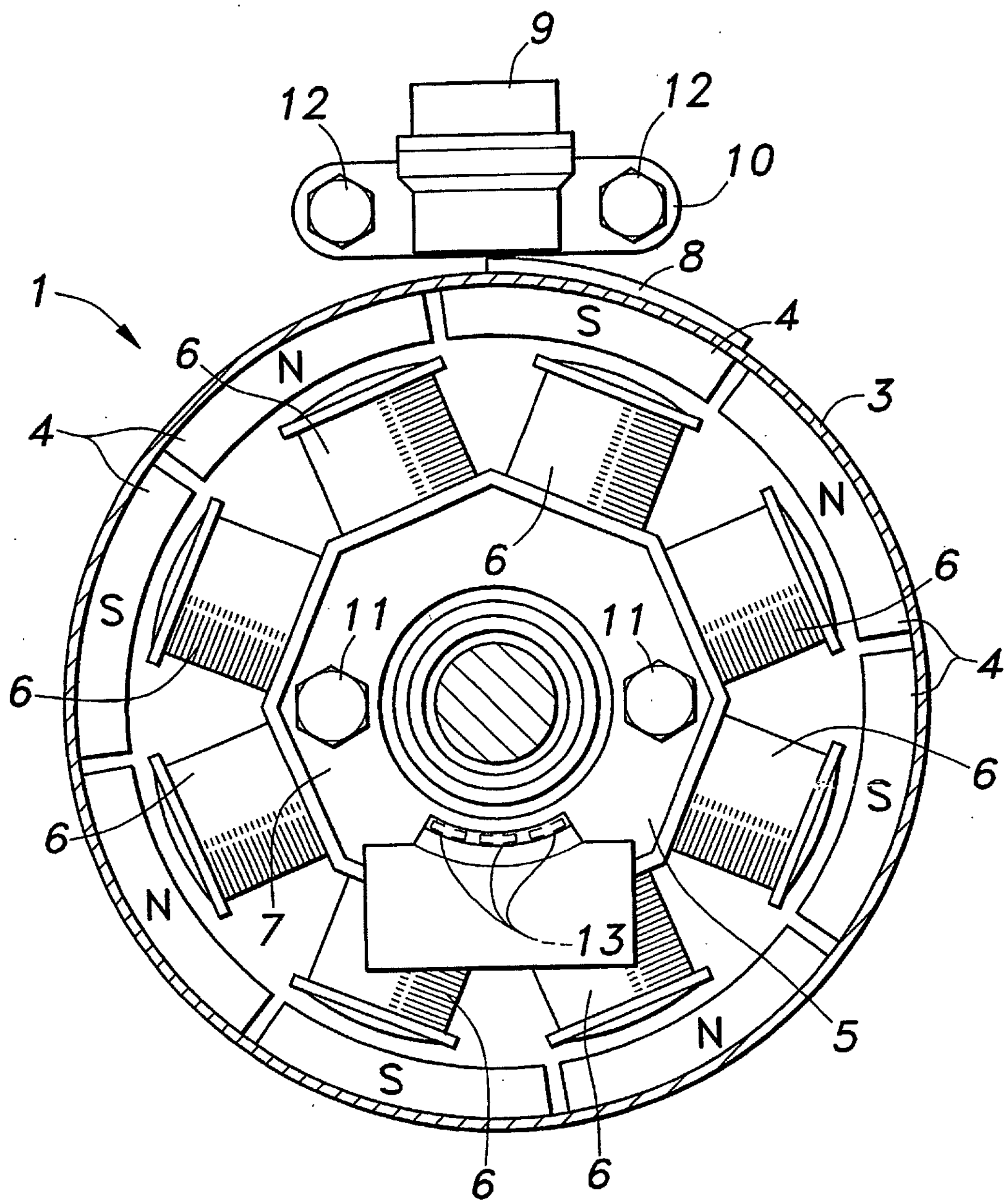
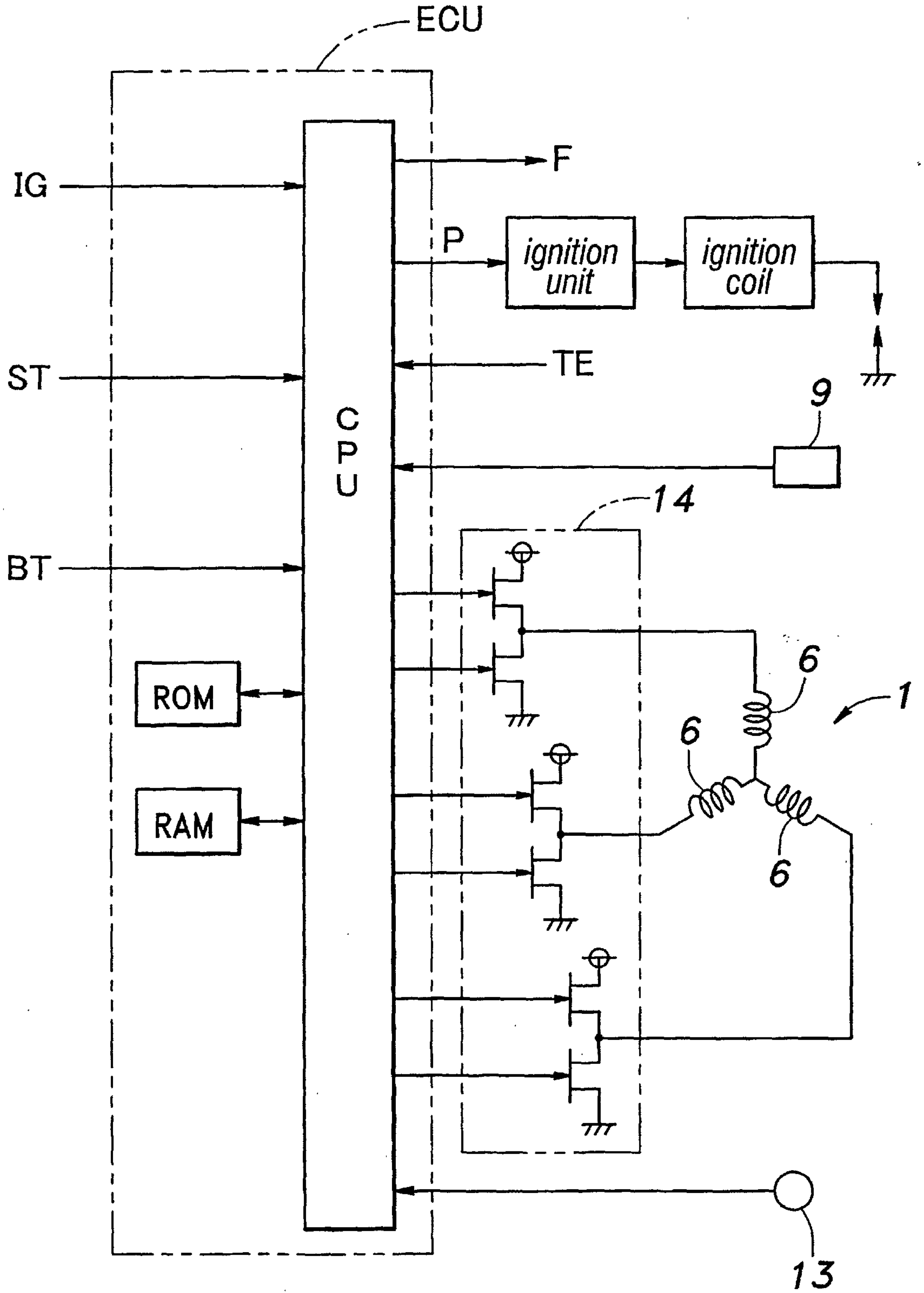


