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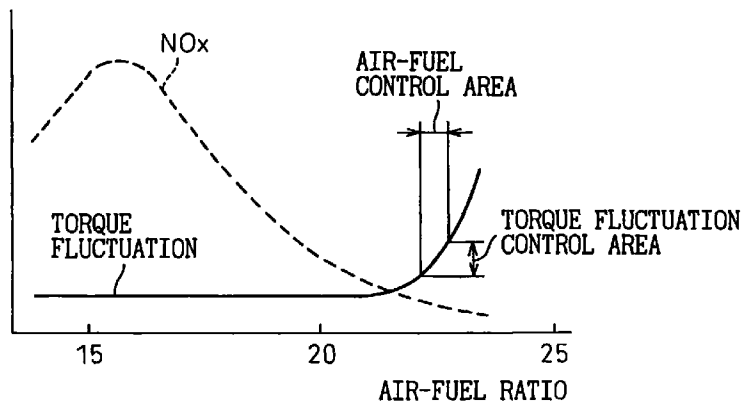
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(54) Method of controlling an air-fuel ratio of an engine

(57) The elapsed time Ta(i) of a 30° crank angle near top dead center of compression and the elapsed time Tb(i) of a 30° crank angle near 90° after top dead center of compression are found. The difference DTa(i) of the elapsed times Ta(i) between 720° crank angle for a first cylinder and a second cylinder performing combustion after the first cylinder is found. The assumed elapsed time when assuming that there is no torque fluctuation is calculated from the difference DTa(i) of the elapsed time of the first cylinder and the elapsed time of the second cylinder is calculated and the assumed

elapsed time is used to calculate the basic amount of torque fluctuation. A set value is found based on the engine speed. The set value represents a deviation of the basic amount of torque fluctuation due to the detection error of the elapsed time, and due to the torsional vibration of the engine drive system and the torsional vibration of the crankshaft. The set value is subtracted from the basic amount of torque fluctuation to calculate the amount of torque fluctuation. The air-fuel ratio is controlled based on the amount of torque fluctuation.

Fig. 3



EP 0 898 066 A2

Description

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

[0001] The present invention relates to a method of controlling an air-fuel ratio of an engine.

10 2. Description of the Related Art

[0002] Known in the art is an internal combustion engine which finds a first angular velocity of the crankshaft during the time required for the crankshaft to rotate from 30° to 60° after top dead center of the compression stroke from this period, finds a second angular velocity of the crankshaft during the time required for the crankshaft to rotate from 90° to 120° after top dead center of the compression stroke from this period, finds the torque generated by a cylinder from the square of the first angular velocity and the square of the second angular velocity, and calculates the amount of fluctuation of the torque from the amount of fluctuation of the generated torque (see U.S. Patent No. 4,691,286).

[0003] That is, when combustion is performed in a cylinder, the combustion pressure causes the angular velocity of the crankshaft to rise from a first angular velocity ωa to a second annular velocity ωb . At this time, if the moment of inertia of rotation of the engine is I , the combustion pressure causes the kinetic energy to rise from $(\frac{1}{2}) \cdot I \omega a^2$ to $(\frac{1}{2}) \cdot I \omega b^2$. Roughly speaking, the amount of rise of the kinetic energy $(\frac{1}{2}) \cdot I \cdot (\omega b^2 - \omega a^2)$ causes a torque to be generated, so the generated torque becomes proportional to $(\omega b^2 - \omega a^2)$. Therefore, the generated torque is found from the difference between the square of the first angular velocity ωa and the square of the second angular velocity ωb and, therefore, in the above-mentioned internal combustion engine, the amount of fluctuation of the torque is calculated from the thus found generated torque.

[0004] However, if it is possible to calculate the amount of fluctuation of the torque in this way, it is also possible to control the air-fuel ratio to the lean limit based on this amount of torque fluctuation. That is, when the air-fuel ratio is at the rich side of the lean limit, the amount of torque fluctuation is small, while when the air-fuel ratio is at the lean side of the lean limit, the amount of torque fluctuation becomes large, so by correcting the air-fuel ratio based on the amount of torque fluctuation so that the amount of torque fluctuation becomes within a predetermined range, it is possible to control the air-fuel ratio to the lean limit. When the engine speed becomes high, however, the time required for the crankshaft to rotate by, for example, 30° crank angle becomes short. This causes the detected time to include an error of detection and, therefore, the amount of torque fluctuation calculated based on the first angular velocity ωa and the second angular velocity ωb may include an error. Such an error becomes larger as the engine speed becomes higher and, therefore, a ratio of the error to the amount of torque fluctuation calculated based on the angular velocities becomes higher as the engine speed becomes higher. However, if the ratio of the error becomes higher, the calculated amount of torque fluctuation does not fall sufficiently even if the air-fuel ratio is made richer to reduce the combustion pressure, and does not increase sufficiently even if the air-fuel ratio is made leaner to increase the combustion pressure. Namely, when the engine speed becomes higher, the rate of change in the calculated amount of torque fluctuation to the change in the air-fuel ratio becomes lower and, therefore, the controllability of the air-fuel ratio for controlling the air-fuel ratio to the lean limit will become lower.

SUMMARY OF THE INVENTION

[0005] An object of the present invention is to provide method of control of an air-fuel ratio capable of ensuring the controllability of the air-fuel ratio regardless of the engine speed.

[0006] According to the present invention, there is provided a method of control of an air-fuel ratio in an engine, comprising the steps of setting a first crank angle range in a crank angle region from the end of a compression stroke to the beginning of an expansion stroke, detecting a first angular velocity of the crankshaft in the first crank angle range, setting a second crank angle range in a crank angle region in the middle of the expansion stroke a predetermined crank angle away from the first crank angle range, detecting a second angular velocity of the crankshaft in the second crank angle range, finding the basic output fluctuation of the cylinders based on the first angular velocity and the second angular velocity, finding a set value based on the engine speed, finding the output fluctuation of the cylinders by correcting the basic output fluctuation of the cylinders based on the set value, and correcting the air-fuel ratio based on the output fluctuation.

55 BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The present invention may be more fully understood from the description of the preferred embodiments of the

invention set forth below together with the accompanying drawings, in which:

- Fig. 1 is an overall view of an internal combustion engine;
- Fig. 2 is a view of a map of the basic fuel injection time;
- 5 Fig. 3 is a view of the amount of generation of NOx and torque fluctuation;
- Fig. 4 is a view of a map of a lean correction coefficient;
- Fig. 5 is a view of a map of a lean limit feedback correction coefficient;
- Figs. 6A and 6B are time charts of the changes in the elapsed times Ta(i) and Tb(i) of 30° crank angle;
- Fig. 7 is a time chart of the changes in the elapsed time Ta(i) of 30° crank angle;
- 10 Fig. 8 is a time chart of the changes in the elapsed times Ta(i) and Tb(i) of 30° crank angle;
- Fig. 9 is a time chart of the changes in the elapsed times Ta(i) and Tb(i) of 30° crank angle;
- Fig. 10 is a time chart of the changes in the elapsed time Ta(i) of 30° crank angle;
- Fig. 11 is a view of the relationship between differences of elapsed times DTa(i) and Kb(i);
- Figs. 12A and 12B are views of the change in the amount of torque fluctuation to the change in the air-fuel ratio;
- 15 Fig. 13 is a view of a map of the set value KDLN;
- Fig. 14 is a view of the relationship between the true torque fluctuation amount and the calculated torque fluctuation amount;
- Fig. 15 is a time chart of the changes in the elapsed time Ta(i) during a deceleration operation;
- Fig. 16 is a time chart of the changes of the difference in the elapsed times DTa(i);
- 20 Fig. 17 is a flow chart of the interruption routine;
- Figs. 18 and 19 are flow charts for calculating the difference of elapsed times DTa(i) and elapsed time Tb(i);
- Fig. 20 is a flow chart for calculating KTa(i);
- Fig. 21 is a flow chart for calculating KTb(i);
- Figs. 22 to 24 are flow charts for checking permission for calculation of the amount of torque fluctuation;
- 25 Fig. 25 is a time chart of the changes in the difference of elapsed times DTa(i) and the changes in the flags XMXREC and XMNREC;
- Fig. 26 is a flow chart for calculating the amount of torque fluctuation;
- Fig. 27 is a flow chart of the processing of the counter CDLNIX;
- Fig. 28 is a view of the timings for calculation of various values;
- 30 Figs. 29A and 29B are views of a target torque fluctuation value;
- Figs. 30A and 30B are views of the fluctuation amount judgement values DH(n) and DL(n) and the levels of torque fluctuation LVLH(n) and LVLL(n);
- Fig. 31 is a flow chart of a main routine;
- Figs. 32 and 33 are flow charts of the calculation of the torque fluctuation value;
- 35 Fig. 34 is a flow chart of the calculation of a lean limit feedback correction coefficient; and
- Fig. 35 is a flow chart of the calculation of the fuel injection time.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

- 40 **[0008]** Referring to Fig. 1, 1 shows an engine body provided with four cylinders consisting of the No. 1 cylinder #1, No. 2 cylinder #2, No. 3 cylinder #3, and No. 4 cylinder #4. The cylinders #1, #2, #3, and #4 are respectively connected through the corresponding intake pipes 2 to a surge tank 3. In the intake pipes 2 are provided fuel injectors 4 for injecting fuel toward the corresponding intake ports. The surge tank 3 is connected through an intake duct 5 and air flow meter 6 to an air cleaner 7. In the intake duct 5, a throttle valve 8 is arranged. On the other hand, the cylinders #1, #2,
- 45 #3, and #4 are connected through an intake manifold 9 and an exhaust pipe 10 to a casing 12 accommodating an NOx absorbent 11. This NOx absorbent 11 has the function of absorbing the NOx included in the exhaust gas when the air-fuel ratio is lean and discharging and reducing the absorbed NOx when the air-fuel ratio is the stoichiometric air-fuel ratio or rich.
- [0009]** The electronic control unit 20 is comprised of a digital computer and is provided with a ROM (read only memory) 22, a RAM (random access memory) 23, a CPU (microprocessor) 24, a backup RAM 25 (B-RAM) connected to a constant power supply, an input port 26, and an output port 27 connected with each other by a bidirectional bus 21. The output shaft 13 of the engine has attached to it a rotor 14 with outer teeth. A crank angle sensor 15 comprising an electromagnetic pickup is arranged facing the outer teeth of the rotor 14. In the embodiment shown in Fig. 1, the rotor 14 has an outer tooth formed on its periphery at every 30° crank angle and, for example, has a part of the outer teeth
- 55 removed for detecting the top dead center of the compression stroke of the No. 1 cylinder. Therefore, except for the portion where the outer teeth are removed, that is, the non-tooth portion, the crank angle sensor 15 generates an output pulse every time the output shaft 13 turns by 30° crank angle. This output pulse is input to the input port 26.
- [0010]** The air flow meter 6 generates an output voltage proportional to the amount of intake air. This output voltage

is input through a corresponding A/D converter 28 to the input port 26. Further, the throttle valve 8 has attached to it an idle switch 16 for detecting when the throttle valve 8 is at the idling opening position. The output signal of this idle switch 16 is input to the input port 26. Further, the intake manifold 9 has disposed in it an air-fuel ratio sensor (O_2 sensor) 17 for detecting the air-fuel ratio. The output signal of this air-fuel ratio sensor 17 is input through the corresponding AD converter 28 to the input port 26. On the other hand, the output port 27 is connected through the corresponding drive circuit 29 to the fuel injectors 4.

[0011] In the internal combustion engine shown in Fig. 1, the fuel injection time TAU is calculated based on the following equation:

$$TAU = TP \cdot FLEAN \cdot FLLFB \cdot FAF + TAUV$$

[0012] Here, TP shows a basic fuel injection time, FLEAN a lean correction coefficient, FLLFB a lean limit feedback correction coefficient, FAF a stoichiometric air-fuel ratio feedback correction coefficient, and TAUV an invalid injection time.

[0013] The basic fuel injection time TP shows the injection time required for making the air-fuel ratio the stoichiometric air-fuel ratio. This basic fuel injection time TP is found by experiment. This basic fuel injection time TP is stored in the ROM 22 in advance in the form of a map shown in Fig. 2 as a function of the engine load Q/N (amount of intake air Q/engine speed N) and the engine speed N.

[0014] The lean correction coefficient FLEAN is a correction coefficient for making the air-fuel ratio a lean air-fuel ratio. This lean correction coefficient FLEAN is stored in advance in the ROM 22 in the form of the map shown in Fig. 4 as a function of the engine load Q/N and the engine speed N.

[0015] The lean limit feedback correction coefficient FLLFB is a correction coefficient for maintaining the air-fuel ratio at the lean limit. In this embodiment according to the present invention, the learning region for the lean air-fuel ratio feedback control for the amount of intake air Q and the engine speed N is divided into nine regions as shown in Fig. 5 for example. Lean limit feedback correction coefficients FLLFB₁₁ to FLLFB₃₃ are set for the learning regions.

[0016] The stoichiometric air-fuel ratio feedback correction coefficient FAF is a coefficient for maintaining the air-fuel ratio at the stoichiometric air-fuel ratio. The stoichiometric air-fuel ratio feedback correction coefficient FAF is controlled based on the output signal of the air-fuel ratio sensor 17 so as to maintain the air-fuel ratio at the stoichiometric air-fuel ratio. At this time, the stoichiometric air-fuel ratio feedback correction coefficient FAF varies substantially about 1.0.

[0017] The lean correction coefficient FLEAN is set in accordance with the operating state of the engine for the operating region enclosed by the broken lines in Fig. 4. In this operating region, the air-fuel ratio is maintained at the lean air-fuel ratio. As opposed to this, in the operating region outside the region enclosed by the broken line in Fig. 4, the air-fuel ratio is maintained at the stoichiometric air-fuel ratio. When the air-fuel ratio is to be maintained at the stoichiometric air-fuel ratio, the lean correction coefficient FLEAN and the lean limit feedback correction coefficient FLLFB are fixed at 1.0 and the stoichiometric air-fuel ratio feedback correction coefficient FAF is controlled based on the output signal of the air-fuel ratio sensor 17.

[0018] On the other hand, when the air-fuel ratio is to be maintained at the lean air-fuel ratio, the stoichiometric air-fuel ratio feedback correction coefficient FAF is fixed at 1.0, that is, the feedback control based on the output signal of the air-fuel ratio sensor 17 is stopped, and the lean correction coefficient FLEAN and the lean limit feedback correction coefficient FLLFB are used to control the air-fuel ratio to the lean air-fuel ratio.

[0019] Next, the lean limit feedback control will be explained referring to Fig. 3. Figure 3 shows the relationship between the amount of torque fluctuation of the engine output and the amount of generation of NO_x and the air-fuel ratio. The leaner the air-fuel ratio, the smaller the fuel consumption rate. Further, the leaner the air-fuel ratio, the smaller the amount of generation of NO_x. Therefore, viewed from these points, the air-fuel ratio should desirably be made as lean as possible. Note, however, that when the air-fuel ratio becomes leaner than a certain extent, the combustion becomes unstable and, as a result, as shown in Fig. 3, the amount of torque fluctuation becomes large. Therefore, in this embodiment according to the present invention, as shown in Fig. 3, the air-fuel ratio is maintained in the air-fuel ratio control region where the torque fluctuation starts to increase.

[0020] That is, in more detail, the lean correction coefficient FLEAN is determined so that the air-fuel ratio is in the middle of the air-fuel ratio control region shown in Fig. 3 when the lean limit feedback correction coefficient FLLFB is made 1.0. On the other hand, the lean limit feedback correction coefficient FLLFB is controlled to within the torque fluctuation control region shown in Fig. 3 in accordance with the amount of torque fluctuation. When the amount of torque fluctuation becomes larger, the lean limit feedback correction coefficient FLLFB is increased, that is, the air-fuel ratio is made smaller, while when the amount of torque fluctuation becomes smaller, the lean limit feedback correction coefficient FLLFB is reduced, that is, the air-fuel ratio is made larger. In this way, the air-fuel ratio is controlled to within the air-fuel ratio control region shown in Fig. 3.

[0021] Note that the lean limit feedback correction coefficient FLLFB is set to cover the engine operating region where the lean correction coefficient FLEAN is set.

[0022] If the amount of torque fluctuation is controlled to within the torque fluctuation control region shown in Fig. 3, an excellent drivability of the vehicle may be ensured while the fuel consumption rate and the amount of generation of NOx can be greatly reduced. However, since the amount of torque fluctuation is controlled to be within the torque fluctuation control region in this way, the amount of torque fluctuation must be detected.

[0023] Various methods have been proposed in the past for calculating the amount of torque fluctuation. To mention typical ones, there are the method of providing a combustion pressure sensor in the combustion chamber and calculating the amount of torque fluctuation based on the output signal of this combustion pressure sensor or the method of, as explained at the beginning, calculating the amount of torque fluctuation from the difference between the square of the first angular velocity ω_a and the square of the second angular velocity ω_b .

[0024] If a combustion pressure sensor is used, there is the advantage that the torque generated in the cylinder provided with the combustion pressure sensor can be reliably detected, but there is conversely the disadvantage that the combustion pressure sensor is required. As opposed to this, the angular velocities ω_a and ω_b can be calculated from the output signal of the crank angle sensor provided in the internal combustion engine in the past, so when calculating the output torque based on the angular velocities ω_a and ω_b , there is the advantage that there is no need to mount a new sensor.

[0025] However, in this case, if the engine drive system or crank shaft itself experiences torsional vibration, there is the problem that the generated torque can no longer be accurately detected. It is clear, however, that if this problem could be solved, then the method of calculation of the torque based on the angular velocity, which does not require a new sensor, would be preferable. Therefore, the embodiment present invention can calculate the generated torque based on the angular velocities and can accurately detect the amount of torque fluctuation even if the engine drive system or crankshaft itself experiences torsional vibration.

[0026] While it is possible to find the output fluctuation and the torque fluctuation of the engine so long as the angular velocity of the crankshaft is used as the basis, when the engine drive system or crankshaft itself suffers from torsional vibration or when the vehicle drives over a bumpy road or when there is variation in the outer teeth of the rotor, it is not possible to accurately calculate the output fluctuation and torque fluctuation of the engine. Therefore, in this embodiment of the present invention, use is made of the new method of calculation of the output fluctuation and torque fluctuation so as to enable accurate detection of the output fluctuation and torque fluctuation of the engine even when the engine drive system or crankshaft itself suffers from torsional vibration or the vehicle drives over a bumpy road or there is variation in the outer teeth of the rotor.

[0027] Next, the method for calculating the output fluctuation and torque fluctuation of the engine will be explained.

[0028] First, the method of calculating the drive force generated by each cylinder and the torque generated in each cylinder will be explained while referring to Figs. 6A and 6B showing the steady operating state where the engine drive system does not experience torsional vibration. As explained above, the crank angle sensor 15 produces an output pulse each time the crankshaft rotates by 30° crank angle. Further, the crank angle sensor 15 is arranged to generate an output pulse at the top dead center TDC of the compression stroke of the cylinders #1, #2, #3, and #4. Therefore, the crank angle sensor 15 produces an output pulse for each 30° crank angle from the top dead center TDC of the compression stroke of the cylinders #1, #2, #3, and #4. Note that, the ignition sequence of the internal combustion engine used in the present invention is 1-3-4-2.

[0029] In Figs 6A and 6B, the vertical axis T30 shows the elapsed time of 30° crank angle from when the crank angle sensor 15 produces an output pulse to when it produces the next output pulse. Further, Ta(i) shows the elapsed time from the top dead center of the compression stroke (hereinafter referred to as TDC) to 30° after top dead center of the compression stroke (hereinafter referred to as ATDC) of the No. i cylinder, while Tb(i) shows the elapsed time from ATDC 60° to ATDC 90° of the No. i cylinder. Therefore, for example, Ta(1) shows the elapsed time from TDC to ATDC 30° of the No. 1 cylinder, while Tb(1) shows the elapsed time from ATDC 60° to ATDC 90° of the No. 1 cylinder. On the other hand, if the 30° crank angle is divided by the elapsed time T30, the result of the division shows the angular velocity ω . In this embodiment according to the present invention, 30° crank angle/Ta(i) is referred to as the first angular velocity ω_a in the No. i cylinder, while 30° crank angle/Tb(i) is referred to as the second angular velocity ω_b in the No. i cylinder. Therefore, 30° crank angle/Ta(1) shows the first angular velocity ω_a of the No. 1 cylinder, while 30° crank angle/Tb(1) shows the second angular velocity ω_b of the No. 1 cylinder.

[0030] Taking note of the No. 1 cylinder of Figs. 6A and 6B, when the combustion is started and the combustion pressure rises, the elapsed time falls from Ta(1) to Tb(1) then rises from Tb(1). In other words, the angular velocity ω of the crankshaft rises from the first angular velocity ω_a to the second angular velocity ω_b , then falls again from the second angular velocity ω_b . That is, the combustion pressure causes the angular velocity ω of the crankshaft to increase from the first angular velocity ω_a to the second angular velocity ω_b . Figure 6A shows the case where the combustion pressure is relatively high, while Fig. 6B shows the case where the combustion pressure is relatively low. As shown in Figs. 6A and 6B, when the combustion pressure is high, the amount of reduction of the elapsed time (Ta(i) - Tb(i)) becomes larger compared with when the combustion pressure is low, therefore the amount of increase ($\omega_b - \omega_a$) of the angular velocity ω becomes larger. When the combustion pressure becomes higher, the drive force generated by the cylinder

becomes larger, therefore if the amount of increase ($\omega_b - \omega_a$) of the angular velocity ω becomes larger, the drive force generated by the cylinder becomes larger. Therefore, it is possible to calculate the drive force generated by a cylinder from the difference ($\omega_b - \omega_a$) between the first angular velocity ω_a and the second angular velocity ω_b .

[0031] On the other hand, if the moment of inertia of rotation of the engine is I , the combustion pressure causes the kinetic energy to increase from $(1/2)I\omega_a^2$ to $(1/2)I\omega^2$. The amount of increase of the kinetic energy $(1/2) \cdot I \cdot (\omega_b^2 - \omega_a^2)$ expresses the torque generated by that cylinder, therefore it becomes possible to calculate the torque generated by a cylinder from the difference ($\omega_b^2 - \omega_a^2$) between the square of the first angular velocity ω_a and the square of the second angular velocity ω_b .

[0032] By detecting the first angular velocity ω_a and the second angular velocity ω_b in this way, it becomes possible to calculate the drive force generated by the corresponding cylinder and the torque generated by the corresponding cylinder from the detected values. Note that the change in the elapsed time T_{30} shown in Figs. 6A and 6B differs somewhat depending on the engine, therefore the crank angle range for detecting the first angular velocity ω_a and the crank angle range for detecting the second angular velocity ω_b are set in accordance with the engine so that $(\omega_b - \omega_a)$ best expresses the drive force generated by the engine or so that $(\omega_b^2 - \omega_a^2)$ best expresses the torque generated by the engine. Therefore, depending on the engine, the crank angle range for detecting the first angular velocity ω_a may be from before the top dead center of the compression stroke BTDC 30° to TDC, while the crank angle range for detecting the second angular velocity ω_b may be from ATDC 90° to ATDC 120° .

[0033] Therefore, explaining the method of detecting the angular velocities ω_a and ω_b in general terms, the first crank angle range is set in the crank angle region from the end of the compression stroke to the beginning of the expansion stroke, the second crank angle range is set in a crank angle region in the middle of the expansion stroke a predetermined crank angle away from the first crank angle range, the first angular velocity ω_a of the crankshaft in the first crank angle range is detected, and the second angular velocity of the crankshaft ω_b in the second crank angle range is detected.

[0034] As explained above, by detecting the angular velocities ω_a and ω_b , it becomes possible to calculate the drive force and the torque generated by a corresponding cylinder based on the detected values. The engine drive system, however, experiences torsional vibration occurring at the natural frequency of the drive system due to the successive explosive actions of the cylinders. If the engine drive system experiences such torsional vibration, it no longer becomes possible to accurately detect the drive force and the torque generated by a cylinder based on the angular velocities ω_a and ω_b . Next, this will be explained with reference to Fig. 7 and Fig. 8.

[0035] Figure 7 shows the changes in the elapsed time $T_a(i)$ successively calculated for each cylinder when the engine drive system experiences torsional vibration. When the engine drive system experiences torsional vibration, this torsional vibration causes the angular velocity of a crankshaft to be cyclically increased and decreased, so the elapsed time $T_a(i)$ increases and decreases cyclically as shown in Fig. 7.

[0036] On the other hand, Fig. 8 shows the portion where the elapsed time $T_a(i)$ is reduced in an enlarged manner. As shown in Fig. 8, the elapsed time $T_a(i)$ falls by exactly the time h_0 between $T_a(1)$ and $T_a(3)$. This reduction of the time h_0 is believed to be due to an increase in the amount of torsion due to the torsional vibration. In this case, the amount of decrease of the elapsed time due to the torsional vibration between $T_a(1)$ and $T_a(3)$ is believed to increase substantially linearly along with the elapse of time, therefore this amount of decrease of the elapsed time due to the torsional vibration is shown by the difference between the broken line connecting $T_a(1)$ and $T_a(3)$ and the horizontal line passing through $T_a(1)$. Therefore, between $T_a(1)$ and $T_b(1)$, the torsional vibration causes the elapsed time to fall by exactly h .

[0037] In this way, when torsional vibration occurs in the engine drive system, $T_b(1)$ is lower in elapsed time than $T_a(1)$, but this lower elapsed time includes the amount of decrease f of the elapsed time due to the combustion pressure and the amount of decrease h of the elapsed time due to the torsional vibration. Therefore, to find just the elapsed time $T_b(1)$ decreased due to the combustion pressure, it becomes necessary to add h to $T_b(1)$. That is, even if finding the drive force or torque generated by each cylinder based on the detected elapsed time $T_a(i)$ and $T_b(i)$, it is not possible to find the true drive output or torque and therefore not possible to find the true output fluctuation or torque fluctuation of the engine.

[0038] Further, in a multi-cylinder internal combustion engine, in addition to the torsional vibration of the engine drive system, there is torsional vibration of the crankshaft itself. When this torsional vibration of the crankshaft itself occurs, it is no longer possible to find the true output fluctuation or torque fluctuation of the engine. Next, this will be explained with reference to Fig. 9.

[0039] In a multi-cylinder internal combustion engine, for example, a four-cylinder internal combustion engine as shown in Fig. 1, a large torsional vibration occurs in the No. 1 cylinder and the No. 2 cylinder. That is, in a cylinder where almost no torsional vibration of the crankshaft itself occurs, for example, the No. 3 cylinder #3, as shown in Fig. 9, the elapsed time gradually falls from $T_a(3)$ to $T_b(3)$, but in the No. 1 cylinder #1, the elapsed time does not gradually fall from $T_a(1)$ to $T_b(1)$ and the torsional vibration of the crankshaft itself causes the elapsed time $T_b(1)$ to become longer. As a result, it is not possible to find the true drive force or torque for the No. 1 cylinder #1 even if finding the drive force or torque generated by the No. 1 cylinder #1 based on the detected elapsed times $T_a(1)$ and $T_b(1)$, therefore it is not

possible to find the true output fluctuation or torque fluctuation of the engine.

[0040] Therefore, in the present invention, use is made of a new method of calculation which enables calculation of the true output fluctuation and torque fluctuation of the engine even if torsional vibration of the engine drive system occurs and even if torsional vibration of the crankshaft occurs. Next, this new method of calculation will be explained with reference to Fig. 10.

[0041] In Fig. 10, $Ta(1)_{j-1}$ and $Tb(1)_{j-1}$ show the elapsed times at the time of the previous combustion of the No. 1 cylinder #1. $Ta(1)_j$ and $Tb(1)_j$ show the elapsed times at the time of the next combustion of the No. 1 cylinder #1. On the other hand, $Ta(3)_{j-1}$ shows the elapsed time at the time of the previous combustion of the No. 3 cylinder #3 performed after the previous combustion of the No. 1 cylinder #1, while $Ta(3)_j$ shows the elapsed time at the time of the next combustion of the No. 3 cylinder #3.

[0042] First, the difference $DTa(1) (= Ta(1)_j - Ta(1)_{j-1})$ between $Ta(1)_j$ and $Ta(1)_{j-1}$ and the difference $DTa(3) (= Ta(3)_j - Ta(3)_{j-1})$ between $Ta(3)_j$ and $Ta(3)_{j-1}$ are found. Next, the assumed elapsed time from ATDC 60° to ATDC 90° at the time of the next combustion of the No. 1 cylinder #1, when assuming that the output torque at the time of the previous combustion of the No. 1 cylinder #1 and the output torque at the time of the next combustion are identical, is made $Tb'(1)$ and the difference $Kb(1) (= Tb'(1)_j - Tb(1)_{j-1})$ between $Tb'(1)_j$ and $Tb(1)_{j-1}$ is found. The differences $DTa(1)$, $Kb(1)$, and $DTa(3)$ become as shown in Fig. 11 when rewritten as heights on a straight line.

[0043] The difference of elapsed times falls by exactly the time l_0 between the differences of elapsed times $DTa(1)$ and $DTa(3)$ as shown in Fig. 11. Even if torsional vibration occurs in the crankshaft itself, the effect of the torsional vibration does not appear in the difference of the elapsed times and therefore the decrease of the time l_0 in the difference of elapsed times is due to the torsional vibration of the drive system. In this case, the amount of decrease of the difference of elapsed times due to the torsional vibration of the engine drive system may be considered to increase substantially linearly along with the elapse of time between $DTa(1)$ and $DTa(3)$. Therefore, if it is assumed that the output torque at the time of the previous combustion of the No. 1 cylinder #1 and the output torque at the time of the next combustion are identical, the difference of elapsed times can be considered to decrease by exactly l due to the torsional vibration of the engine drive system between the differences of elapsed times $DTa(1)$ and $Kb(1)$. Therefore, as will be understood from Fig. 11, the assumed difference of elapsed times $Kb(1)$ when assuming that the output torque at the time of previous combustion of the No. 1 cylinder #1 and the output torque at the time of the next combustion are identical is expressed as an interpolated value from $DTa(1)$ and $DTa(3)$ and becomes as shown in the following equation:

$$Kb(1) = (2DTa(1) + DTa(3))/3$$

[0044] The assumed elapsed time $Tb'(1)_j$ of the No. 1 cylinder #1, when assuming that the output torque at the time of the previous combustion of the No. 1 cylinder #1 and the output torque at the time of the next combustion are identical, is expressed as follows:

$$Tb'(1)_j = Tb(1)_{j-1} + Kb(1)$$

[0045] Therefore, the assumed output torque $DNS(1)$ at the time of the next combustion of the No. 1 cylinder #1, when assuming that the output torque at the time of the previous combustion of the No. 1 cylinder #1 and the output torque at the time of the next combustion are identical, is expressed as follows:

$$\begin{aligned} DNS(1) &= \{30^\circ/Tb'(1)_j\}^2 - \{30^\circ/Ta(1)_j\}^2 \\ &= \{30^\circ/Tb(1)_{j-1} + Kb(1)\}^2 - \{30^\circ/Ta(1)_j\}^2 \end{aligned}$$

[0046] On the other hand, when calculating the actual output torque using the actual elapsed time $Tb(1)_j$ from ATDC 60° to ATDC 90° at the time of the next combustion of the No. 1 cylinder #1, the output torque $DN(1)$ is expressed by the following equation:

$$DN(1) = \{30^\circ/Tb(1)_j\}^2 - \{30^\circ/Ta(1)_j\}^2$$

[0047] In this case, the difference between the assumed output torque $DNS(1)$ of the No. 1 cylinder #1 and the actual output torque $DN(1)$ shows the amount of torque fluctuation of the No. 1 cylinder #1. Therefore, the amount of torque fluctuation $DLN(1)$ of the No. 1 cylinder #1 is shown by the following equation:

$$\begin{aligned} DLN(1) &= DNS(1) - DN(1) \\ &= \{30^\circ/Tb'(1)_j\}^2 - \{30^\circ/Ta(1)_j\}^2 \end{aligned}$$

[0048] Expressed generally, the amount of torque fluctuation DLN(i) of the No. i cylinder can be shown by the following equation:

$$DLN(i) = DNS(i) - DN(i) \\ = \{30^\circ/Tb'(i)\}^2 - \{30^\circ/Tb(i)\}^2$$

[0049] That is, the amount of torque fluctuation of the No. i cylinder can be found from the difference between the square of the assumed second angular velocity of the No. i cylinder and the square of the actual second angular velocity. By calculating the amount of torque fluctuation by this method, even if torsional vibration occurs in the engine drive system, it is possible to accurately detect the amount of torque fluctuation of the cylinders even if torsional vibration occurs in the crankshaft itself.

[0050] However, it is not possible to calculate the amount of torque fluctuation of the cylinders accurately when the engine speed becomes high, as explained at the beginning. That is, when the engine speed becomes high, the elapsed time Ta(i), Tb(i) becomes short and, therefore, it becomes difficult to detect the elapsed time Ta(i), Tb(i) accurately and the elapsed time Ta(i), Tb(i) includes the error. As a result, the first angular velocity ωa and the second angular velocity ωb also include the error and, therefore, the amount of torque fluctuation DLN(i) calculated based on the angular velocities ωa and ωb includes the error. Such an error becomes larger as the engine speed becomes higher.

[0051] On the other hand, when the engine speed becomes higher, the higher components of the torsional vibration of the engine drive system and the torsional vibration of the crankshaft itself become larger. The higher component affects the difference of elapsed time DTa(1), DTa(3). That is, the calculated amount of torque fluctuation will deviate from the true amount of torque fluctuation, even if the assumed second angular velocity is adapted. The deviation in the calculated amount of torque fluctuation becomes larger as the engine speed becomes higher.

[0052] Namely, a ratio of the error to the calculated amount of torque fluctuation becomes higher as the engine speed becomes higher. As a result, as shown in Fig. 12B, the rate of change in the calculated amount of torque fluctuation to the change in the air-fuel ratio becomes lower. However, if the rate of change in the amount of torque fluctuation becomes lower around the torque fluctuation control area (see Fig. 3), the controllability of the air-fuel ratio for maintaining the amount of torque fluctuation within the torque fluctuation control area becomes lower.

[0053] On the other hand, the amounts of the error and the deviation explained above depend on the engine speed, that is, they become larger as the engine speed becomes higher, but the amounts of the error and the deviation do not depend on the air-fuel ratio and the cylinder. Therefore, by finding a set value KDLN representing the error and the deviation in advance based on the engine speed, and subtracting the set value KDLN from DLN(i) explained above, the result of the subtraction accurately represents the amount of torque fluctuation. Therefore, in the embodiment of the present invention, the set value KDLN is found by experiment in advance, and is stored in the ROM 22, in advance, in the form of a map shown in Fig. 13, and then the amount of torque fluctuation DLN(i) of the No. i cylinder is calculated by subtracting the set value KDLN from the difference between the assumed output torque DNS (i) of the No. i cylinder and the actual output torque DN(i).

[0054] Namely, if the difference (DNS(i) - DN(i)) between the assumed output torque DNS(i) of No. i cylinder and the actual output torque DN(i) is referred to as a basic amount of torque fluctuation DLNB(i) of the No. i cylinder, the amount of torque fluctuation DLN(i) of the No. i cylinder is calculated based on the following equation:

$$DLN(i) = DLNB(i) - KDLN \\ = DNS(i) - DN(i) - KDLN$$

[0055] By calculating the amount of torque fluctuation in this way, the rate of change in the amount of torque fluctuation to the change in the air-fuel ratio can be kept larger as shown in Fig. 12A and, therefore, the controllability of the air-fuel ratio for maintaining the amount of torque fluctuation within the torque fluctuation control area can be kept higher.

[0056] As can be seen from Fig. 13, the set value KDLN becomes larger when the average of the engine speed N_{AVE} becomes larger. Note, however, that the amount of torque fluctuation DLN(i) varies with the engine speed for the identical true amounts of torque fluctuation, even when the amount of torque fluctuation DLN(i) is calculated in the above-mentioned manner. That is, as shown in Fig. 14, DLN(i) becomes larger as the average of the engine speed N_{AVE} becomes higher when the true amount of torque fluctuation is small, and DLN(i) becomes smaller as the average of the engine speed N_{AVE} becomes higher when the true amount of torque fluctuation is large. However, the variation or the constancy can be determined based on the set value KDLN. Therefore, in the embodiment of the present invention, the set value KDLN is set so that the amount of torque fluctuation DLN(i) is almost constant regardless of the average of the engine speed N_{AVE} when the true amount of torque fluctuation is at the approximately middle of the torque fluctuation control area (Fig. 3).

[0057] On the other hand, when calculating the amount of torque fluctuation by this method, it is not possible to accurately detect the amount of torque fluctuation of the cylinders if there is a variation in the spaces of the outer teeth formed along the outer circumference of the rotor 14 (Fig. 1). Therefore, in this embodiment of the present invention, even if there is a variation in the spaces of the outer teeth of the rotor 14, it is made possible to correct the elapsed times Ta(i), Tb(i) detected so as to enable accurate detection of the amount of torque fluctuation of the cylinders. Next, an explanation will be made of the method of correction of the elapsed time Ta(i) with reference to Fig. 15.

[0058] In this embodiment of the present invention, the elapsed time Ta(i) is calculated based on the following equation:

$$Ta(i) = (\text{time required from TDC to ATDC } 30^\circ \text{ of No. } i \text{ cylinder}) \cdot (1 + KTa(i))$$

[0059] Here, KTa(i) shows the correction coefficient for the No. i cylinder. The correction coefficient KTa(i) is calculated at the time when the fuel supply is stopped during a deceleration operation where torsional vibration of the engine drive system does not occur and torsional vibration of the crankshaft does not occur either.

[0060] Figure 15 shows the change of the elapsed time Ta(i) at the time of a deceleration operation. At the time of a deceleration operation, the rotational speed of the crankshaft gradually falls, so the elapsed time Ta(i) gradually increases as shown by Ta(1)_{j-1}, Ta(3)_{j-1}, Ta(4)_{j-1}, Ta(2)_{j-1}, Ta(1)_j, Ta(3)_j, Ta(4)_j, and Ta(2)_j. At this time, if the spaces between the outer teeth of the rotor 14 are the same, the elapsed time Ta(i) can be considered to change along the solid line in Fig. 15. When the detected elapsed time Ta(i) deviates from the solid line of Fig. 15, it is considered that the spaces of the outer teeth for detection of the elapsed time Ta(i) deviated from the solid line deviate from the correct spaces. Therefore, in this embodiment of the present invention, when the elapsed time Ta(i) deviates from the line shown in Fig. 15, the elapsed time Ta(i) is corrected by the correction coefficient KTa(i) so that the elapsed time Ta(i) is positioned on the solid line of Fig. 15.