Fig.4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ST
BT
C
P
U
F
P
ignition unit
ignition coil
TE
9
14
ROM
RAM
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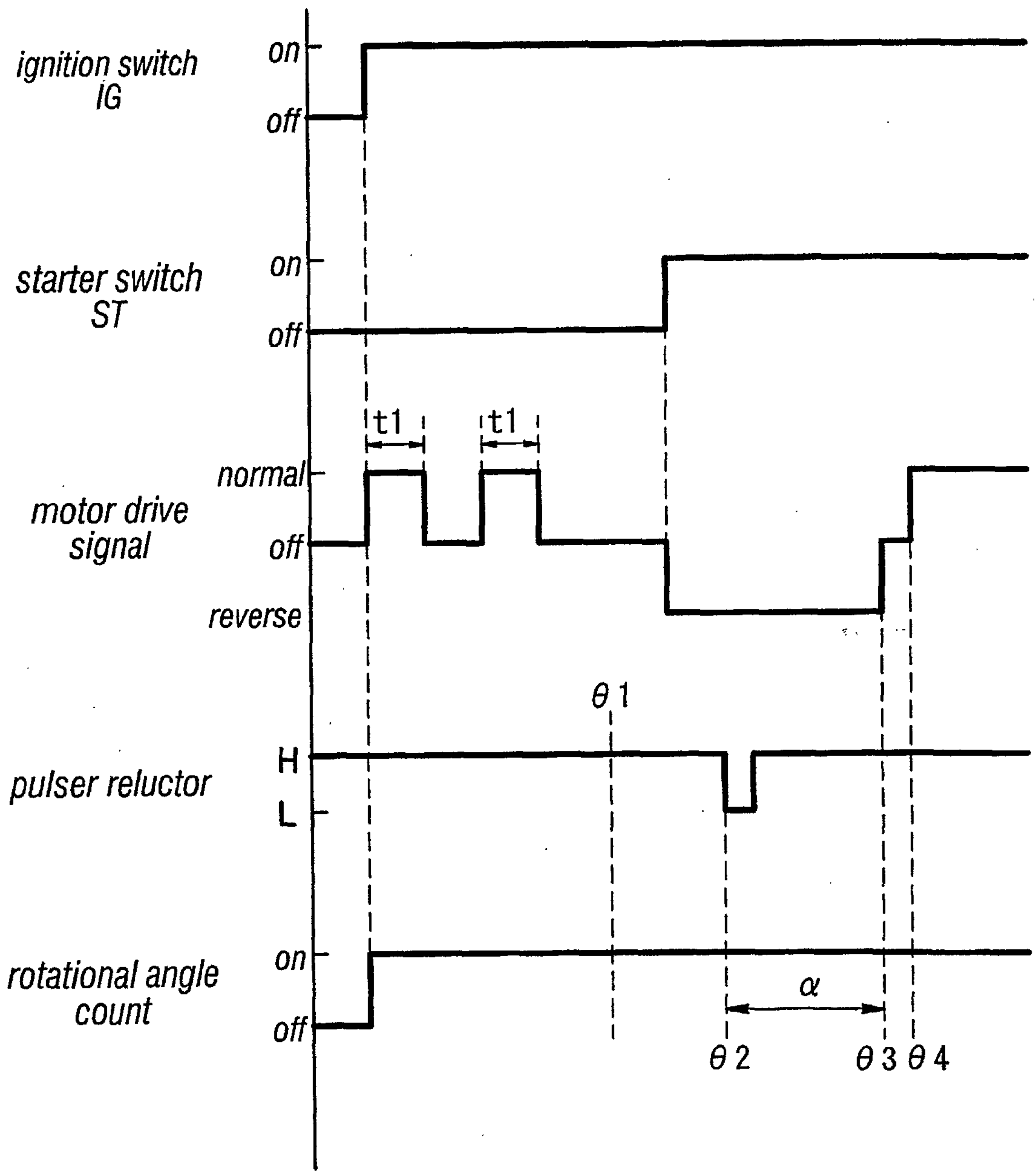
6
6
1
13

Fig.5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IG
on
off
starter switch
ST
on
off
t1
t1
motor drive
signal
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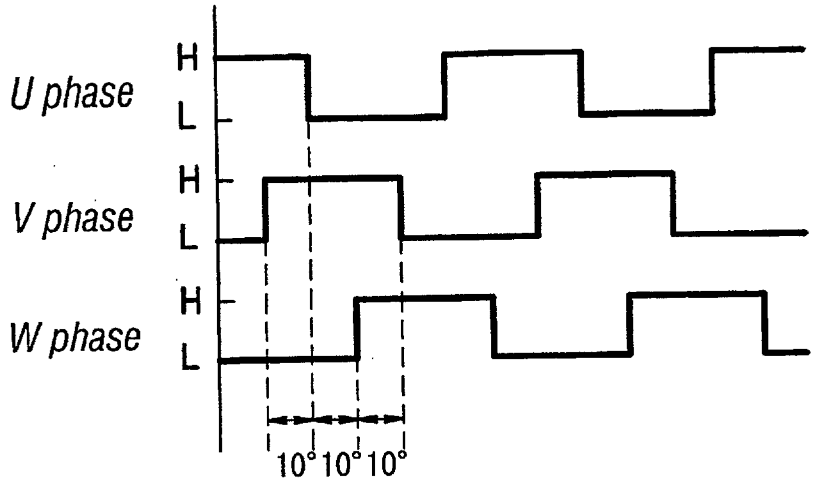
L
rotational angle
count
on
off
α
θ2
θ3
θ4