[0061] Explaining this in more detail, in this embodiment of the present invention, the average value TaAV_{j-1} {= (Ta(1)_{j-1} + Ta(3)_{j-1} + Ta(4)_{j-1} + Ta(2)_{j-1})/4}, TaAV_j {= (Ta(1)_j + Ta(3)_j + Ta(4)_j + Ta(2)_j)/4}, ... of the elapsed times TA(i) of four cylinders in a 720° crank angle range (j-1), (j) ... are found in turn. Next, it is considered that the elapsed times Ta(4)_{j-1}, Ta(2)_{j-1}, Ta(1)_j, and Ta(3)_j increase by an average constant rate of increase from the average value TaAV_{j-1} to average value TaAV_j, and the elapsed times AAV(4), AAV(2), AAV(1), and AAV(3) for the cylinders when considering an increase by an average constant rate of increase are found by the following equations:

$$AAV(4) = (TaAV_j - TaAV_{j-1}) \cdot (1/8) + TaAV_{j-1}$$

$$AAV(2) = (TaAV_j - TaAV_{j-1}) \cdot (3/8) + TaAV_{j-1}$$

$$AAV(1) = (TaAV_j - TaAV_{j-1}) \cdot (5/8) + TaAV_{j-1}$$

$$AAV(3) = (TaAV_j - TaAV_{j-1}) \cdot (7/8) + TaAV_{j-1}$$

[0062] Next, the ratios of deviation KAFC(4), KAFC(2), KAFC(1), and KAFC(3) for the actually measured elapsed times Ta(4)_{j-1}, Ta(2)_{j-1}, Ta(1)_j, and Ta(3)_j for the elapsed times AAV(4), AAV(2), AAV(1), and AAV(3) for the cylinders are found based on the following equations:

$$KAFC(4) = (Ta(4)_{j-1} - AAV(4))/AAV(4)$$

$$KAFC(2) = (Ta(2)_{j-1} - AAV(2))/AAV(2)$$

$$KAFC(1) = (Ta(1)_j - AAV(1))/AAV(1)$$

$$KAFC(3) = (Ta(3)_j - AAV(3))/AAV(3)$$

[0063] Next, the basic correction coefficient KTaB(i) is found for each cylinder using the following equation:

$$KTaB(i) = KTa(i)_{j-1} - KAFC(i)/4$$

[0064] That is, the basic correction coefficient KTaB(i) is calculated by subtracting 1/4 of the ratio of deviation KAFC(i) from the correction coefficient KTa(i)_{j-1} up to then for each cylinder.

[0065] Next, the mean value tKTaM of the basic correction coefficient KTaB(i) is calculated based on the following equation:

$$tK\text{Ta}M = \{K\text{Ta}B(1) + K\text{Ta}B(2) + K\text{Ta}B(3) + K\text{Ta}B(4)\}/4$$

[0066] Next, the correction coefficient $K\text{Ta}(i)$ for each cylinder is calculated by subtracting the average value $tK\text{Ta}M$ from the basic correction coefficient $K\text{Ta}B(i)$ as shown by the following equation:

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$$K\text{Ta}(i) = K\text{Ta}B(i) - tK\text{Ta}M$$

[0067] The correction coefficient $K\text{Ta}(i)_{j-1}$ is not directly corrected based on the ratio of deviation $K\text{AFC}(i)$. The basic correction coefficient $K\text{Ta}B(i)$ is found once in this way for the following reason. For example, assume that there is a ratio of deviation $K\text{AFC}(1)$ for only the No. 1 cylinder #1 and that only the correction coefficient $K\text{Ta}(1)$ of the No. 1 cylinder #1 is corrected based on the ratio of deviation $K\text{AFC}(1)$. In this case, the elapsed time $\text{Ta}(1)$ of only the No. 1 cylinder #1 is increased or decreased. If the elapsed time $\text{Ta}(1)$ of only the No. 1 cylinder #1 is increased or decreased, deviation will occur in the correction coefficients $K\text{Ta}(2)$, $K\text{Ta}(3)$, and $K\text{Ta}(4)$ of the remaining cylinders #2, #3, and #4.

[0068] To prevent this problem from occurring, the basic correction coefficient $K\text{Ta}B(i)$ is found once and the mean value $tK\text{Ta}M$ of the basic correction coefficient is subtracted from the basic correction coefficient $K\text{Ta}B(i)$ to find the final correction coefficient $K\text{Ta}(i)$. That is, for example, when the basic correction coefficient $K\text{Ta}(1)$ of the No. 1 cylinder #1 is increased, the mean value $tK\text{Ta}M$ of the basic correction coefficient is subtracted from the basic correction coefficients $K\text{Ta}B(i)$ of all of the cylinders #1, #2, #3, and #4. If $tK\text{Ta}M$ is subtracted from the basic correction coefficients $K\text{Ta}B(i)$ of all of the cylinders in this way, the correction coefficient $K\text{Ta}(1)$ of the No. 1 cylinder #1 will increase, but the correction coefficients $K\text{Ta}(2)$, $K\text{Ta}(3)$, and $K\text{Ta}(4)$ of the remaining cylinders #2, #3, and #4 will be decreased and the sum of $K\text{Ta}(1)$, $K\text{Ta}(2)$, $K\text{Ta}(3)$, and $K\text{Ta}(4)$ will be maintained constantly at zero. If the correction coefficient $K\text{Ta}(i)$ is corrected so that the sum of $K\text{Ta}(1)$, $K\text{Ta}(2)$, $K\text{Ta}(3)$, and $K\text{Ta}(4)$ is maintained constantly at zero, then no matter which correction coefficient $K\text{Ta}(i)$ is corrected, deviation will no longer occur in the other correction coefficients $K\text{Ta}(i)$.

[0069] In the embodiment shown in Fig. 15, when the elapsed time $\text{Ta}(1)_j$ of the No. 1 cylinder #1, for example, is larger than the elapsed time $\text{AAV}(1)$ when assuming an increase by an average constant rate of increase, the ratio of deviation $K\text{AFC}(1)$ for the No. 1 cylinder #1 becomes a positive value. As a result, the correction coefficient $K\text{Ta}(1)$ is decreased until the ratio of deviation $K\text{AFC}(1)$ becomes zero. If the ratio of deviation $K\text{AFC}(1)$ becomes zero, the value of the correction coefficient $K\text{Ta}(1)$ settles down to a constant value. At this time, the elapsed time $\text{Ta}(1)$ matches with the elapsed time $\text{AVV}(1)$. If the correction coefficients $K\text{Ta}(1)$ for all cylinders settle down to constant values, when the rotational speed of the rotor 14 is constant, the elapsed times $\text{Ta}(i)$ of the cylinders corrected using the correction coefficients $K\text{Ta}(i)$ all become equal. Therefore, even if there is variation in the spaces of the outer teeth of the rotor 14, it is possible to accurately detect the torque fluctuation of the cylinders.

[0070] Returning the discussion to the calculation of torque fluctuation once again, when torsional vibration occurs in the engine drive system, the difference in elapsed times $\text{DTa}(i)$ fluctuates as shown in Fig. 10. This difference in elapsed times $\text{DTa}(i)$, however, fluctuates even when the vehicle is driving over a bumpy road. Further, at this time, the degree of fluctuation of the $\text{DTa}(i)$ becomes extremely large in some cases. Figure 16 shows the fluctuation in $\text{DTa}(i)$ when the vehicle is riding over a bumpy road. AMP in Fig. 16 shows the difference between the minimum $\text{DTa}(i)$ and the maximum $\text{DTa}(i)$, that is, the amplitude. When this amplitude AMP is small, it is possible to accurately detect the output fluctuation and torque fluctuation of the cylinders by the method described above.

[0071] When the amplitude AMP becomes large, however, it no longer becomes possible to accurately detect the output fluctuation or torque fluctuation of the cylinder giving the maximum or minimum $\text{DTa}(i)$. That is, in Fig. 16, first, assuming that the cylinder giving the maximum $\text{DTa}(i)$ is the No. 1 cylinder #1, the amount of decrease l due to the torsional vibration of the assumed difference of elapsed times $\text{Kb}(1)$ of the No. 1 cylinder #1 is found from the slope of the broken line connecting $\text{DTa}(1)$ and $\text{DTa}(3)$ in Fig. 11. Near where $\text{DTa}(1)$ becomes a maximum, the amount of increase or amount of decrease of the elapsed time due to the torsional vibration changes along a smooth curve passing through $\text{DTa}(2)$, $\text{DTa}(1)$, and $\text{DTa}(3)$. Therefore, if the $\text{Kb}(1)$ of the No. 1 cylinder #1 is found from $\text{DTa}(1)$ and $\text{DTa}(3)$, the value of $\text{Kb}(1)$ is calculated considerably smaller than the actual value. As a result, $\text{Kb}(1)$ no longer shows the correct value and therefore the amount of output fluctuation and the amount of torque fluctuation can no longer be accurately detected. If the amplitude AMP becomes larger, the same thing happens in the cylinder giving the minimum $\text{DTa}(i)$.

[0072] Further, the value of $\text{Kb}(i)$ deviates from the actual value even in cylinders where the $\text{DTa}(i)$ sharply changes from the $\text{DTa}(i)$ of the cylinder where combustion was performed one time before, therefore it no longer becomes possible to accurately detect the output fluctuation and torque fluctuation. Therefore, in this embodiment according to the present invention, when the amplitude AMP is large, the amount of output fluctuation or amount of torque fluctuation is not sought for the cylinders giving the maximum or minimum $\text{DTa}(i)$. Further, the amount of output fluctuation or the amount of torque fluctuation is not sought for cylinders where $\text{DTa}(i)$ changes sharply from the $\text{DTa}(i)$ of the cylinder where combustion was performed one time before.

[0073] Next, the routines for finding the amount of fluctuation of torque at each cylinder will be explained referring to Fig. 17 to Fig. 28. Note that Fig. 28 shows the timing for calculation of the various values performed in each routine.

[0074] Figure 17 shows an interruption routine performed at every 30° crank angle. Referring to Fig. 17, first the routine (step 100) for calculating the difference of elapsed times DTa(i) and the elapsed time Tb(i) is followed. This routine is shown in Fig. 18 to Fig. 21. Next, the routine (step 200) for checking if calculation of the torque fluctuation is permitted or not is followed. This routine is shown in Fig. 22 to Fig. 24. Next, the routine for calculating the torque fluctuation (step 300) is followed. This routine is shown in Fig. 26. Next, the routine for processing of the counter CDLNIX used for calculating the torque fluctuation value is followed. This routine is shown in Fig. 27.

[0075] Referring to Fig. 18 to Fig. 21 showing the routine for calculation of the difference of elapsed times DTa(i) and the elapsed time Tb(i), first, at step 101, the time TIME is made the TIME0. The electronic control unit 20 is provided with a free run counter showing the time. The time TIME is calculated from the count value of this free run counter. Next, at step 102, the current time TIME is fetched. Therefore, the TIME0 of step 101 expresses the time of 30° crank angle before.

[0076] Next, at step 103, whether the No. i cylinder is currently at ATDC 30° or not is judged. When the No. i cylinder is not currently at ATDC 30°, step 111 is jumped to, where it is judged whether the No. i cylinder is currently at ATDC 90° or not. When the No. i cylinder is not currently at ATDC 90°, the routine for calculation of the difference of elapsed times DTa(i) and the elapsed time Tb(i) is ended.

[0077] As opposed to this, when it is judged at step 103 that the No. i cylinder is currently at ATDC 30°, the routine proceeds to step 104, where the elapsed time Ta(i) calculated 720° crank angle before is made TaO(i). Next, at step 105, the final elapsed time Ta(i) from TDC to ATDC 30° of the No. No. i cylinder is calculated based on the following equation:

$$Ta(i) = (TIME - TIME0) \cdot (1 + KTa(i))$$

[0078] That is, for example, when the No. 1 cylinder #1 is currently at ATDC 30°, the final elapsed time Ta(1) from TDC to ATDC 30° of the No. 1 cylinder #1 is calculated from $(TIME - TIME0) \cdot (1 + KTa(i))$. Here, $(TIME - TIME0)$ expresses the elapsed time Ta(1) actually measured from the crank angle sensor 15 and KTa(1) is a correction coefficient for correction of the error due to the spaces of the outer teeth of the rotor 14, therefore the final elapsed time Ta(1) obtained by multiplying $(TIME - TIME0)$ with $(1 + KTa(1))$ comes to accurately express the elapsed time when the crankshaft rotates by 30° crank angle.

[0079] Next, at step 106, the elapsed time Ta(i) currently calculated is reduced by the elapsed time TaO(i) calculated 720° crank angle before so as to calculate the difference of elapsed times DTa(i) (= Ta(i) - TaO(i)). Next, at step 107, it is judged if No. 2 cylinder #2 is currently at ATDC 30°. When the No. 2 cylinder #2 is not at ATDC 30°, the routine jumps to step 110, where the flag XCAL(i-1) of the No. (i-1) cylinder where combustion had been performed one time before showing that the amount of torque fluctuation should be calculated is set (XCAL(i-1) ← "1"). Next, the routine proceeds to step 111. In this embodiment according to the present invention, as explained above, since the ignition sequence is 1-3-4-2, when the No. 1 cylinder #1 is currently at ATDC 30°, the flag XCAL(2) of the No. 2 cylinder #2 where the combustion had been performed one time before showing that the amount of torque fluctuation should be calculated is set. In the same way, when the final elapsed time Ta(3) is calculated as shown in Fig. 28, the flag XCAL(1) is set, when the final elapsed time Ta(4) is calculated, the flag XCAL(3) is set, and when the final elapsed time Ta(2) is calculated, the flag XCAL(4) is set.

[0080] On the other hand, when it is judged at step 111 that the No. 1 cylinder is currently at ATDC 90°, the routine proceeds to step 112, where the elapsed time Tb(i) calculated 720° crank angle before is made TbO(i). Next, at step 113, the final elapsed time Tb(i) from ATDC 60° to ATDC 90° of the No. i cylinder is calculated based on the following equation:

$$Tb(i) = (TIME - TIME0) \cdot (1 + KTb(i))$$

[0081] That is, for example, when the No. 1 cylinder #1 is currently at ATDC 90°, the final elapsed time Tb(1) from ATDC 60° to ATDC 90° of the No. 1 cylinder #1 is calculated from $(TIME - TIME0) \cdot (1 + KTb(1))$. In this case as well, since the value $(1 + KTb(1))$ for correcting the error due to the spaces of the outer teeth of the rotor 14 is multiplied by $(TIME - TIME0)$, the final elapsed time Tb(1) accurately expresses the elapsed time in the cycle when the crankshaft rotates by 30° crank angle. Next, at step 114, it is judged if the No. 2 cylinder #2 is currently at ATDC 90° or not. When the No. 2 cylinder #2 is not currently at ATDC 90°, the routine for calculation of the difference of elapsed times DTa(i) and the elapsed time Tb(i) is ended.

[0082] On the other hand, when it is judged at step 107 that the No. 2 cylinder #2 is currently at ATDC 30°, the routine proceeds to step 108, where the average value TaAV_j of the elapsed times Ta(i) in the 720° crank angle range (j) shown in Fig. 15 is calculated based on the following equation:

$$TaAV_j = (Ta(1) + Ta(3) + Ta(4) + Ta(2))/4$$

[0083] Here, Ta(1), Ta(3), Ta(4), and Ta(2) correspond to Ta(1)_j, Ta(3)_j, Ta(4)_j, and Ta(2)_j in Fig. 15. Next, the routine for calculation of the correction coefficient KTa(i) of step 109 is followed. This routine is shown in Fig. 20.

[0084] Referring to Fig. 20, first, at step 120, it is judged if the fuel supply is stopped during a deceleration operation or not. When the fuel supply is not stopped during a deceleration operation, the processing cycle ends, while when the fuel is stopped during the deceleration operation, the routine proceeds to step 121. At step 121, the elapsed times AAV(4), AAV(2), AAV(1), and AAV(3) shown in Fig. 15 when assuming an increase by an average constant rate of increase are calculated as follows from the average value TaAv_j of the elapsed times Ta(i) calculated at step 108 and the average value TaAV_{j-1} of the elapsed time Ta(i) at the 720° crank angle range (j-1) of Fig. 15 calculated previously (= (Ta(1) + Ta(3) + Ta(4) + Ta(2))/4) (where Ta(1), Ta(3), Ta(4), and Ta(2) correspond to Ta(1)_{j-1}, Ta(3)_{j-1}, Ta(4)_{j-1}, and Ta(2)_{j-1} shown in Fig. 12).

$$AAV(4) = (TaAV_j - TaAV_{j-1}) \cdot (1/8) + TaAV_{j-1}$$

$$AAV(2) = (TaAV_j - TaAV_{j-1}) \cdot (3/8) + TaAV_{j-1}$$

$$AAV(1) = (TaAV_j - TaAV_{j-1}) \cdot (5/8) + TaAV_{j-1}$$

$$AAV(3) = (TaAV_j - TaAV_{j-1}) \cdot (7/8) + TaAV_{j-1}$$

[0085] Next, at step 122, the ratios of deviation KAFC(4), KAFC(2), KAFC(1), and KAFC(3) for the actually detected elapsed times TaO(4), TaO(2), TaO(1), and TaO(3) for the elapsed times AAV(4), AAV(2), AAV(1), and AAV(3) are found based on the following equations: Here, TaO(4), TaO(2), Ta(1), and Ta(3) correspond to the Ta(4)_{j-1}, Ta(2)_{j-1}, Ta(1)_j, and Ta(3)_j shown in Fig. 15.

$$KAFC(4) = (TaO(4) - AAV(4))/AAV(4)$$

$$KAFC(2) = (TaO(2) - AAV(2))/AAV(2)$$

$$KAFC(1) = (Ta(1) - AAV(1))/AAV(1)$$

$$KAFC(3) = (Ta(3) - AAV(3))/AAV(3)$$

[0086] Next, at step 123, it is judged if the conditions for learning the correction coefficient KTa(i) are satisfied or not. For example, when a predetermined time has elapsed from when the fuel supply is stopped and the engine speed is in a predetermined range and the vehicle is not driving over rough roads, for example, when the amplitude AMP of the difference of elapsed times DTa(i) shown in Fig. 16 does not exceed a set value, it is judged that the learning conditions are satisfied. When the learning conditions are not satisfied, the routine proceeds to step 128, where the cumulative count KAFCI(i) of the amount of deviation KAFC(i) is made zero. Next, at step 129, the count CKAFC is cleared.

[0087] As opposed to this, when the learning conditions are satisfied, the routine proceeds to step 124, where the amount of deviation KAFC(i) for the cylinders is added to the corresponding cumulative value KAFCI(i). Next, at step 125, the cumulative count CKAFC is incremented by exactly 1. Next, at step 126, it is judged if the cumulative count CKAFC has become "8". When the cumulative count CKAFC is not "8", the processing cycle ends, while when the cumulative count CKAFC becomes "8", the routine proceeds to step 127, where the correction coefficient KTa(i) is calculated. That is, when the amount of deviation KAFC(i) is cumulatively added eight times for each cylinder, the routine proceeds to step 127, where the correction coefficient KTa(i) is calculated.

[0088] At step 127, the correction coefficient KTa(i) is calculated in the following way. That is, first, the cumulative value KAFCI(i) is replaced by KAFCE(i). Next, the basic correction coefficient KTaB(i) is calculated based on the following equation:

$$KTaB(i) = KTa(i) - (KAFCI(i)/8)/4$$

[0089] That is, when deviation occurs from the elapsed time AAC(i) when assuming the actually detected elapsed time Ta(i) increases by an average constant rate of increase, the value of the current correction coefficient KTa(i) revised by exactly 1/4 of the average value of the cumulative value KAFCI(i) is made the basic correction coefficient KTaB(i). Next, the mean value tKTaM of the basic correction coefficient KTaB(i) for all of the cylinders is calculated based on the following equation:

$$tKTaM = (KTaB(1) + KTaB(2) + KTaB(3) + KTaB(4))/4$$

[0090] Next, the basic correction coefficient $KTaB(i)$ is revised by the average value $tKTaM$ as shown by the following equation so as to update the correction coefficient $KTa(i)$.

$$KTa(i) = KTaB(i) - tKTaM$$

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[0091] The correction coefficients $KTa(i)$ for all cylinders at the time the fuel injection is stopped during a deceleration operation are updated in this way.

[0092] On the other hand, when it is judged at step 114 of Fig. 19 that the No. 2 cylinder #2 is currently at ATDC 90°, the routine proceeds to step 115, where the same method as when finding $TaAV_j$ is used to calculate the average value

10 $TbAV_j$ of the elapsed time $Tb(i)$ in the 720° crank angle range based on the following equation:

$$TbAV_j = (Tb(1) + Tb(3) + Tb(4) + Tb(2))/4$$

[0093] Next, the routine for calculation of the correction coefficient $KTb(i)$ of step 116 is followed. This routine is shown in Fig. 21.

15

[0094] Referring to Fig. 21, first, at step 130, it is judged if the supply of fuel has been stopped during a deceleration operation. When the supply of fuel has not been stopped during a deceleration operation, the processing cycle is ended, while when the supply of fuel has been stopped during a deceleration operation, the routine proceeds to step 131. At step 131, the elapsed times $BAV(4)$, $BAV(2)$, $BAV(1)$, and $BAV(3)$ when assuming an increase by an average constant rate of increase are calculated from the average value $TbAV_j$ of the elapsed time $Tb(i)$ calculated at step 115 and the average value $TbAV_{j-1}$ of the elapsed time $Tb(i)$ in the one previous 720° crank angle range (= $(Tb(1) + Tb(3) + Tb(4) + Tb(2))/4$).

20

$$BAV(4) = (TbAV_j - TbAV_{j-1}) \cdot (1/8) + TbAV_{j-1}$$

25

$$BAV(2) = (TbAV_j - TbAV_{j-1}) \cdot (3/8) + TbAV_{j-1}$$

$$BAV(1) = (TbAV_j - TbAV_{j-1}) \cdot (5/8) + TbAV_{j-1}$$

30

$$BAV(3) = (TbAV_j - TbAV_{j-1}) \cdot (7/8) + TbAV_{j-1}$$

[0095] Next, the ratios of deviation $KBFC(4)$, $KBFC(2)$, $KBFC(1)$, and $KBFC(3)$ for the actually detected elapsed times $TbO(4)$, $TbO(2)$, $Tb(1)$, and $Tb(3)$ for the elapsed times $BAV(4)$, $BAV(2)$, $BAV(1)$, and $BAV(3)$ are found based on the following equations:

35

$$KBFC(4) = (TbO(4) - BAV(4))/BAV(4)$$

$$KBFC(2) = (TbO(2) - BAV(2))/BAV(2)$$

$$KBFC(1) = (Tb(1) - BAV(1))/BAV(1)$$

40

$$KBFC(3) = (Tb(3) - BAV(3))/BAV(3)$$

[0096] Next, at step 133, it is judged if the correction coefficient $KTb(i)$ is satisfied or not. As explained above, when a predetermined time elapses from when the fuel supply is stopped, the engine speed is within a predetermined range, and the vehicle is not driving over rough roads, for example, when the amplitude AMP of the difference of elapsed times $DTa(i)$ shown in Fig. 16 is not over the set value, it is judged that the learning conditions are satisfied. When the learning conditions are not satisfied, the routine proceeds to step 138, where the cumulative value $KBFCI(i)$ of the amount of deviation $KBFC(i)$ is made zero. Next, at step 139, the cumulative count $CKBFC$ is cleared.

45

[0097] As opposed to this, when the learning conditions are satisfied, the routine proceeds to step 134, where the amount of deviation $KBFC(i)$ with respect to the cylinders is added to the corresponding cumulative value $KBFCI(i)$, then the cumulative count $CKBFC$ is incremented by exactly 1 at step 135. Next, at step 136, it is judged if the cumulative count $CKBFC$ has become "8" or not. When the cumulative count $CKBFC$ is not "8", the processing cycle is ended. When the cumulative count $CKBFC$ has become "8", the routine proceeds to step 137, where the correction coefficient $KTb(i)$ is calculated. That is, if the amount of deviation $KBFC(i)$ is cumulatively added eight times for each cylinder, the routine proceeds to step 137, where the correction coefficient $KTb(i)$ is calculated.

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[0098] At step 137, the correction coefficient $KTb(i)$ is calculated in the following way. That is, first, the cumulative value $KBFCI(i)$ is replaced by $KBFCI(i)$. Next, the basic correction coefficient $KTbB(i)$ is calculated based on the follow-

ing equation:

$$KTbB(i) = KTb(i) - (KBFCE(i)/8)/4$$

5 **[0099]** That is, when a deviation occurs from the elapsed time BAV(i) when assuming the actually detected elapsed time Tb(i) increases by an average constant rate of increase, the value of the current correction coefficient KTb(i) revised by exactly 1/4 of the average value of the cumulative value KBFCE(i) is made the basic correction coefficient KTbB(i). Next, the average value tKTbM of the basic correction coefficients KTbB(i) for all of the cylinders is calculated based on the following equation:

10

$$tKTbM = (KTbB(1) + KTbB(2) + KTbB(3) + KTbB(4))/4$$

[0100] Next, as shown by the following equation, the basic correction coefficient KTbB(i) is revised by the average value tKTbM to update the correction coefficient KTb(i):

15

$$KTb(i) = KTbB(i) - tKTbM$$

[0101] The correction coefficients KTb(i) for all cylinders at the time the fuel injection is stopped during a deceleration operation are updated in this way.

20 **[0102]** Next, the routine for checking permission for calculation of the torque fluctuation shown in Fig. 22 to Fig. 24 will be explained referring to Fig. 25. This routine is set so as to prohibit the calculation of the amount of torque fluctuation for a specific cylinder when the amplitude AMP of the fluctuation of difference of elapsed times DTa(i) (Fig. 16) becomes large due to the vehicle traveling over a bumpy road.

25 **[0103]** That is, referring to Fig. 22 to Fig. 24, first, at step 201, whether one of the cylinders is currently at ATDC 30° or not is judged. When none of the cylinders is currently at ATDC 30°, the processing cycle is ended, while when one of the cylinders is at ATDC 30°, the routine proceeds to step 202.

30 **[0104]** At step 202 to step 204, the maximum difference of elapsed times DT30max when the difference of elapsed times DTa(i) increases and then decreases is calculated. That is, at step 202, whether the DTa(i) calculated at step 106 of Fig. 18 is larger than the maximum difference of elapsed times DT30max or not is judged. When DT30max > DTa(i), the routine jumps to step 205, while when DT30max ≤ DTa(i), the routine proceeds to step 203, where DTa(i) is made DT30max. Next, at step 204, the increase flag XMXREC showing that DTa(i) is increasing is set (XMXREC ← "1"), then the routine proceeds to step 205.

35 **[0105]** At step 205 to step 207, the minimum difference of elapsed times DT30min when the difference of elapsed time DTa(i) decreases and then increases is calculated. That is, at step 205, it is judged whether the DTa(i) calculated at step 106 of Fig. 18 is smaller than the minimum difference of elapsed times DT30min or not. When DT30min < DTa(i), the routine jumps to step 208, while when DT30min ≥ DTa(i), the routine proceeds to step 206, where DTa(i) is made DT30min. Next, at step 207, the decrease flag XMNREC showing that DTa(i) has decreased is set (XMNREC ← "1"), then the routine proceeds to step 208.

40 **[0106]** At step 208 to step 214, when the amplitude AMP of the fluctuation of DTa(i) (Fig. 16) has exceeded the set value A₀, the prohibit flag prohibiting the calculation of the amount of torque fluctuation for the cylinder giving the maximum DTa(i) is set. That is, at step 208, it is judged whether DT30max > DTa(i) and XMXREC = "1" or not. When DT30max ≤ DTa(i) or the increase flag XMXREC is reset (XMXREC = "0"), the routine jumps to step 215, while when DT30max > DTa(i) and XMXREC = "1", the routine proceeds to step 209.

45 **[0107]** That is, as shown in Fig. 25 at the time t₁, the difference of the elapsed times DTa(1) of the No. 1 cylinder #1 has become maximum. In this case, in the interruption routine performed at the time t₁, the routine proceeds to step 202 to step 203, where the DTa(1) is made DT30max, then, at step 204, the maximum flag XMXREC is set. On the other hand, in the interruption routine performed at the time t₂ of Fig. 25, the routine jumps to step 202 to step 205. At this time, since it is judged at step 208 that DT30max > DTa(3) and XMXREC = "1", the routine proceeds to step 209. That is, the routine proceeds to step 209 at the time t₂ when the elapsed time DTa(i) starts to decrease.

50 **[0108]** At step 209, the maximum difference of elapsed times DT30max is made TMXREC. Next, at step 210, the minimum difference of elapsed times TMNREC (found at the later explained step 216) is subtracted from the maximum difference of elapsed times TMXREC so as to calculate the amplitude AMP of the fluctuation of DTa(i). Next, at step 211, the initial value of the minimum difference of elapsed times DT30min is made DTa(i). Next, at step 212, the increase flag XMXREC is reset (XMXREC ← "0"). Next, at step 213, whether the amplitude AMP is larger than the set value A₀ or not is judged. When AMP < A₀, the routine jumps to step 215. As opposed to this, when AMP ≥ A₀, the routine proceeds to step 214, where the torque fluctuation calculation prohibition flag XNOCAL is set (XNOCAL ← "1"). That is, in the interruption routine performed at the time t₂ of Fig. 25 as explained above, the amount of torque fluctuation of the No. 1 cylinder #1 is calculated. Therefore, in this interruption routine, when AMP ≥ A₀ and the torque fluctuation calcu-

lation prohibition flag XNOCAL is set, the calculation of the amount of torque fluctuation of the No. 1 cylinder #1, that is, the calculation of the amount of torque fluctuation of the cylinder giving the maximum DTa(i), is prohibited.

[0109] At step 215 to step 221, when the amplitude AMP of the fluctuation of DTa(i) has exceeded the set value A₀, the prohibition flag prohibiting the calculation of the amount of torque fluctuation of the cylinder giving the minimum DTa(i) is set. That is, at step 215, it is judged whether DT30min < DTa(i) and XMNREC = "1" or not. When DT30min ≥ DTa(i) or the decrease flag XMNREC is reset (XMNREC = "0"), the routine jumps to step 222, while when DT30min < DTa(i) and XMNREC = "1", the routine proceeds to step 216.

[0110] That is, as shown in Fig. 25 at the time t₃, the difference of elapsed times DTa(1) of the No. 1 cylinder #1 is considered to have become the minimum. In this case, at the interruption routine performed at the time t₃, the routine proceeds to step 205 to step 206, where the DTa(1) is made DT30min, then at step 207, the decrease flag XMNREC is set. On the other hand, the interruption routine performed at the time t₄ of Fig. 25 jumps from step 205 to step 208. At this time, since it is judged at step 215 that DT30min < DTa(3) and XMNREC = "1", the routine proceeds to step 216. That is, the routine proceeds to step 216 at the time t₄ where the difference of elapsed times DTa(i) starts to be increased.

[0111] At step 216, the minimum difference of elapsed times DT30min is made TMNREC. Next, at step 217, the minimum difference of elapsed times TMNREC is subtracted from the maximum difference of elapsed times TMXREC whereby the amplitude AMP of the fluctuation of DTa(i) is calculated. Next, at step 218, the initial value of the maximum difference of elapsed times DT30max is made DTa(i). Next, at step 219, the decrease flag XMNREC is reset (XMNREC ← "0"). Next, at step 220, it is judged whether the amplitude AMP is larger than the set value A₀ or not. When AMP < A₀, the routine jumps to step 222. As opposed to this, when AMP ≥ A₀, the routine proceeds to step 221, where the torque fluctuation calculation prohibition flag XNOCAL is set (XNOCAL ← "1"). That is, in the interruption routine performed at the time t₄ of Fig. 25, the amount of torque fluctuation of the No. 1 cylinder #1 is calculated. Therefore, in this interruption routine, when AMP ≥ A₀ and the torque calculation prohibition flag XNOCAL is set, the calculation of the amount of torque fluctuation of the No. 1 cylinder #1, that is, the calculation of the amount of torque fluctuation of the cylinder where DTa(i) becomes smallest, is prohibited.

[0112] At step 222 and step 223, the calculation of the amount of torque fluctuation of a cylinder where the elapsed time DTa(i) changes sharply is prohibited. That is, at step 222, whether |DTa(i-2) - DTa(i-1)| is larger than K₀ · |DTa(i-1) - DTa(i)| or not is judged. Here, the constant K₀ is a value of about 3.0 to 4.0. When it is judged at step 222 that |DTa(i-2) - DTa(i-1)| < K₀ · |DTa(i-1) - DTa(i)|, the processing routine is ended, while when it is judged that |DTa(i-2) - DTa(i-1)| ≥ K₀ · |DTa(i-1) - DTa(i)|, the routine proceeds to step 223, where the torque fluctuation calculation prohibition flag XNOCAL is set.

[0113] That is, when the interruption routine is at the time t₃ of Fig. 25, whether at this time |DTa(4) - DTa(2)| ≥ K₀ · |DTa(2) - DTa(1)| or not is judged. As shown in Fig. 25, when DTa(2) changes rapidly from DTa(4), |DTa(4) - DTa(2)| becomes larger than K₀ · |DTa(2) - DTa(1)|. At this time, the torque fluctuation calculation prohibition flag is set and the calculation of the amount of torque fluctuation of the No. 2 cylinder #2 where the elapsed time DTa(i) has changed sharply is prohibited.

[0114] Next, the torque fluctuation calculation routine shown in Fig. 26 will be explained. Referring to Fig. 26, first, at step 301, whether the flag XCAL(i-1) showing that the amount of torque fluctuation of the No. (i-1) cylinder where combustion had been performed one time before should be calculated is set or not is judged. When the flag XCAL(i-1) = "0", that is, when the flag XCAL(i-1) is not set, the processing cycle is ended. As opposed to this, when the flag XCAL(i-1) = "1", that is, the flag XCAL(i-1) is set, the routine proceeds to step 302, where the flag XCAL(i-1) is reset, then the routine proceeds to step 303.

[0115] At step 303, whether the prohibition flag XNOCAL prohibiting the calculation of the amount of torque fluctuation for the cylinder at which the combustion was performed one time before is reset (XNOCAL = "0") or not is judged. When this prohibition flag is set (XNOCAL = "1"), the routine proceeds to step 313, where the prohibition flag XNOCAL is reset. As opposed to this, when the prohibition flag is reset, the routine proceeds to step 304. That is, only when the flag XCAL is set and the prohibition flag XNOCAL is reset, the routine proceeds to step 304.

[0116] At step 304, the assumed difference of elapsed times Kb(i-1) of the No. (i-1) cylinder where the combustion was performed one time before (see Fig. 10 and Fig. 11) is calculated based on the following equation:

$$Kb(i-1) = \{2 \cdot DTa(i-1) + DTa(i)\}/3$$

[0117] Next, at step 305, the actual output torque DN(i-1) of the No. (i-1) cylinder where combustion was performed one time before is calculated based on the following equation:

$$DN(i-1) = \{30^\circ/Tb(i-1)\}^2 - \{30^\circ/Ta(i-1)\}^2$$

[0118] Next, at step 306, the assumed output torque DNS(i-1) of the No. (i-1) cylinder where combustion had been

performed one time before is calculated based on the following equation:

$$DNS(i-1) = \{30^\circ / (TbO(i-1) + Kb(i-1))\}^2 - \{30^\circ / Ta(i-1)\}^2$$

5 [0119] Next, at step 307, as shown in the following equation, the actual output torque DN(i-1) is subtracted from the assumed output torque DNS(i-1) to calculate the basic amount of torque fluctuation DLNB(i-1) of the No. (i-1) cylinder where combustion had been performed one time before.

$$DLNB(i-1) = DNS(i-1) - DN(i-1)$$

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[0120] Next, at step 308, the set value KDLN is found from the average of the engine speed NAVE (step 409 in Fig. 27) using the map shown in Fig. 13. Next, at step 309, as shown in the following equation, the set value KDLN is subtracted from the basic amount of torque fluctuation DLNB(i-1) to calculate the amount of torque fluctuation DLN(i-1) of the No. (i-1) cylinder where combustion had been performed one time before.

15

$$DLN(i-1) = DLNB(i-1) - KDLN$$

[0121] That is, for example, when the No. 3 cylinder #3 is at ATDC 30° and the flag XCAL(1) is set, the difference of elapsed times Kb(1) for the No. 1 cylinder #1 is calculated at step 304, then the actual output torque DN(1) of the No. 1 cylinder #1 is calculated at step 305, the assumed output torque DNS(1) of the No. 1 cylinder #1 is calculated at step 306, then the basic amount of torque fluctuation DLNB(1) of the No. 1 cylinder #1 is calculated at step 307, then the set value KDLN is calculated at step 308, and then the amount of torque fluctuation DLN(1) of the No. 1 cylinder #1 is calculated at step 309.

20

[0122] Note that when finding the amount of output fluctuation GLN(i-1) of the cylinders, the following calculation may be performed from step 305 to step 309.

25

[0123] That is, at step 305, instead of finding the actual amount of torque fluctuation DN(i-1), the actual amount of output fluctuation GN(i-1) is calculated based on the following equation:

$$GN(i-1) = \{30^\circ / Tb(i-1)\} - \{30^\circ / Ta(i-1)\}$$

30

[0124] Next, at step 306, instead of finding the assumed amount of torque fluctuation DNS(i-1), the assumed amount of output fluctuation GNS(i-1) is calculated based on the following equation:

$$GNS(i-1) = \{30^\circ / (TbO(i-1) + Kb(i-1))\} - \{30^\circ / Ta(i-1)\}$$

35

[0125] Next, at step 307, instead of finding the basic amount of torque fluctuation DLNB(i-1), the basic amount of output fluctuation GLNB(i-1) is calculated based on the following equation;

$$GLNB(i-1) = GNS(i-1) - GN(i-1)$$

40

[0126] Next, at step 308, instead of finding the set value KDLN for the amount of torque fluctuation, the set value KGLN for the amount of output fluctuation is found. The set value KGLN represents the amount of increase of the amount of output fluctuation due to the higher component of the torsional vibration of the engine drive system and the torsional vibration of the crankshaft itself. The set value KGLN is found by experiments and is stored in the ROM 22 in advance.

45

[0127] Next, when the amount of torque fluctuation DLN(i-1) is calculated at step 309, the routine proceeds to step 310, where it is judged whether the amount of torque fluctuation DLN(i-1) is positive or not. When DLN(i-1) ≥ 0, the routine jumps to step 312, where the cumulative addition request flag XCDLN(i-1) showing that the amount of torque fluctuation DLN(i-1) of the cylinder at which the combustion was performed one time before should be cumulatively added is set (XCDLN(i-1) ← "1"). As opposed to this, when DLN(i-1) < 0, the routine proceeds to step 311, where DLN(i-1) is made zero, then the routine proceeds to step 312. Note that, the torque of each cylinder repeatedly rises and falls, so in this case, to find the amount of torque fluctuation, it is sufficient to cumulatively add either the amount of increase of the torque or the amount of decrease of the torque. In the routine shown in Fig. 26, just the amount of decrease of the torque is cumulatively added, therefore, as explained above, when DLN(i-1) < 0, DLN(i-1) is made zero.

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[0128] Next, the processing of the counter CDLNIX will be explained referring to Fig. 27. The count value of the counter CDLNIX is used for the later explained calculation of the torque fluctuation value of the engine.

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[0129] Referring to Fig. 27, first, at step 401, whether the No. 3 cylinder #3 is currently at ATDC 30° or not is judged. When the No. 3 cylinder #3 is currently not at ATDC 30°, the processing cycle is ended, while when the No. 3 cylinder

#3 is currently at ATDC 30°, the routine proceeds to step 402. At step 402, whether the conditions for calculating the torque fluctuation value are satisfied or not is judged. For example, when the conditions for making the air-fuel ratio lean are not satisfied or the amount of change per unit time $\Delta Q/N$ of the engine load Q/N is more than the set value or the amount of change per unit time ΔN of the engine speed is more than a set value, it is judged that the conditions for calculating the torque fluctuation value are not satisfied, while at other times it is judged that the conditions for calculating the torque fluctuation value are satisfied.

[0130] When it is judged at step 402 that the conditions for calculating the torque fluctuation value are satisfied, the routine proceeds to step 408, where the count value CDLNIX is incremented by exactly 1. The increment action of this count value CDLNIX is performed every time the No. 3 cylinder #3 reaches ATDC 30°, that is, every 720° crank angle. Next, at step 409, the average value of the engine speed N_{AVE} and the average value Q_{AVE} of the amount of intake air Q in the cycle, from when the increment action of the count value CDLNIX is started to when the count value CDLNIX is cleared, are calculated.

[0131] On the other hand, when it is judged at step 402 that the conditions for calculating the torque fluctuation value are not satisfied, the routine proceeds to step 403, where the count value CDLNIX is cleared. Next, at step 404, the cumulative value DLNI(i) of the torque fluctuation value DLN(i) for each cylinder (this cumulative value is calculated by the later explained routine) is cleared. Next, at step 405, the cumulative count value CDLNI(i) for each cylinder (this cumulative count value is calculated by the later explained routine) is cleared.