Fig.6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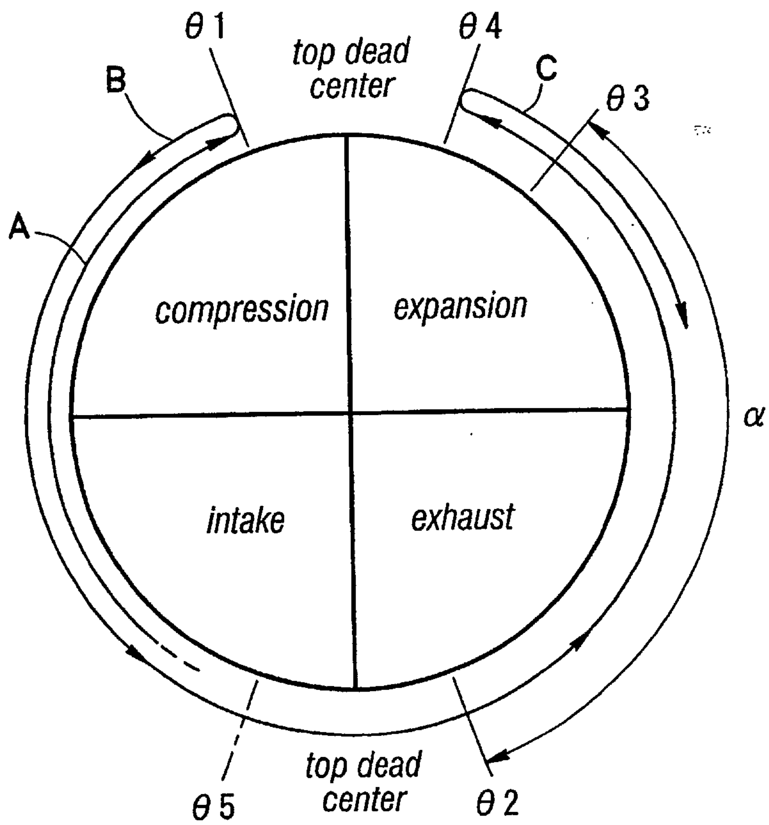
V phase
W phase
H
L
H
L
H
L
10° 10° 10°

Fig.7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θ4
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C
θ3
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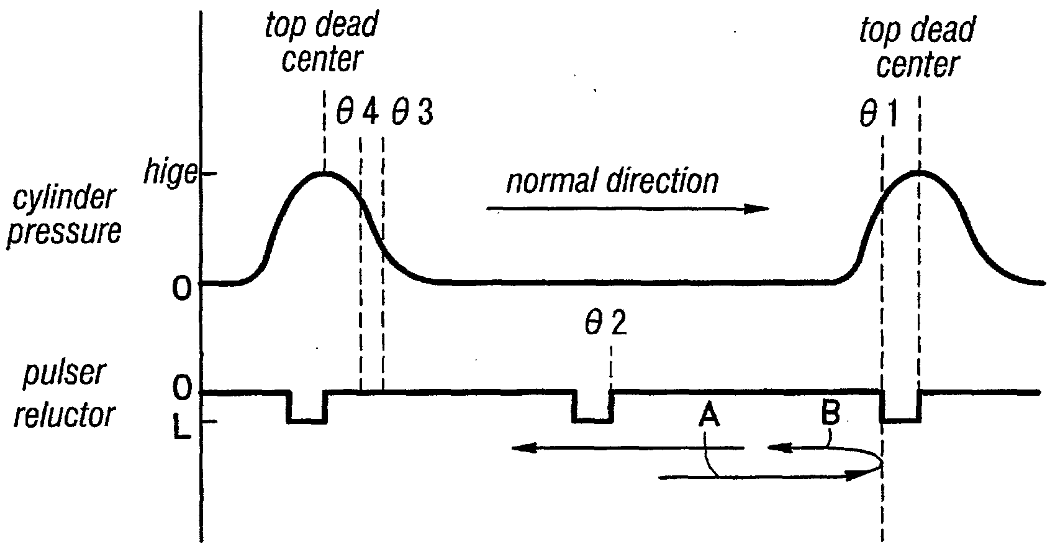
expansion
α
intake
exhaust
top dead center
θ5
θ2

Fig.8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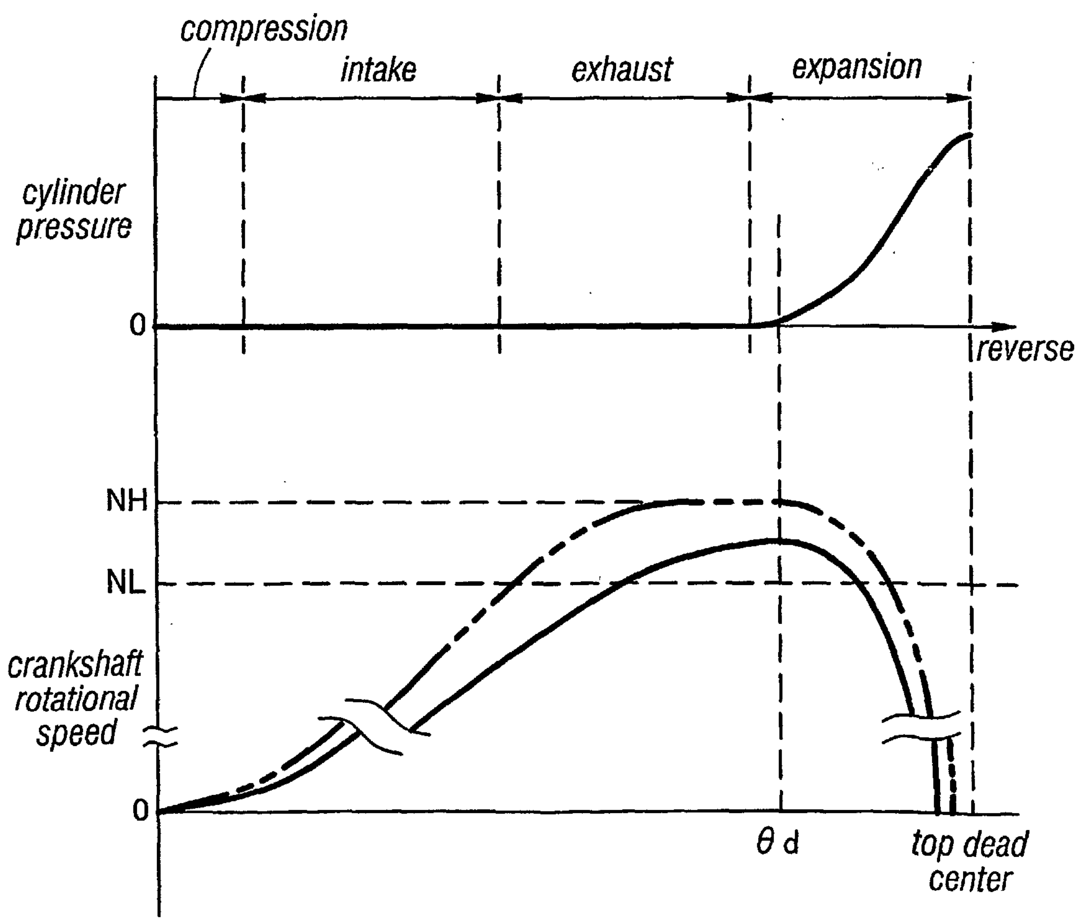
top dead center
θ1
hige
cylinder pressure
0
normal direction
θ2
pulser reluctor
0
L
A
B

Fig.9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expansion
cylinder pressure
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reverse
NH
NL
crankshaft rotational speed
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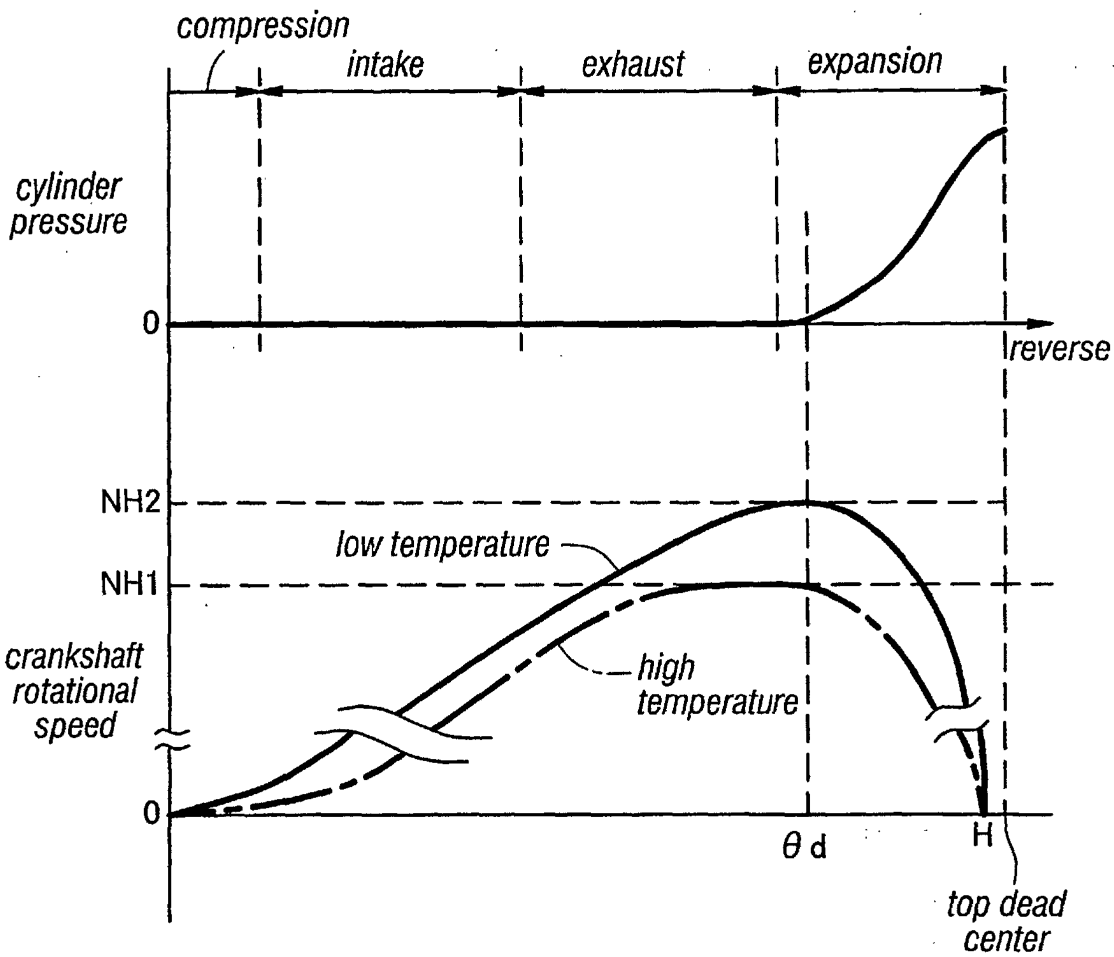
θd
top dead center