[0132] Next, at step 406, the target torque fluctuation value LVLLFB is calculated. In this embodiment according to the present invention, as explained later, the air-fuel ratio is feedback controlled so that the calculated torque fluctuation value becomes this target torque fluctuation value LVLLFB. This target torque fluctuation value LVLLFB, as shown by Fig. 29A showing the equivalent fluctuation value by the solid line, becomes larger the higher the engine load Q/N and becomes larger the higher the engine speed N . This target torque fluctuation value LVLLFB is stored in the ROM 22 in advance in the form of a map shown in Fig. 29B as a function of the engine load Q/N and the engine speed N . Next, at step 407, the torque fluctuation value DLNISM(i) of each cylinder (this torque fluctuation value is calculated by the later explained routine) is made the target torque fluctuation value LVLLFB calculated from the map of Fig. 29B.

[0133] Figure 31 shows the repeatedly executed main routine. In this main routine, first the routine for calculation of the torque fluctuation value (step 600) is executed. This routine is shown in Fig. 32 and Fig. 33. Next, the routine for calculation of the lean limit feedback correction coefficient FLLFB (step 700) is executed. This routine is shown in Fig. 34. Next, when the predetermined crank angle is reached, the routine for calculation of the fuel injection time (step 800) is executed. This routine is shown in Fig. 35. Next, the other routines (step 900) are executed.

[0134] Next, the routine for calculation of the torque fluctuation value shown in Fig. 32 and Fig. 33 will be explained.

[0135] Referring to Fig. 32 and Fig. 33, first, at step 601, whether the cumulative addition request flag XDLN(i) showing that the amount of torque fluctuation DLN(i) should be cumulatively added is set ($XDLN(i) = "1"$) or not is judged. When the cumulative addition request flag XDLN(i) is not set, the routine jumps to step 609, while when the cumulative addition request flag XDLN(i) is set, the routine proceeds to step 602. At step 602, the cumulative addition request flag XDLN(i) is reset. Next, at step 603, the amount of torque fluctuation DLN(i) is added to the cumulative value DLNI(i) of the amount of torque fluctuation. Next, at step 604, the cumulative count value CDLNI(i) is incremented by exactly 1. That is, for example, at step 601, if the cumulative addition request flag CDLN(1) is set for the No. 1 cylinder, this flag XDLN(1) is reset at step 602, then the cumulative value DLNI(1) of the amount of torque fluctuation is calculated at step 603, and the cumulative count value CDLNI(1) is incremented by exactly 1 at step 604.

[0136] Next, at step 605, whether the cumulative count value CDLNI(i) has become "8" or not is judged. When CDLNI(i) is not "8", the routine jumps to step 609, while when CDLNI(i) becomes "8", the routine proceeds to step 606, where the torque fluctuation value DLNISM(i) of the cylinders is calculated from the following equation:

$$DLNISM(i) = DLNISM(i) + \{DLNI(i) - DLNISM(i)\}/4$$

[0137] Next, at step 607, the cumulative value DLNI(i) of the amount of torque fluctuation for the cylinders is cleared. Next, at step 608, the cumulative count value CDLNI(i) is reset.

[0138] That is, when there is a difference between the calculated cumulative value DLNI(i) of the amount of torque fluctuation and the previously used amount of torque fluctuation DLNISM(i), the value of the difference $\{DLNI(i) - DLNISM(i)\}$ multiplied by 1/4 is added to the amount of torque fluctuation DLNISM(i). Therefore, for example, when the cumulative count value CDLNI(1) for the No. 1 cylinder #1 becomes "8", at step 606, the torque fluctuation value DLNISM(1) is calculated.

[0139] Next, at step 609, whether the count value CDLNIX calculated at the routine shown in Fig. 27 has become "8" or not is judged. When CDLNIX is not "8", the processing cycle is ended, while when CDLNIX becomes "8", the routine proceeds to step 610, where the mean value DLNISM (= $\{DLNISM(1) + DLNISM(2) + DLNISM(3) + DLNISM(4)\}/4$) of the mean torque fluctuation values DLNISM (i) of the cylinders is calculated. Next, at step 611 the count value CDLNIX is cleared. In this way, the value DLNISM expressing the amount of torque fluctuation of the engine is calculated.

[0140] Note that, as explained above, the count value CDLNIX is incremented by exactly 1 with each 720° crank angle. Unless the calculation of the torque is prohibited for one of the cylinders, when the count value CDLNIX has become "8", the cumulative count values CDLNI(1), CDLNI(2), CDLNI(3), and CDLNI(4) for all of the cylinders have already become "8". Therefore, in this case, the torque fluctuation value DLNISM(i) for all of the cylinders is calculated. On the other hand, for example, if the calculation of the amount of torque fluctuation for the No. 1 cylinder #1 is prohibited, when the count value CDLNIX has become "8", just the cumulative count value CDLNI(1) of the No. 1 cylinder #1 does not become "8", so the new cumulative value DLNI(1) of the amount of torque fluctuation for the No. 1 cylinder #1 is not calculated. Therefore, in this case, when finding the mean torque fluctuation value DLNISM at step 610, the previously calculated torque fluctuation value DLNISM(1) is used just for the No. 1 cylinder #1.

[0141] Next, the routine for calculation of FLLFB will be explained referring to Fig. 34.

[0142] Referring to Fig. 34, first, at step 701, whether the conditions for updating the lean limit feedback correction coefficient FLLFB are satisfied or not is judged. For example, at the time of engine warmup or when the operating state of the engine is not in the learning region enclosed by the broken lines in Fig. 5, it is judged that the conditions for updating are not satisfied, while at other times it is judged that the conditions for updating are satisfied. When the conditions for updating are not satisfied, the processing cycle is ended, while when the conditions for updating are satisfied, the routine proceeds to step 702.

[0143] At step 702, the target torque fluctuation value LVLLFB is calculated from the engine load Q/N and the engine speed N based on the map shown in Fig. 29B. Next, at step 703 and step 704, the levels of torque fluctuation LVLH(n) and LVLL(n) shown in the following equations are calculated based on the fluctuation amount judgement values DH(n) and DL(n) in accordance with the target torque fluctuation value LVLLFB:

$$LVLH(n) = LVLLFB + DH(n)$$

$$LVLL(n) = LVLLFB + DL(n)$$

[0144] Here, the fluctuation amount judgement values DH(n) and DL(n) are determined in advance as shown in Fig. 30A. That is, as will be understood from Fig. 30A, three positive values are set for DH(n) which are in the relationship of $DH(3) > DH(2) > DH(1)$. Further, these DH(1), DH(2), and DH(3) gradually increase as the target torque fluctuation value LVLLFB becomes larger. On the other hand, three negative values are set for DL(n) which are in the relationship of $DL(1) > DL(2) > DL(3)$. Further, the absolute values of these DL(1), DL(2), and DL(3) gradually increase as the target torque fluctuation value LVLLFB becomes larger.

[0145] Assume, however, that the target torque fluctuation value LVLLFB calculated at step 702 is the value shown by the broken line. In this case, at step 703, the values of DH(1), DH(2), and DH(3) on the broken line plus the target torque fluctuation value LVLLFB are made the levels of torque fluctuation LVLH(1), LVLH(2), and LVLH(3) and, at step 704, the values of DL(1), DL(2), and DL(3) on the broken line plus the target torque fluctuation value LVLLFB are made the levels of torque fluctuation LVLL(1), LVLL(2), and LVLL(3).

[0146] On the other hand, the feedback correction values $+a_1, +a_2, +a_3, +a_4, -b_1, -b_2, -b_3,$ and $-b_4$ are determined in advance for the regions between the levels of torque fluctuation LVLH(n) and LVLL(n) as shown in Fig. 30B. For example, the feedback correction value becomes $+a_2$ for the region where the level of torque fluctuation is between LVLH(1) and LVLH(2). These feedback correction values are $+a_4 > +a_3 > +a_2 > +a_1$ and $-b_1 > -b_2 > -b_3 > -b_4$. The feedback correction values $+a_1, +a_2, +a_3, +a_4, -b_1, -b_2, -b_3$ and $-b_4$ shown in Fig. 30B are shown in the corresponding regions of Fig. 30A.

[0147] When the levels of torque fluctuation LVLH(n) and LVLL(n) are calculated at step 703 and step 704, the routine proceeds to step 705, where whether the mean torque fluctuation value DLNISM calculated in the routine for calculation of the torque fluctuation value shown in Fig. 32 and Fig. 33 is between the levels of torque fluctuation LVLH(n) and LVLL(n) shown in Fig. 30B or not is judged. Next, at step 706, the corresponding feedback correction value DLFB is calculated. For example, when the target fluctuation level LVLLFB is the value shown by the broken line in Fig. 30A and the calculated mean torque fluctuation value DLNISM is between LVLH(1) and LVLH(2) of Fig. 30B, that is, the deviation of the mean torque fluctuation value DLNISM from the target fluctuation level LVLLFB is between DH(1) and DH(2) on the broken line in Fig. 50A, the feedback correction value DLFB is made $+a_2$.

[0148] Next, at step 707, it is determined what lean limit feedback correction coefficient of which learning region shown in Fig. 5 the lean limit feedback correction coefficient FLLFB_i is to be updated based on the average value of the engine speed N_{AVE} and the average value Q_{AVE} of the amount of intake air Q found at step 409 of the processing routine of CDLNIX shown in Fig. 27. Next, at step 708, the lean limit feedback correction coefficient FLLFB_i determined at step 707 is increased by the feedback correction value DLFB.

[0149] That is, as explained above, when, for example, $DLNISM > LVLLFB$ and $LVLH(1) < DLNISM < LVLH(2)$, the lean limit feedback correction coefficient FLLFB_i is increased by $+a_2$. As a result, the air-fuel ratio becomes smaller, so the amount of torque fluctuation of each cylinder is reduced. On the other hand, when $DLNISM < LVLLFB$ and $LVLL(1)$

> DLNISM > LVLL(2), the lean limit feedback correction coefficient $FLLFB_{ij}$ is increased by $-b_2$. As a result, the air-fuel ratio becomes large, so the amount of torque fluctuation of the cylinders is increased. In this way the air-fuel ratio at the time of lean operation is controlled so that the mean torque fluctuation value DLNISM of all of the cylinders becomes the target torque fluctuation value LVLLFB.

5 [0150] Note that, when the conditions for calculation of the torque fluctuation value in the routine shown in Fig. 27 are not satisfied, at step 407, the DLNISM(i) for all of the cylinders is made LVLLFB and therefore the mean torque fluctuation value DLNISM is also made the target torque fluctuation value LVLLFB. Therefore, at this time, the lean limit feedback correction coefficient $FLLFB_{ij}$ is not updated.

[0151] Next, the routine for calculation of the fuel injection time will be explained with reference to Fig. 35.

10 [0152] Referring to Fig. 35, first, at step 801, the basic fuel injection time TP is calculated from the map shown in Fig. 2. Next, at step 802, whether the operating state is one in which a lean operation should be performed or not is judged. When the operating state is one in which a lean operation should be performed, the routine proceeds to step 803, where the value of the stoichiometric air-fuel ratio feedback correction coefficient FAF is fixed at 1.0. Next, at step 804, the lean correction coefficient FLEAN is calculated from the map shown in Fig. 4, then at step 805, the lean limit feedback correction coefficient FLLFB is read from the map shown in Fig. 5. Next, at step 809, the fuel injection time TAU is calculated from the following equation:

$$TAU = TP \cdot FLEAN \cdot FLLFB \cdot FAF + TAUV$$

20 [0153] As opposed to this, when it is judged at step 802 that the operating state is not one where a lean operation should be performed, that is, when the air-fuel ratio should be made the stoichiometric air-fuel ratio, the routine proceeds to step 806, where the lean correction coefficient FLEAN is fixed at 1.0, then, at step 807, the lean limit feedback correction coefficient FLLFB is fixed at 1.0. Next, at step 808, the stoichiometric air-fuel ratio feedback correction coefficient FAF is controlled based on the output signal of the air-fuel ratio sensor 17 so that the air-fuel ratio becomes the stoichiometric air-fuel ratio. Next, the routine proceeds to step 809, where the fuel injection time TAU is calculated.

25 [0154] Note that, to find the true output fluctuation or torque fluctuation of the engine, it is possible to correct the torsional vibration of the engine drive system or crankshaft itself or the effects of the variation of the spaces between the outer teeth of the rotor 14 in any way.

[0155] In this way, according to the present invention, it becomes possible to ensure the controllability of the air-fuel ratio regardless of the engine speed.

30 [0156] While the invention has been described by reference to specific embodiments chosen for purposes of illustration, it should be apparent that numerous modifications could be made thereto by those skilled in the art without departing from the basic concept and scope of the invention.

35 **Claims**

1. A method of control of an air-fuel ratio in an engine, characterized in that the method comprises the steps of
 - 40 setting a first crank angle range in a crank angle region from the end of a compression stroke to the beginning of an expansion stroke,
 - detecting a first angular velocity of the crankshaft in the first crank angle range,
 - setting a second crank angle range in a crank angle region in the middle of the expansion stroke a predetermined crank angle away from the first crank angle range,
 - 45 detecting a second angular velocity of the crankshaft in the second crank angle range,
 - finding the basic output fluctuation of the cylinders based on the first angular velocity and the second angular velocity,
 - finding a set value based on the engine speed,
 - finding the output fluctuation of the cylinders by correcting the basic output fluctuation of the cylinders based on the set value, and
 - 50 correcting the air-fuel ratio based on the output fluctuation.
2. A method as set forth in claim 1, characterized in that the output fluctuation are found by subtracting the set value from the basic output fluctuation.
- 55 3. A method as set forth in claim 1, characterized in that the set value becomes larger when the engine speed becomes higher.
4. A method as set forth in claim 1, characterized in that the set value is predetermined and stored in a memory device

in advance.

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5. A method as set forth in claim 1, characterized in that the set value represents an error in detecting the first angular velocity and the second angular velocity of the crankshaft.
 6. A method as set forth in claim 1, characterized in that the average value of the output fluctuation is found and the air-fuel ratio is corrected based on the average value of the output fluctuation.
 7. A method as set forth in claim 6, characterized in that the air-fuel ratio is corrected so that the average value of the output fluctuation is in a predetermined range.
 8. A method as set forth in claim 1, characterized in that the amount of basic output torque fluctuation of the engine is found from the first angular velocity and the second angular velocity, the amount of output torque fluctuation of the engine is found by subtracting the set value from the amount of basic output torque fluctuation, and the air-fuel ratio is corrected based on the amount of output torque fluctuation.
 9. A method as set forth in claim 8, characterized in that the set value represents the deviation of the basic amount of output torque fluctuation from the true amount of output torque fluctuation due to the torsional vibration of the engine drive system and the crankshaft itself.
 10. A method as set forth in claim 8, characterized in that the air-fuel ratio is corrected so that the amount of output torque fluctuation is in a predetermined range.
 11. A method as set forth in claim 10, characterized in that the set value is predetermined so that the amount of output torque fluctuation is almost constant when the true amount of output torque fluctuation is at approximately middle of the predetermined range, regardless of the engine speed.
 12. A method as set forth in claim 1, characterized in that combustion is performed at a first cylinder and then combustion is performed at a second cylinder, the amount of change between the first angular velocity at the time of a previous combustion and the first angular velocity at the time of a next combustion for the first cylinder is found, the amount of change between the first angular velocity at the time of a previous combustion and the first angular velocity at the time of a next combustion for the second cylinder is found, an assumed second angular velocity at the time of the next combustion of the first cylinder assuming that the output of the first cylinder does not fluctuate is found based on the amount of change of the first angular velocity of the first cylinder, the amount of change of the first angular velocity of the second cylinder, and the second angular velocity at the time of the previous combustion of the first cylinder, and the output fluctuation of the first cylinder is found based on the actual second angular velocity at the time of the next combustion of the first cylinder and the assumed second angular velocity.
 13. A method as set forth in claim 12, characterized in that the amount of basic output torque fluctuation of the first cylinder is found from the difference between a square of the actual second angular velocity and a square of the assumed second angular velocity, a amount of basic output torque fluctuation is found for each cylinder, the amount of output torque fluctuation of the cylinders is found by subtracting the set value from the amount of basic output torque fluctuation for each cylinder, the amount of output torque fluctuation of the engine is found from the amounts of output torque fluctuation of the cylinders, and the air-fuel ratio is corrected based on the amount of output torque fluctuation.