Fig.10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expansion
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NH1
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high temperature
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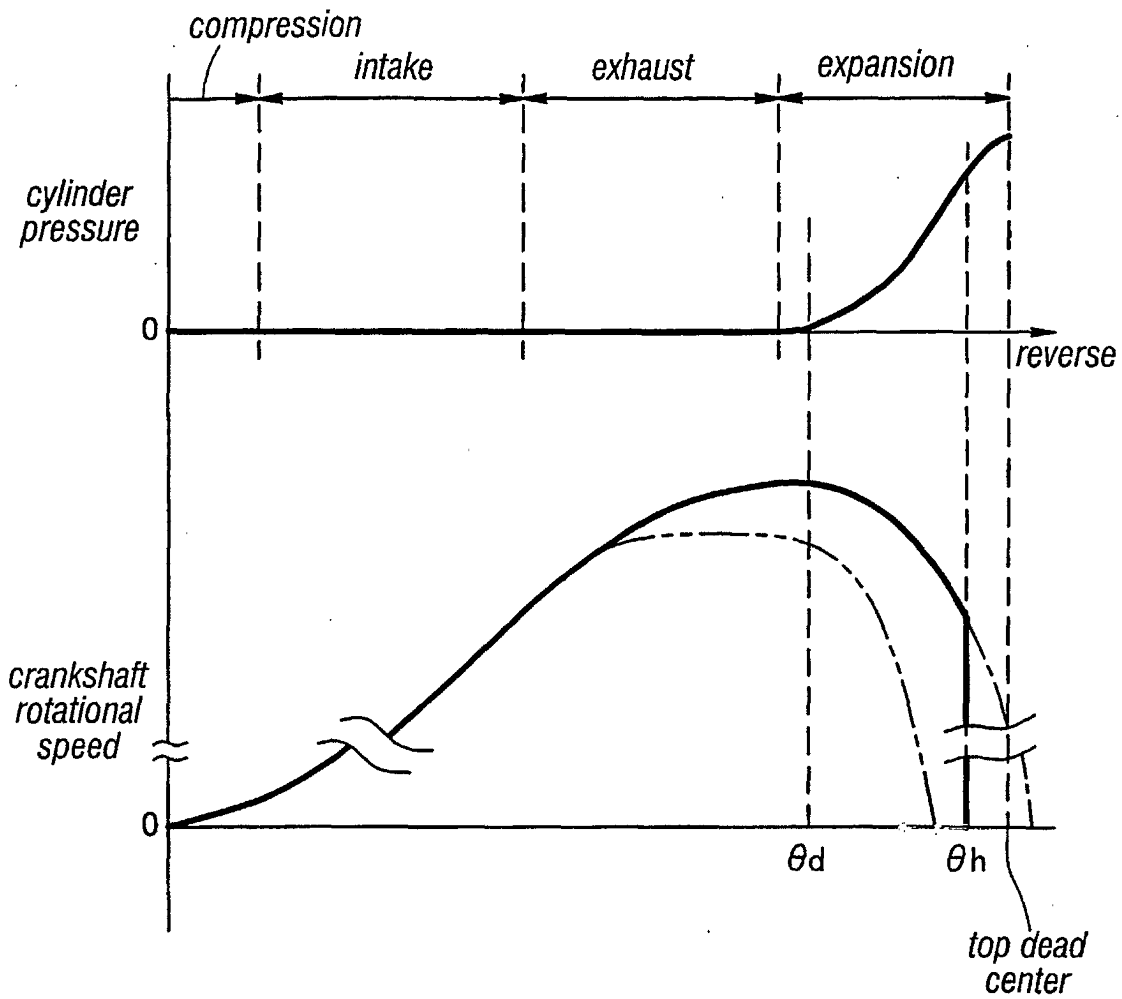
θ d
H
top dead center

Fig.11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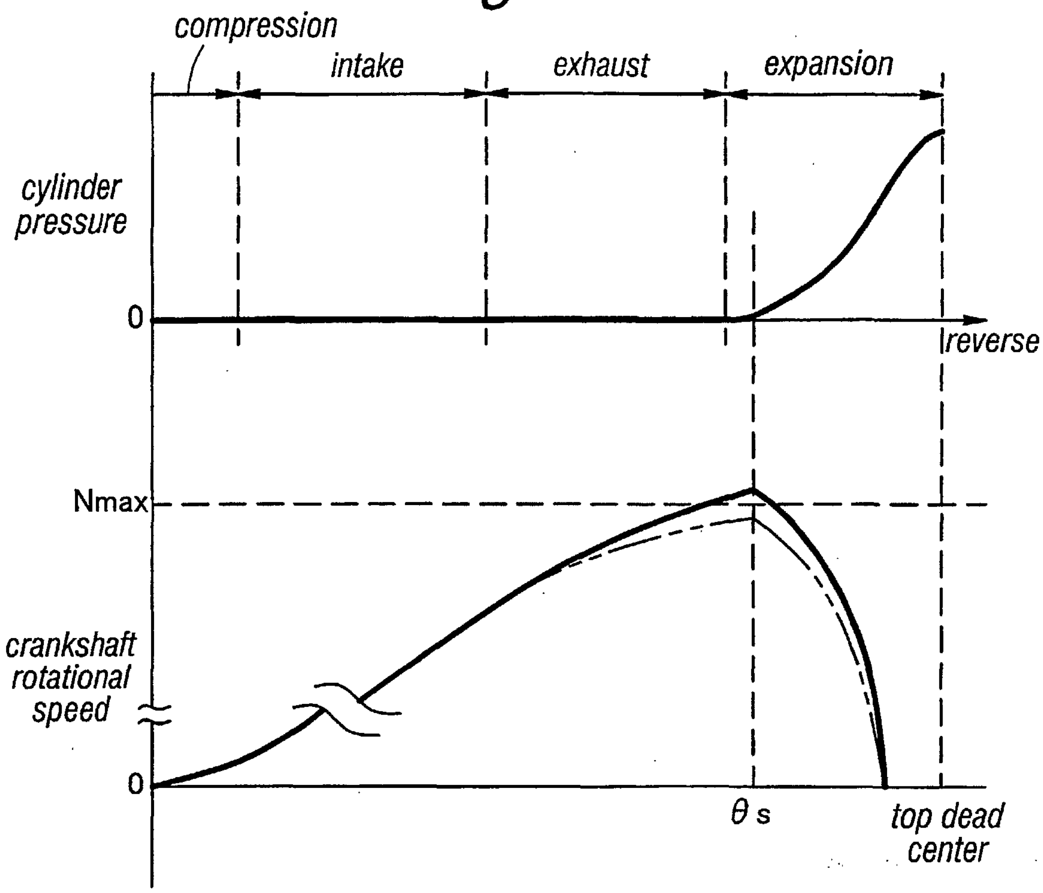
θd
θh
top dead center

Fig. 12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Nmax
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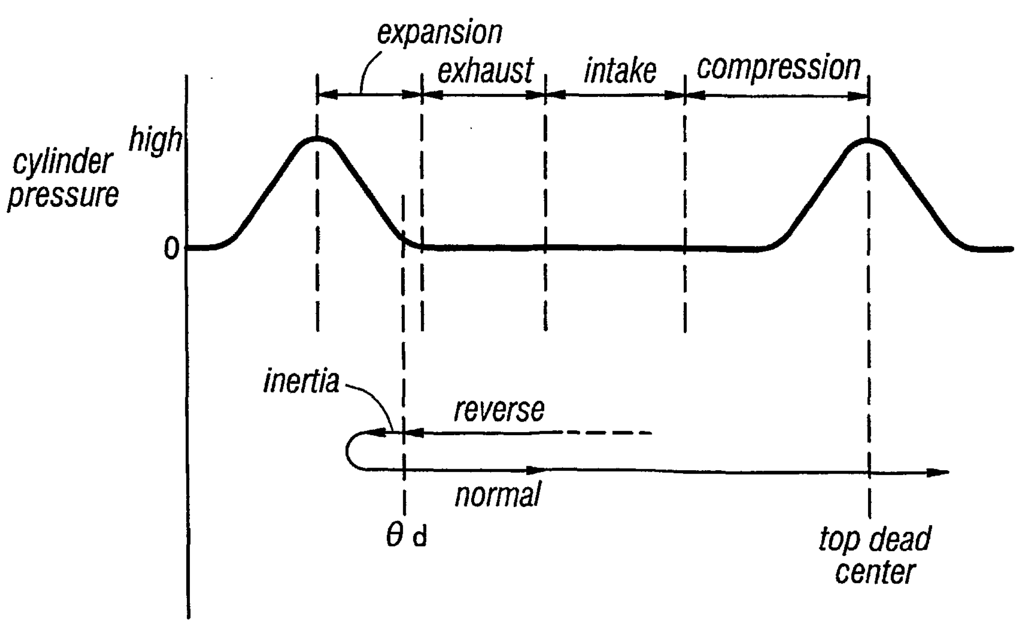
θ s
top dead center