Fig.1

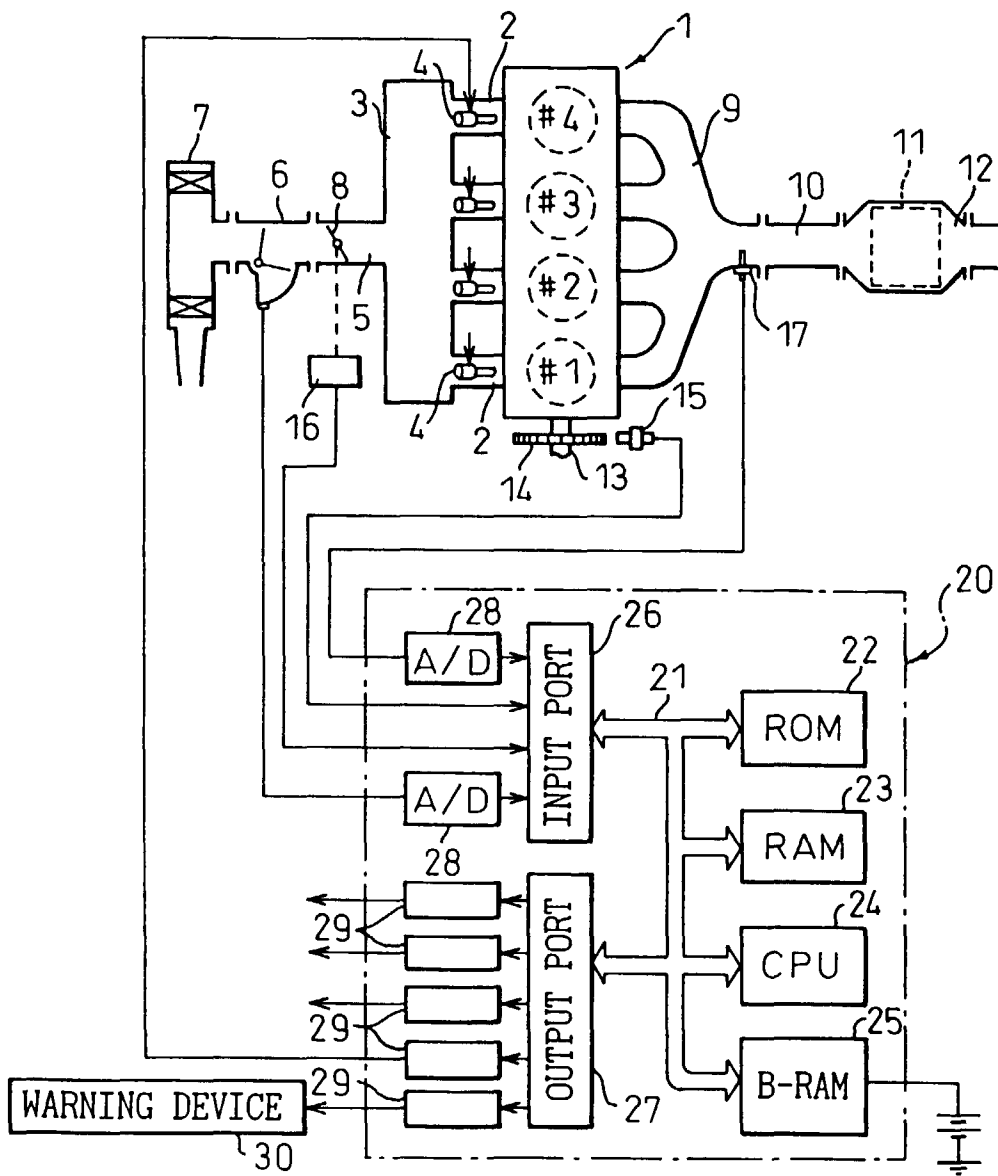


Fig. 2

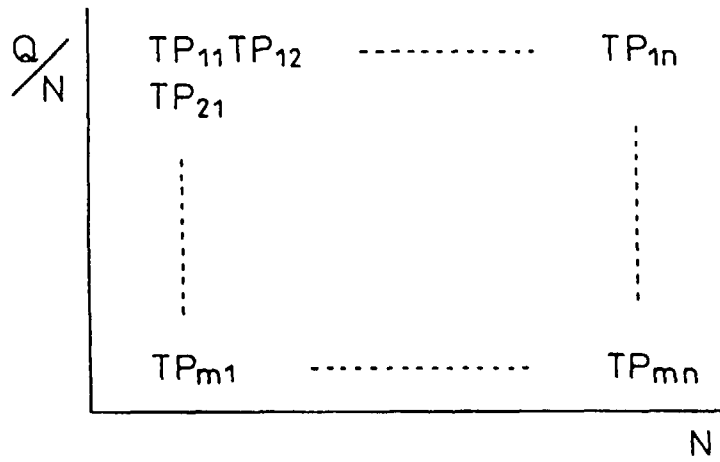


Fig. 3

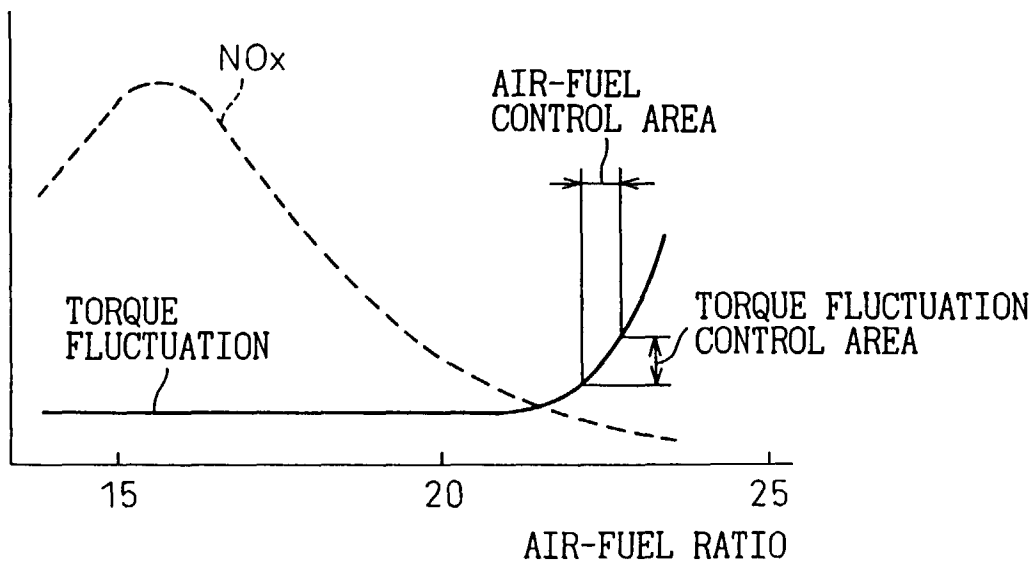


Fig. 4

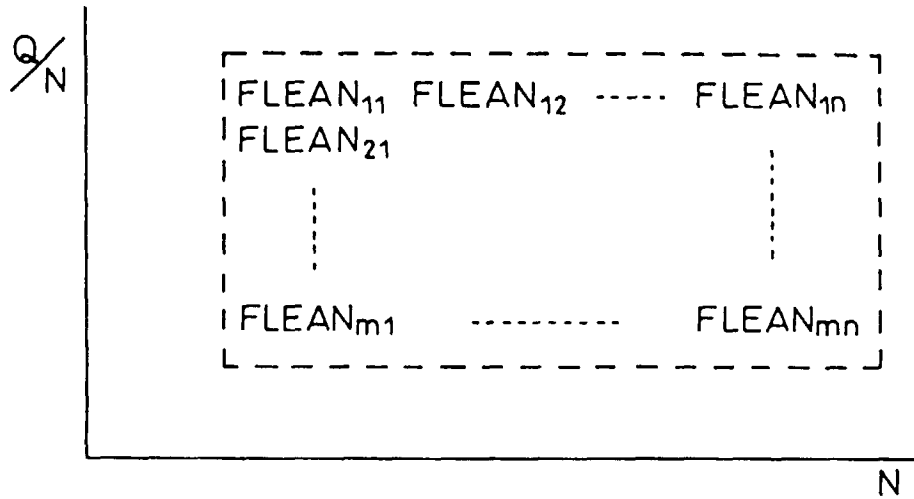


Fig. 5

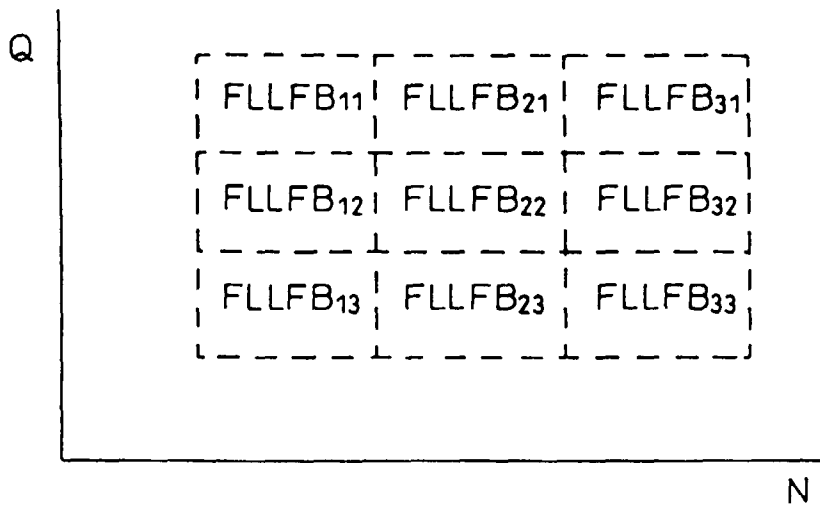


Fig. 6A

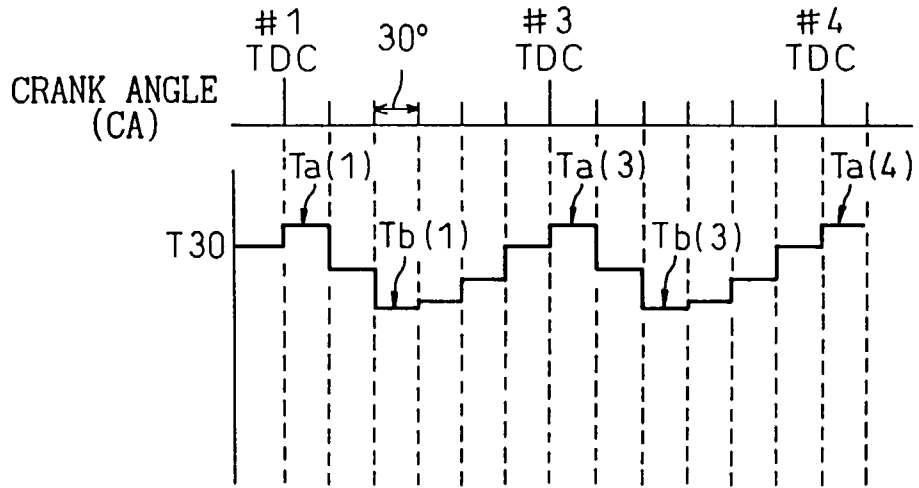


Fig. 6B

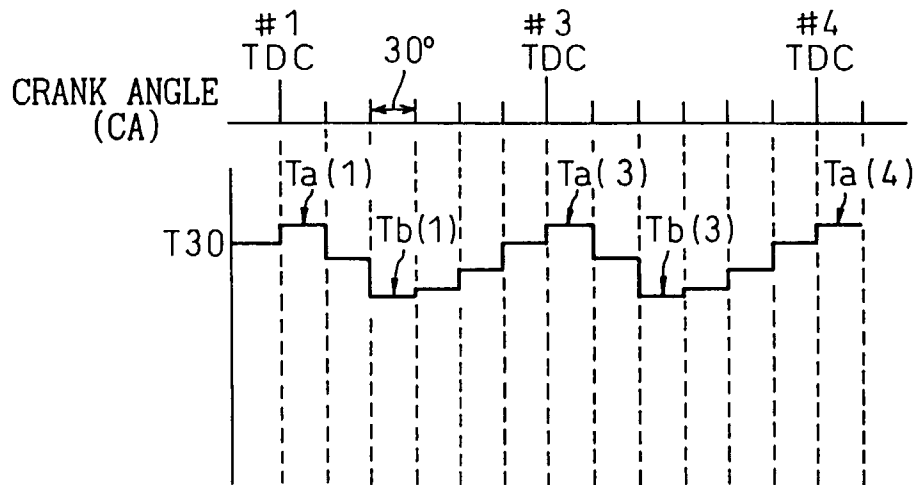


Fig.7



Fig.8

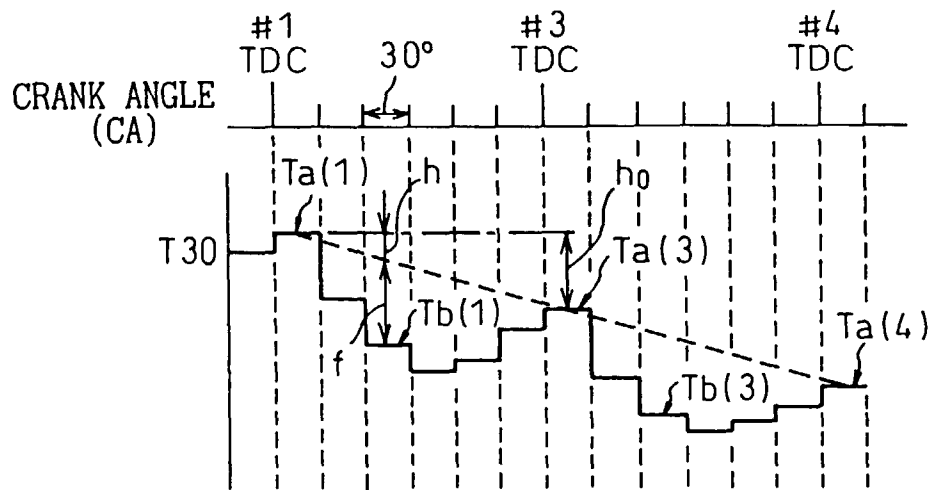


Fig. 9

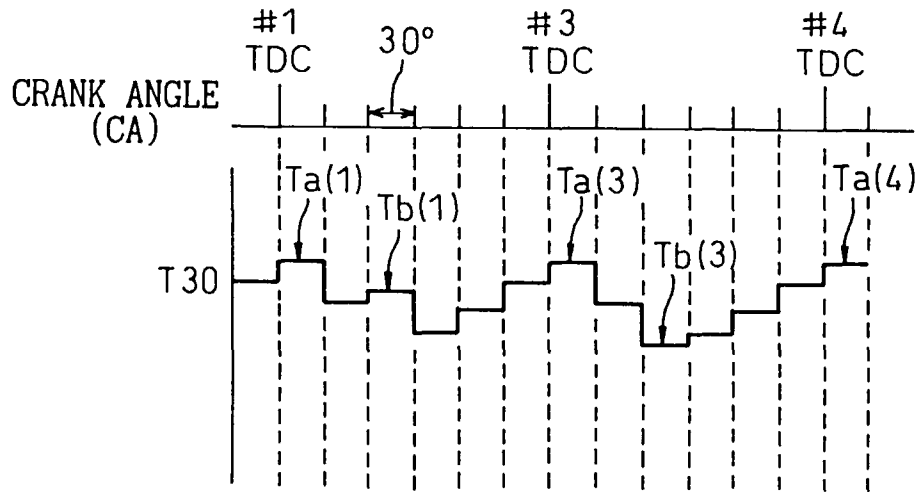


Fig.10

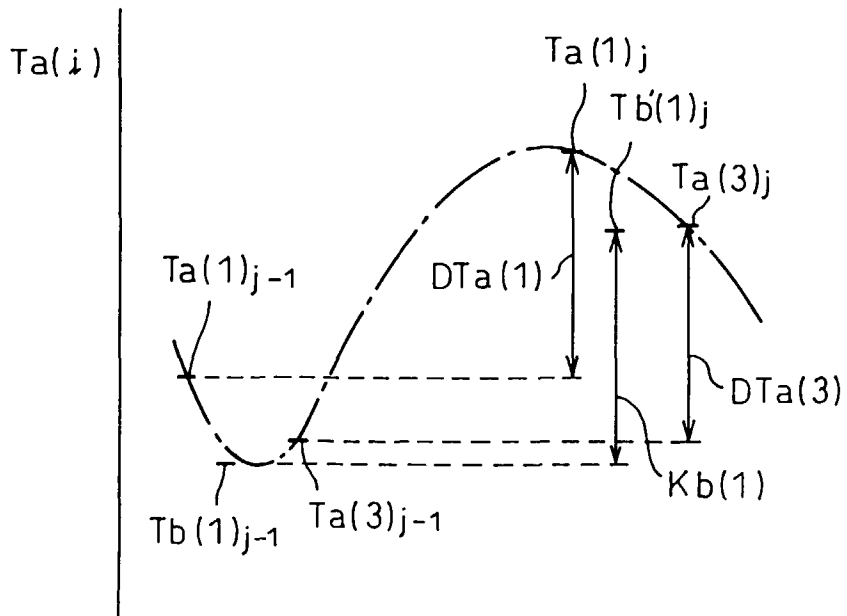


Fig. 11

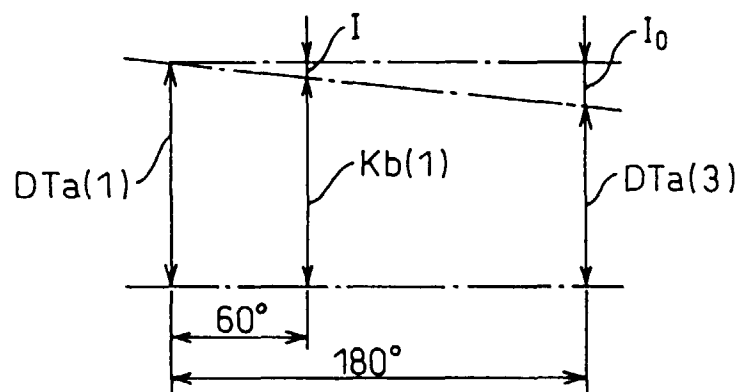


Fig.12A

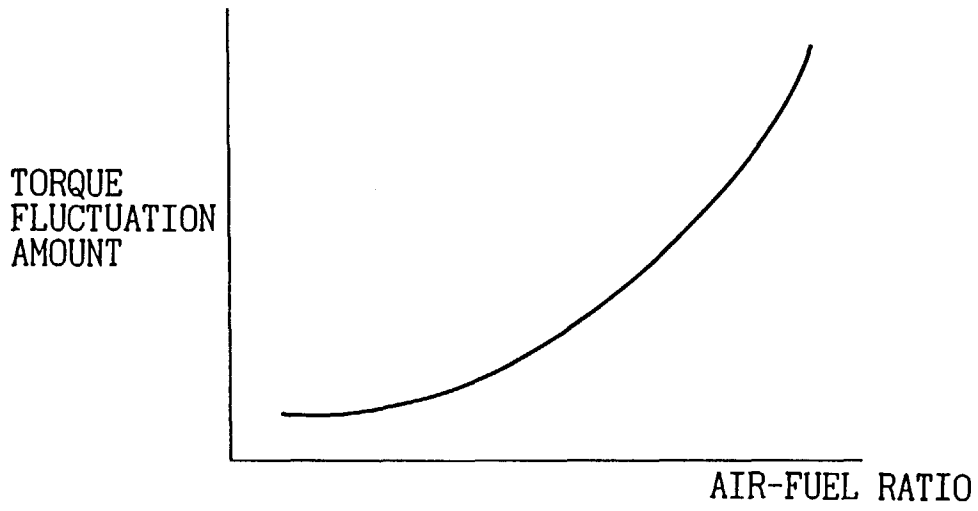


Fig.12B

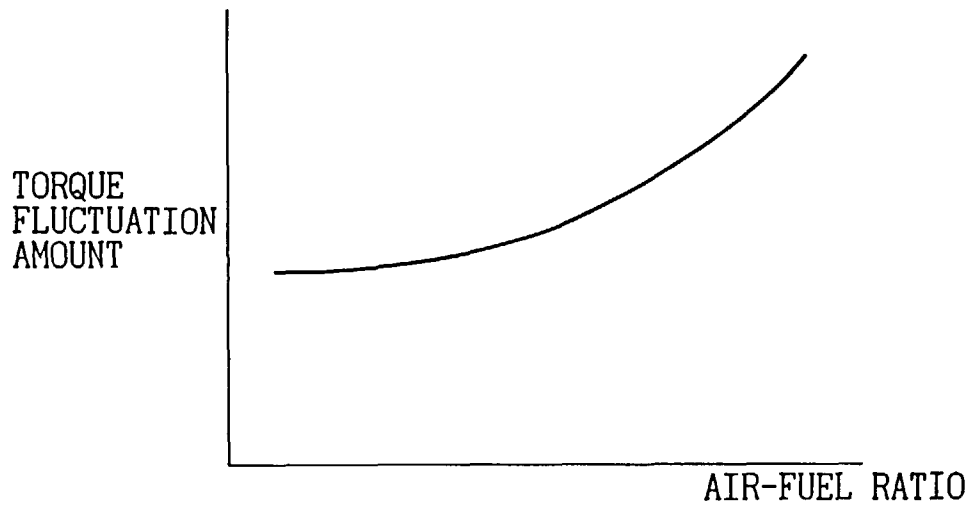


Fig.13

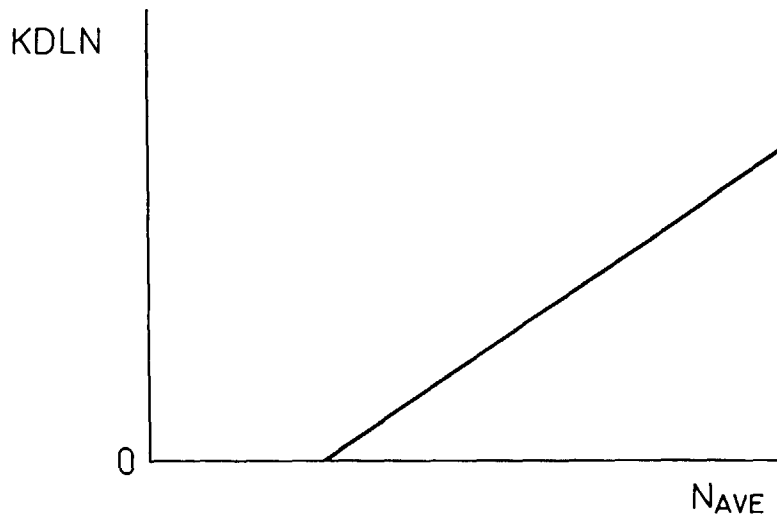


Fig.14

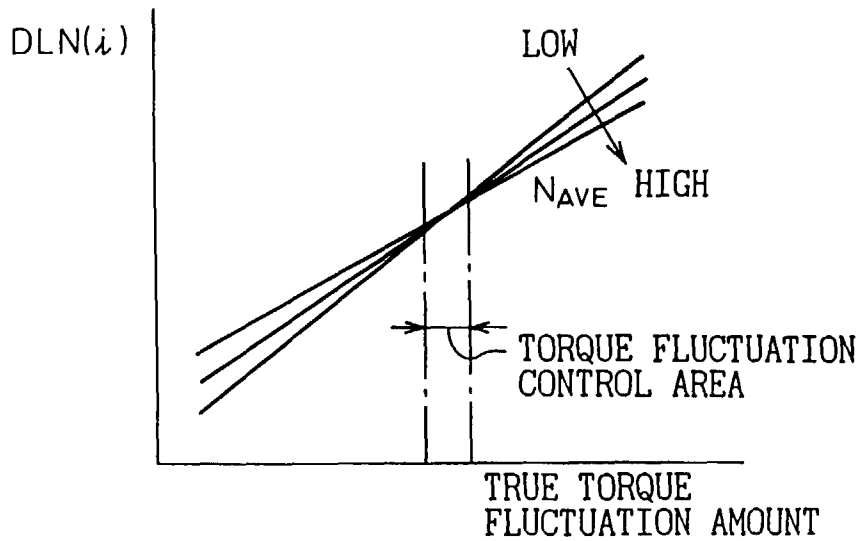


Fig.15

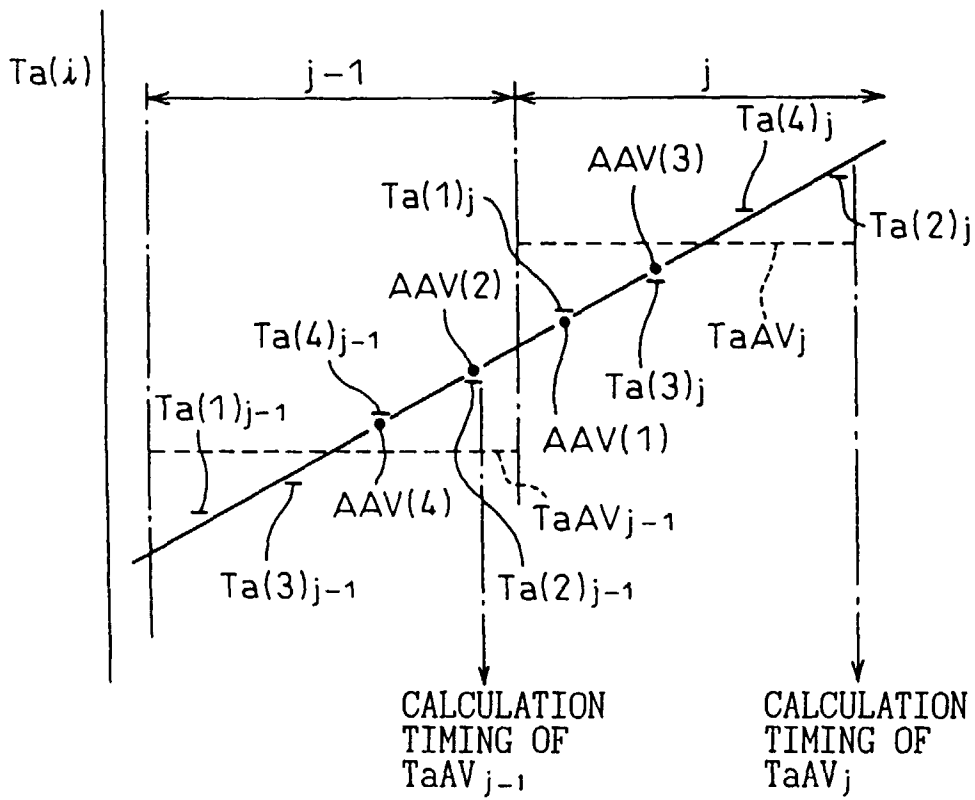


Fig.16

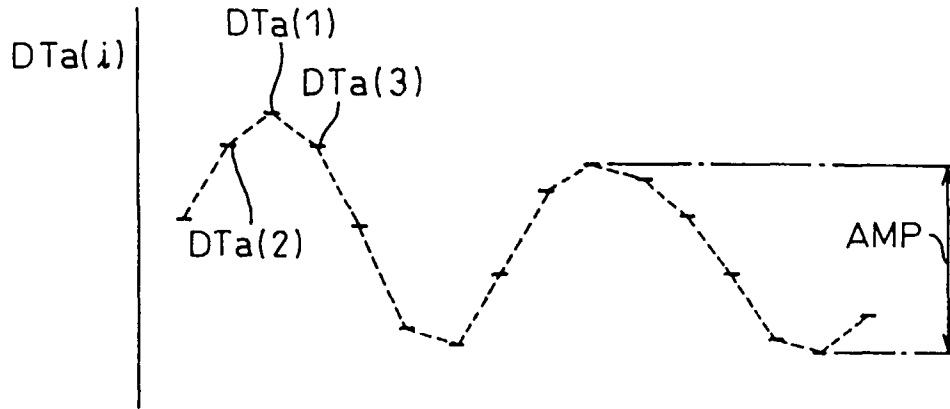


Fig.17

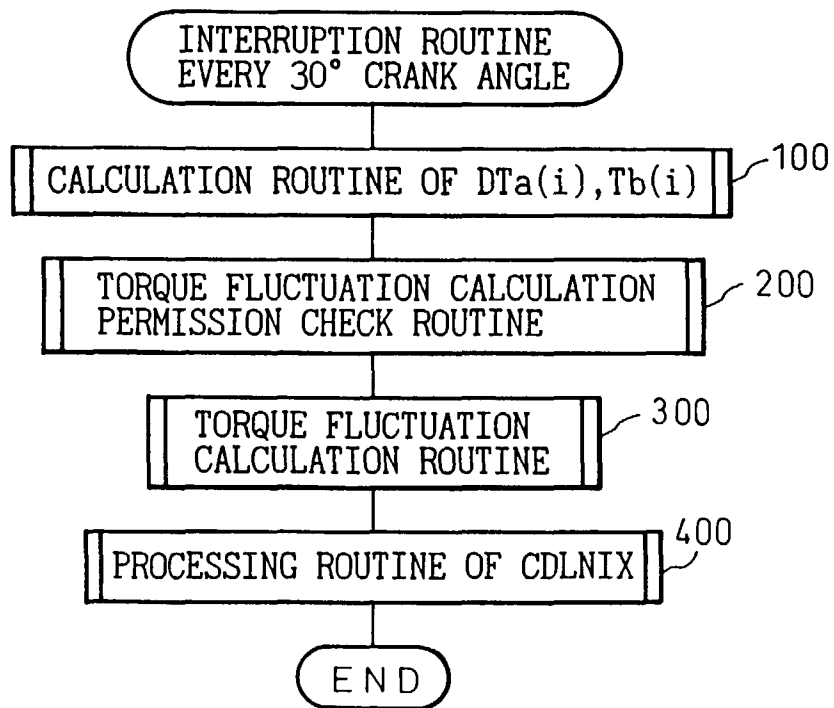


Fig.18

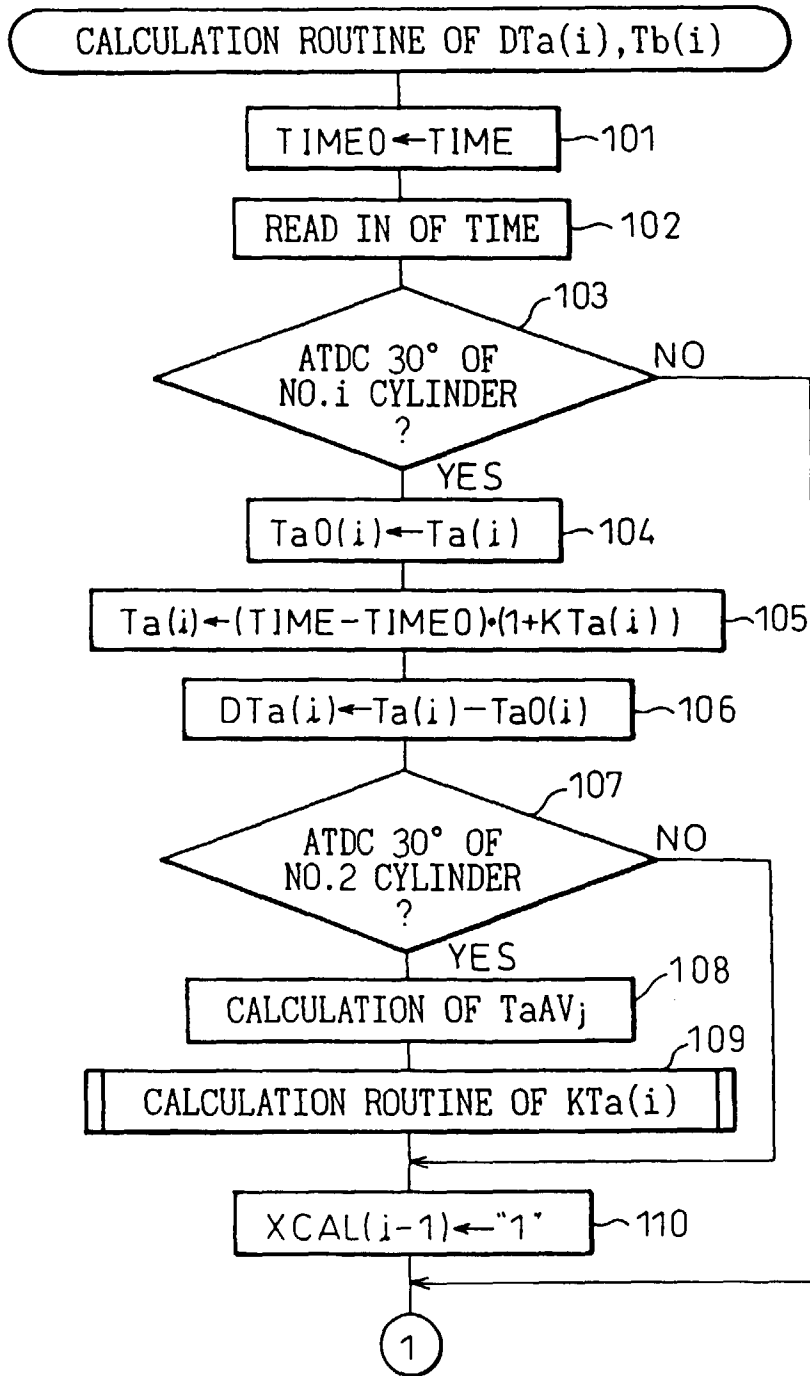