Fig. 16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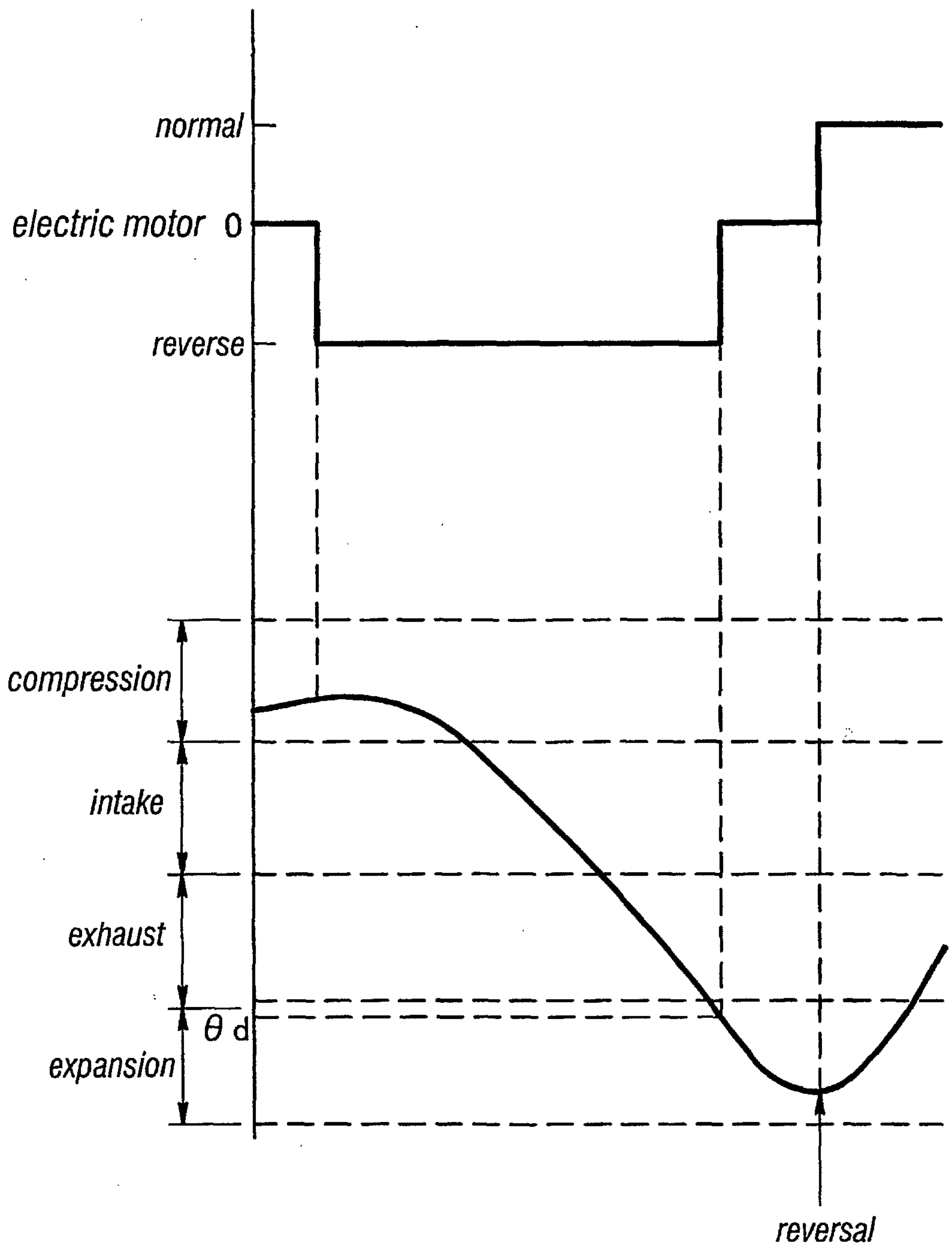
inertia
reverse
normal
θ d
top dead center

Fig.13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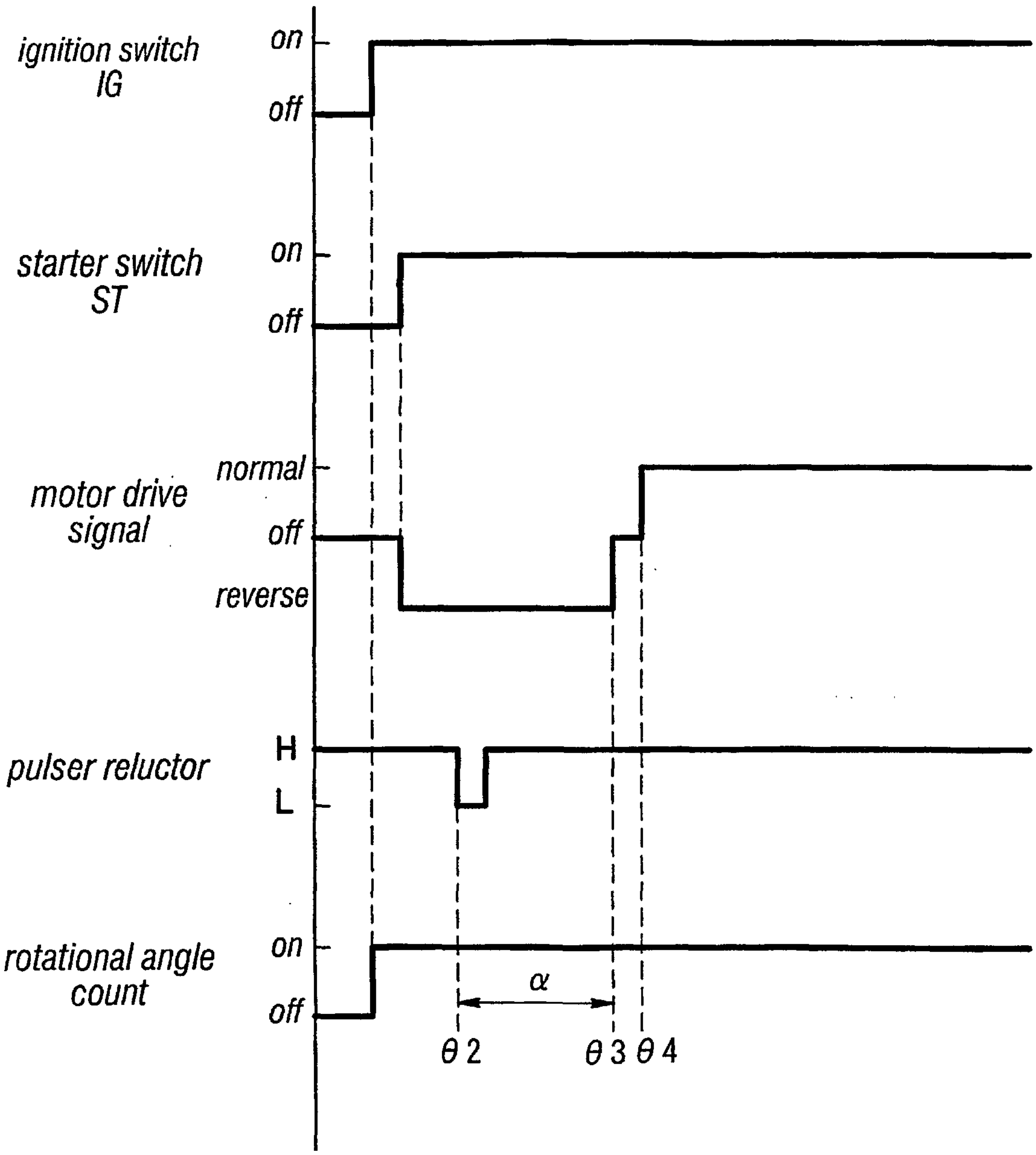
intake
exhaust
θ d
expansion
reversal

Fig.14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on
off
starter switch
ST
on
off
motor drive
signal
normal
off
reverse
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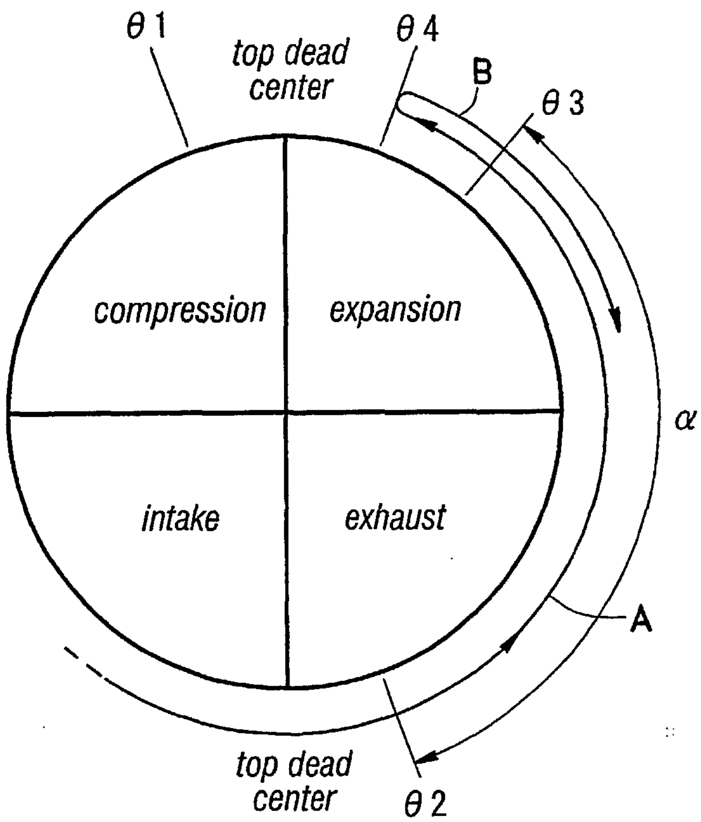
H
L
rotational angle
count
on
off
α
θ2
θ3
θ4

Fig. 15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θ4
B
θ3
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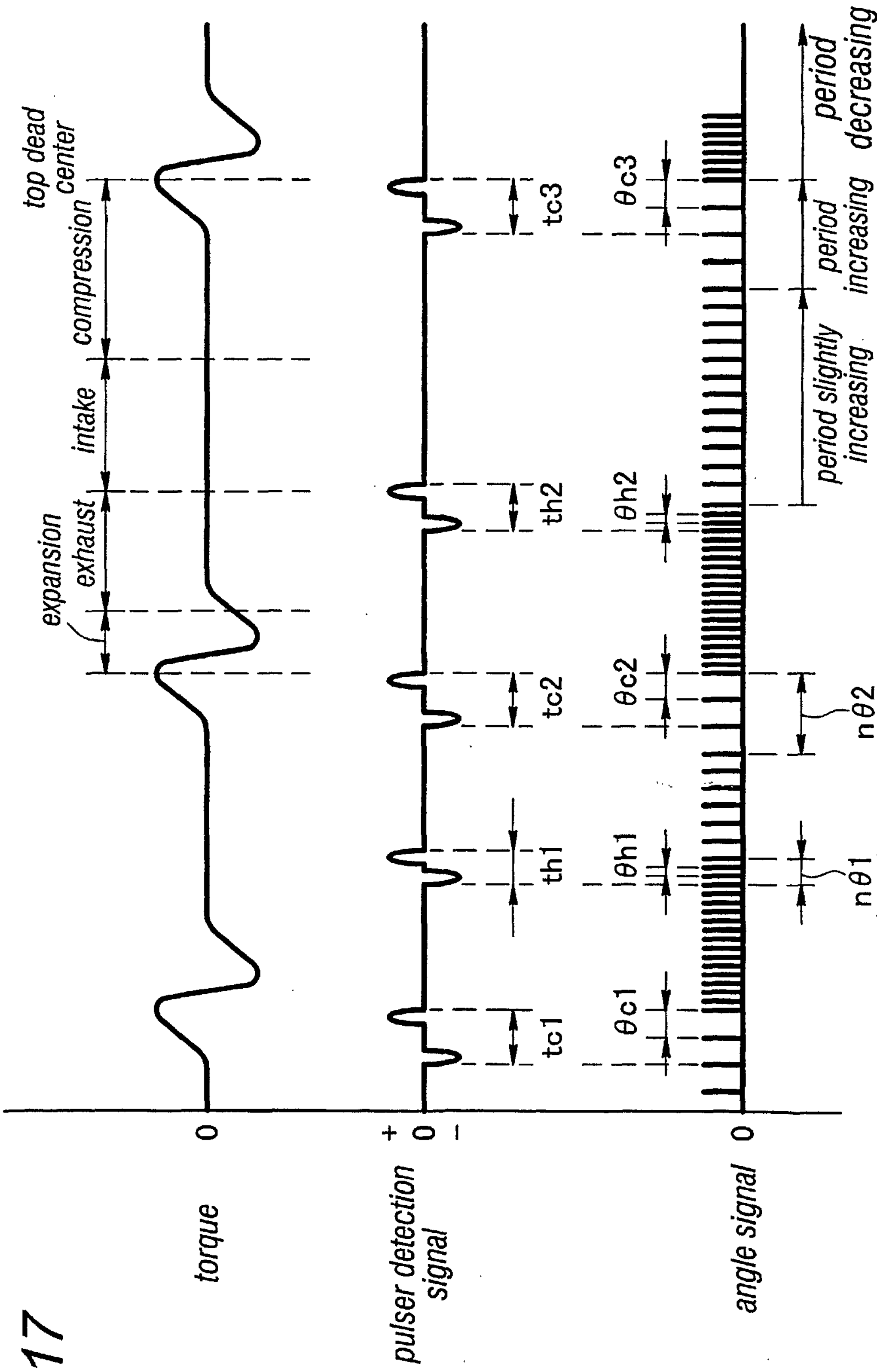
expansion
α
intake
exhaust
A
top dead center
θ2

Fig.17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pulser detection signal
angle signal
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+ 0 −
0
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intake
exhaust
expansion
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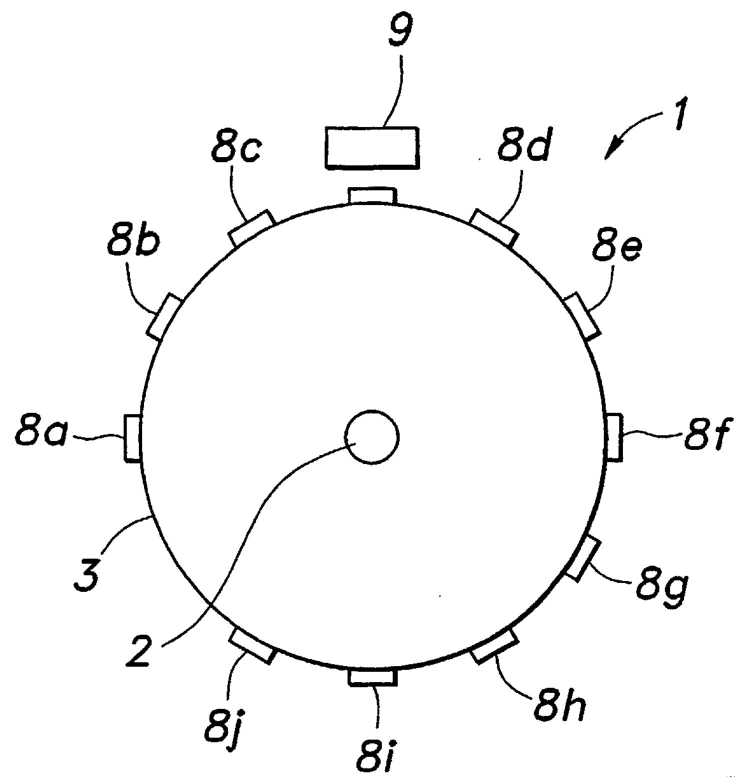
th1
tc2
th2
tc3
θc1
θh1
θc2
θh2
θc3
nθ1 (Aθ1)
nθ2 (Aθ2)
period slightly increasing
period increasing
period decreasing

Fig. 18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8c
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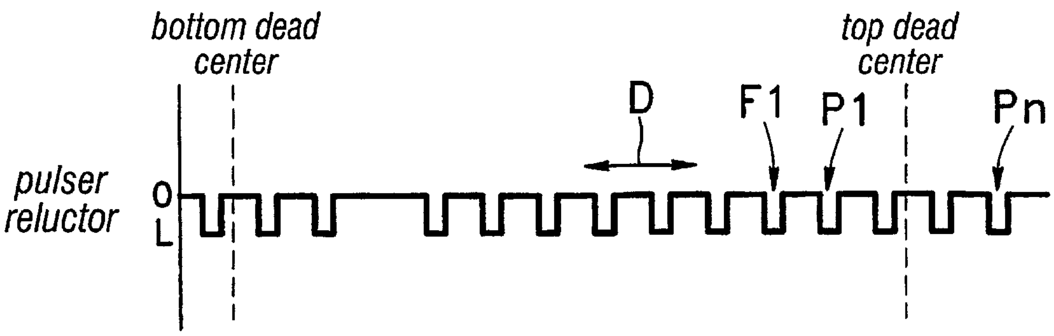
8e
8a
8f
3
8g
2
8h
8j
8i

Fig. 19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top dead center
D
F1
P1
Pn
pulser reluctor
0
L

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP01/08519

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] F02N11/08, F02N17/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Toroku Jitsuyo Shinan Koho 1994-2001
Kokai Jitsuyo Shinan Koho 1971-2001 Jitsuyo Shinan Toroku Koho 1996-2001

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 7-71350 A (Nippon Denso Co., Ltd.), 14 March, 1995 (14.03.95), Full text; Figs. 1 to 6 & DE 4430651 A & US 5458098 A	1
A	JP 3-3969 A (Mazda Motor Corporation), 10 January, 1991 (10.01.91), Full text; Figs. 1 to 8 (Family: none)	1-15
EA	JP 2000-283010 A (Honda Motor Co., Ltd.), 10 October, 2000 (10.10.00), Full text; Figs. 1 to 24 & CN 1269466 A	1-15
EA	JP 2000-303938 A (Honda Motor Co., Ltd.), 31 October, 2000 (31.10.00), Full text; Figs. 1 to 20 & EP 1046813 A & CN 1271813 A	1-15

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

* Special categories of cited documents:
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"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
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 December, 2001 (20.12.01)	15 January, 2002 (15.01.02)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

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