Fig.19

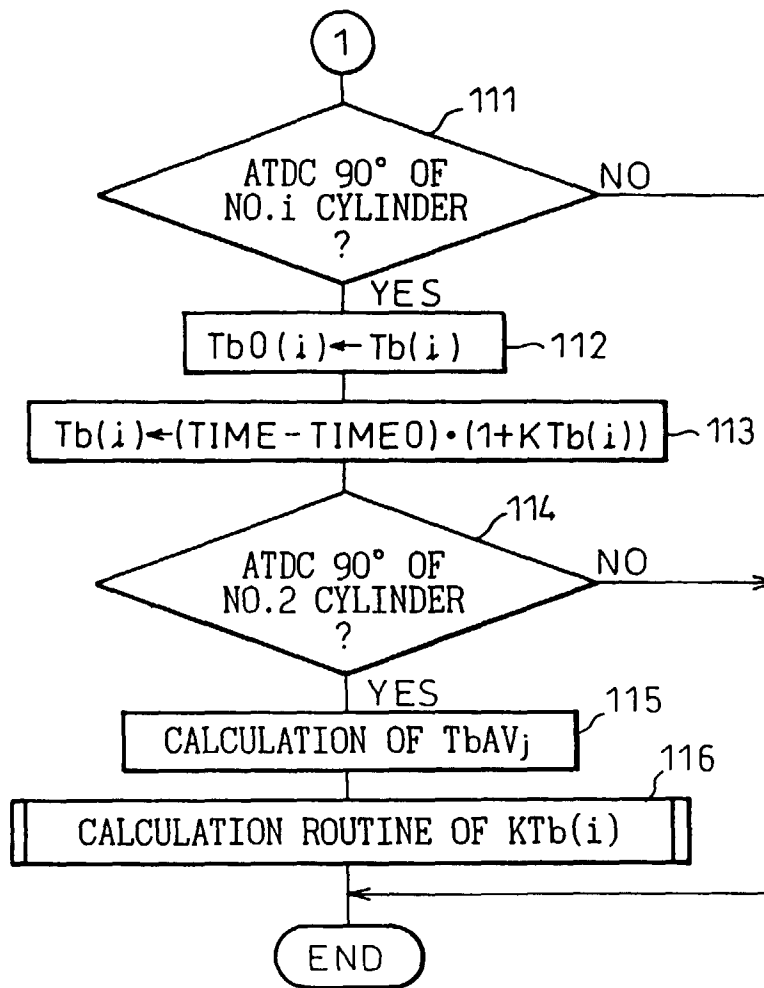


Fig. 20

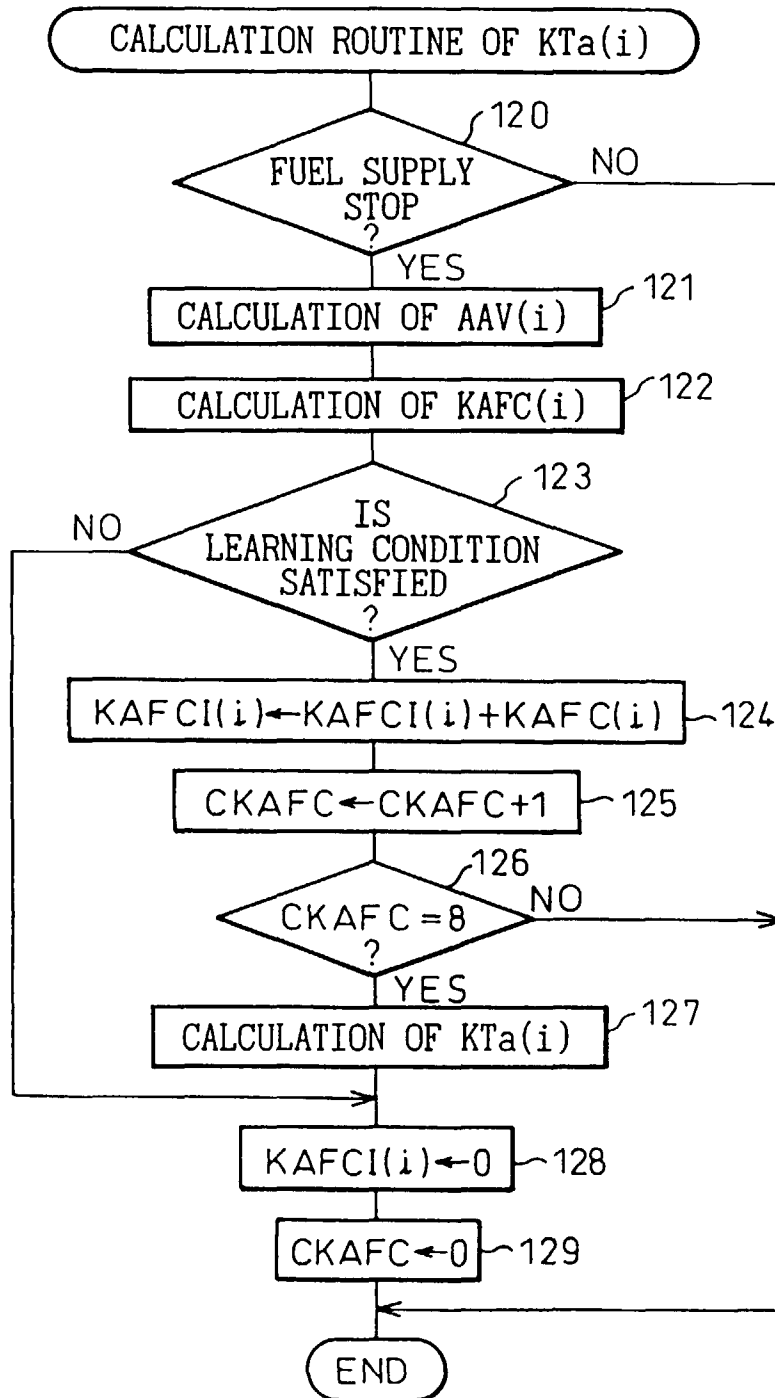


Fig. 21

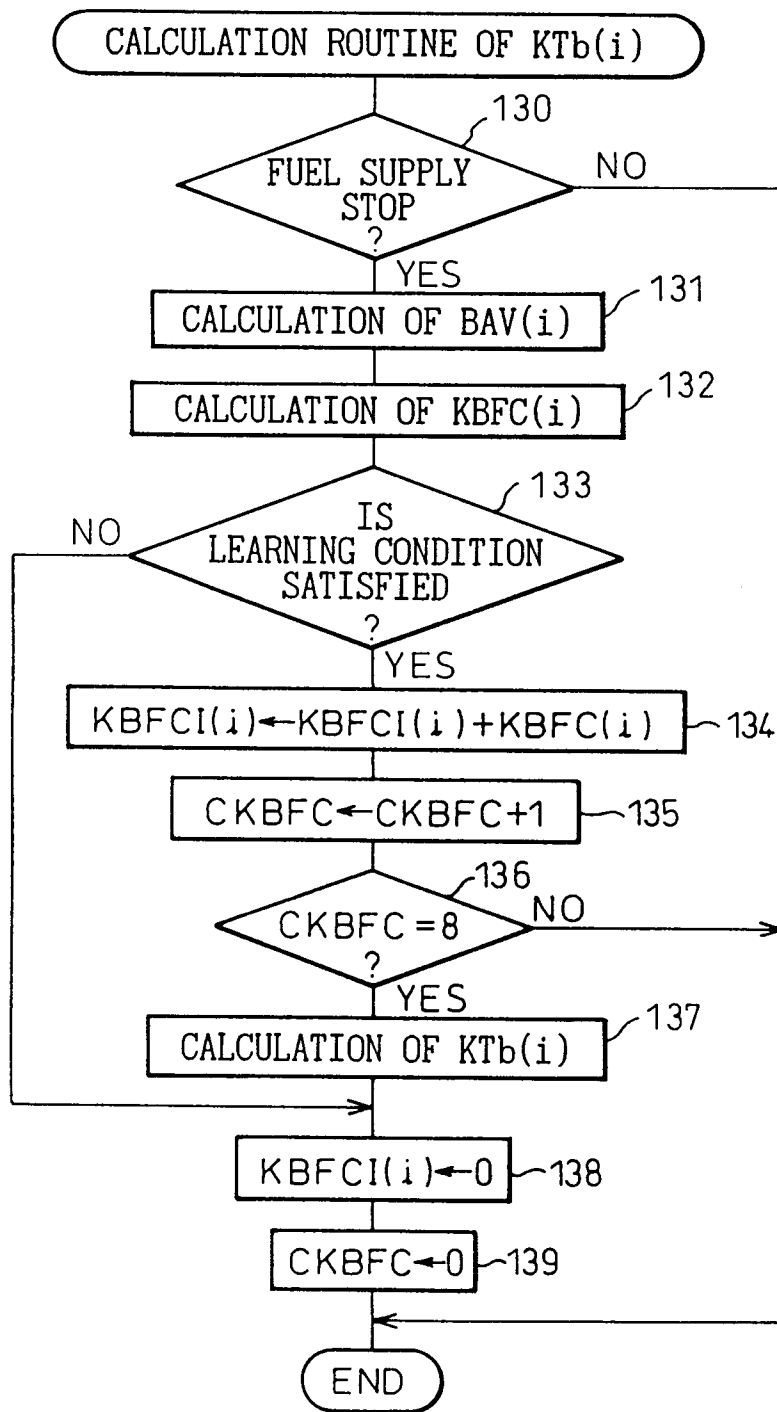


Fig. 22

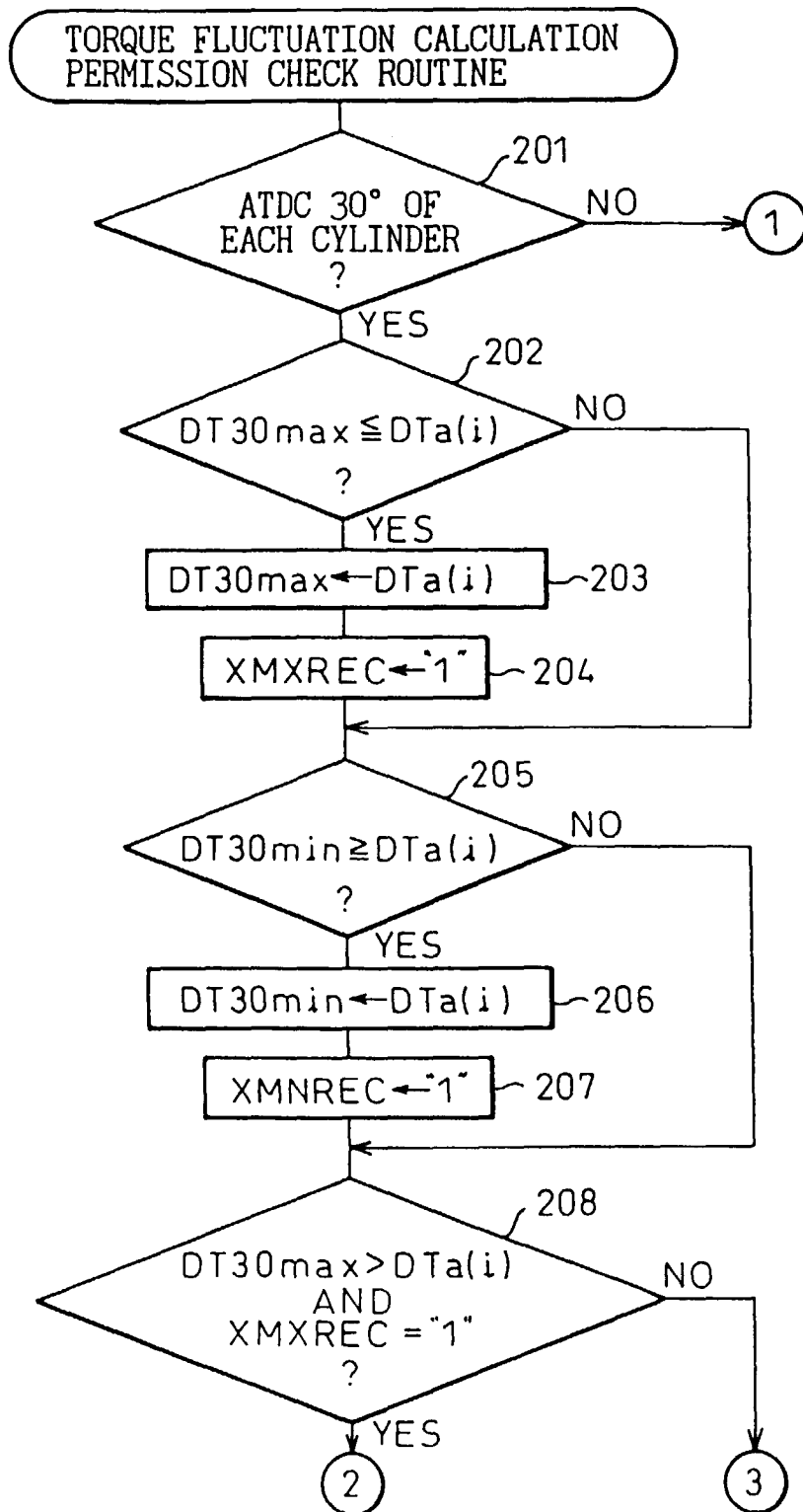


Fig. 23

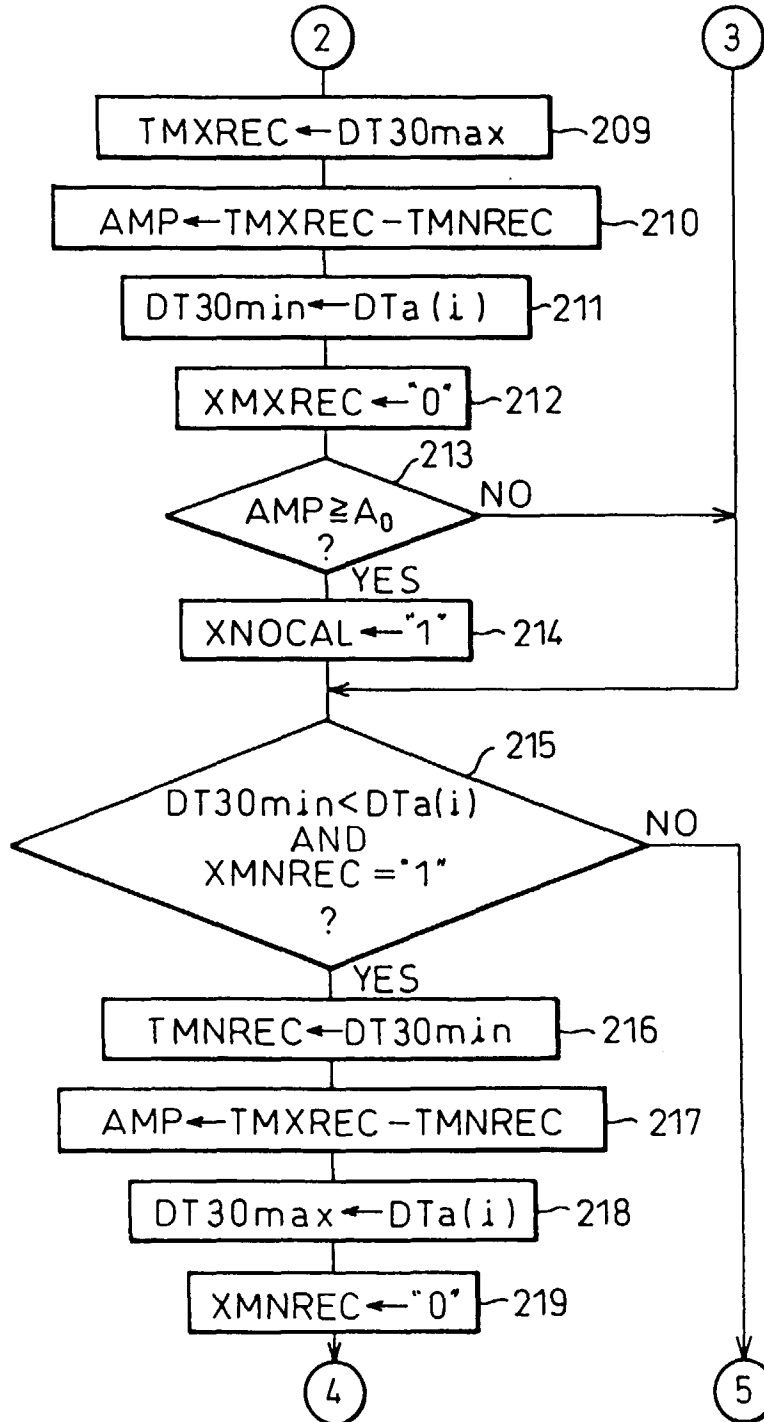


Fig. 24

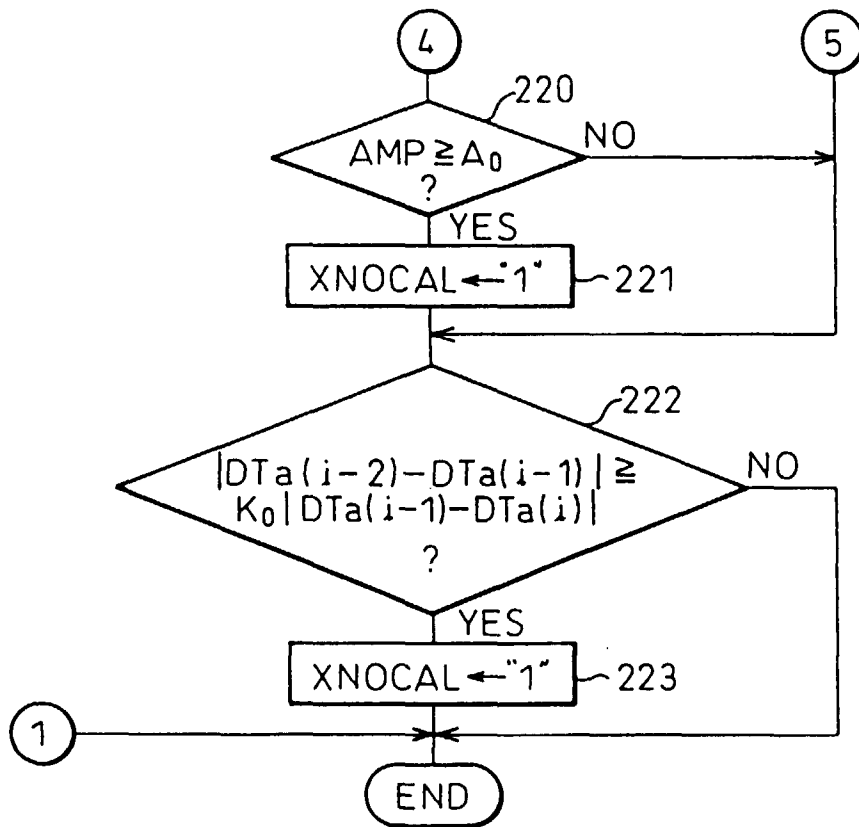


Fig. 25

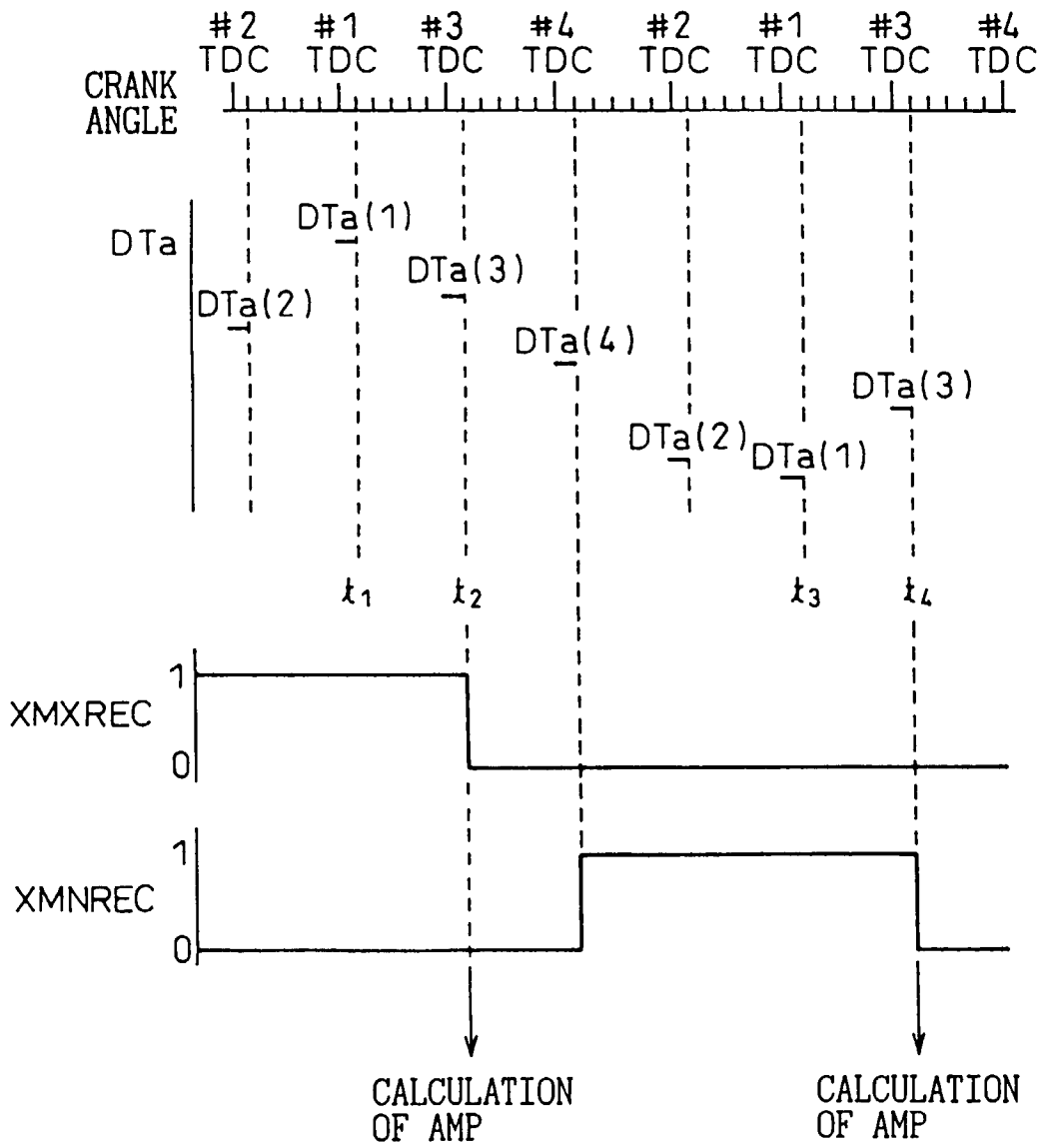


Fig.26

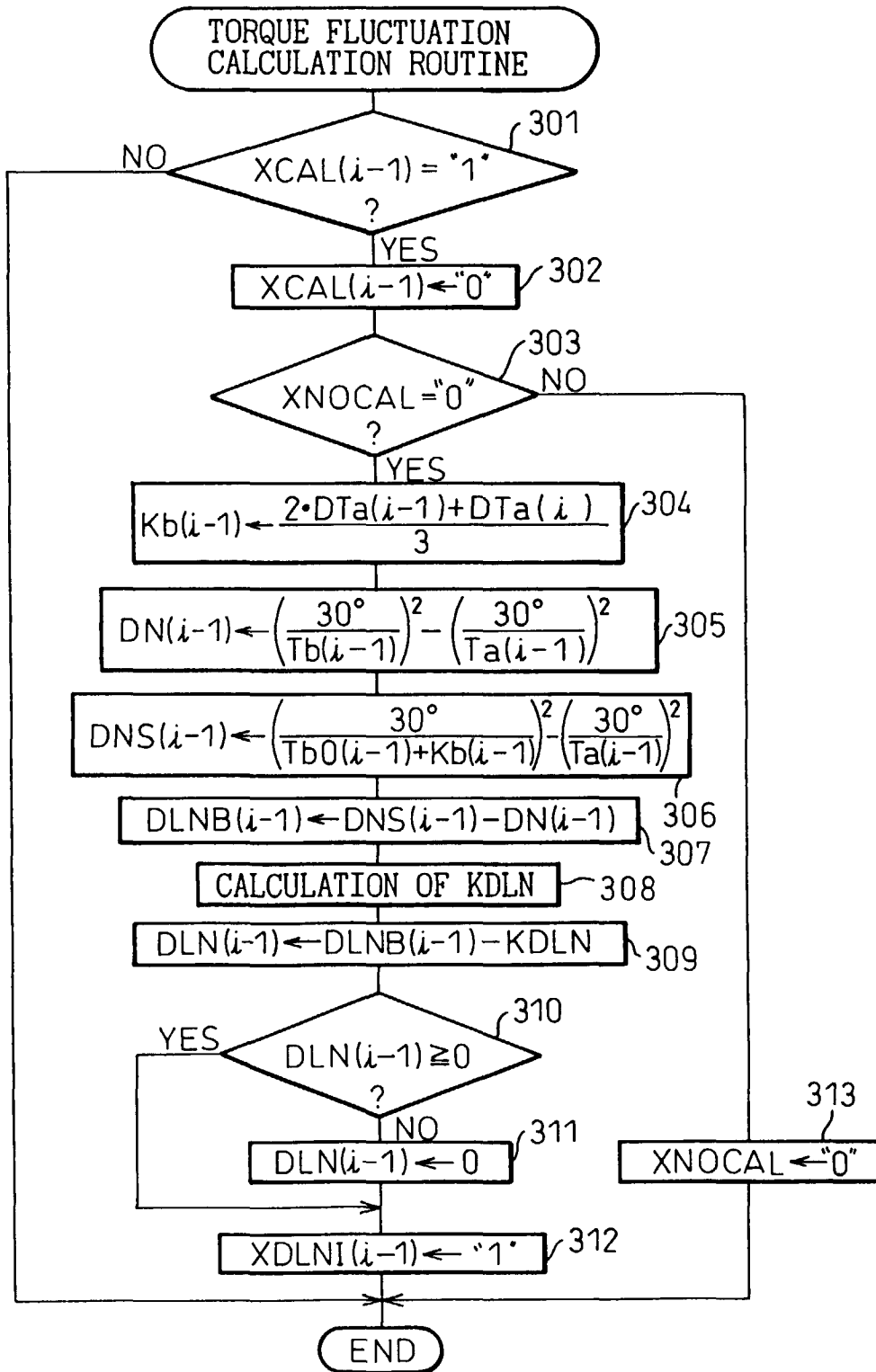


Fig.27

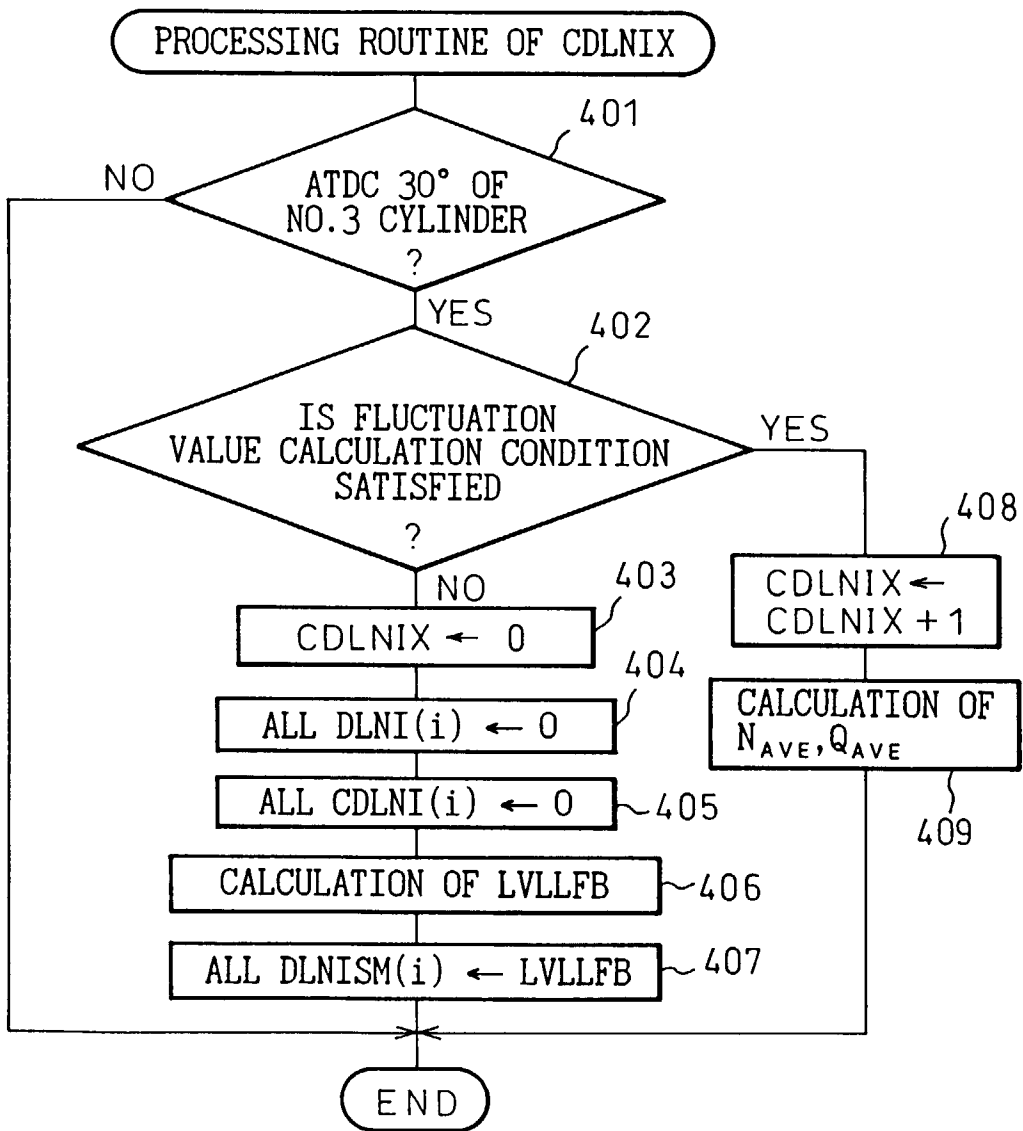


Fig. 28

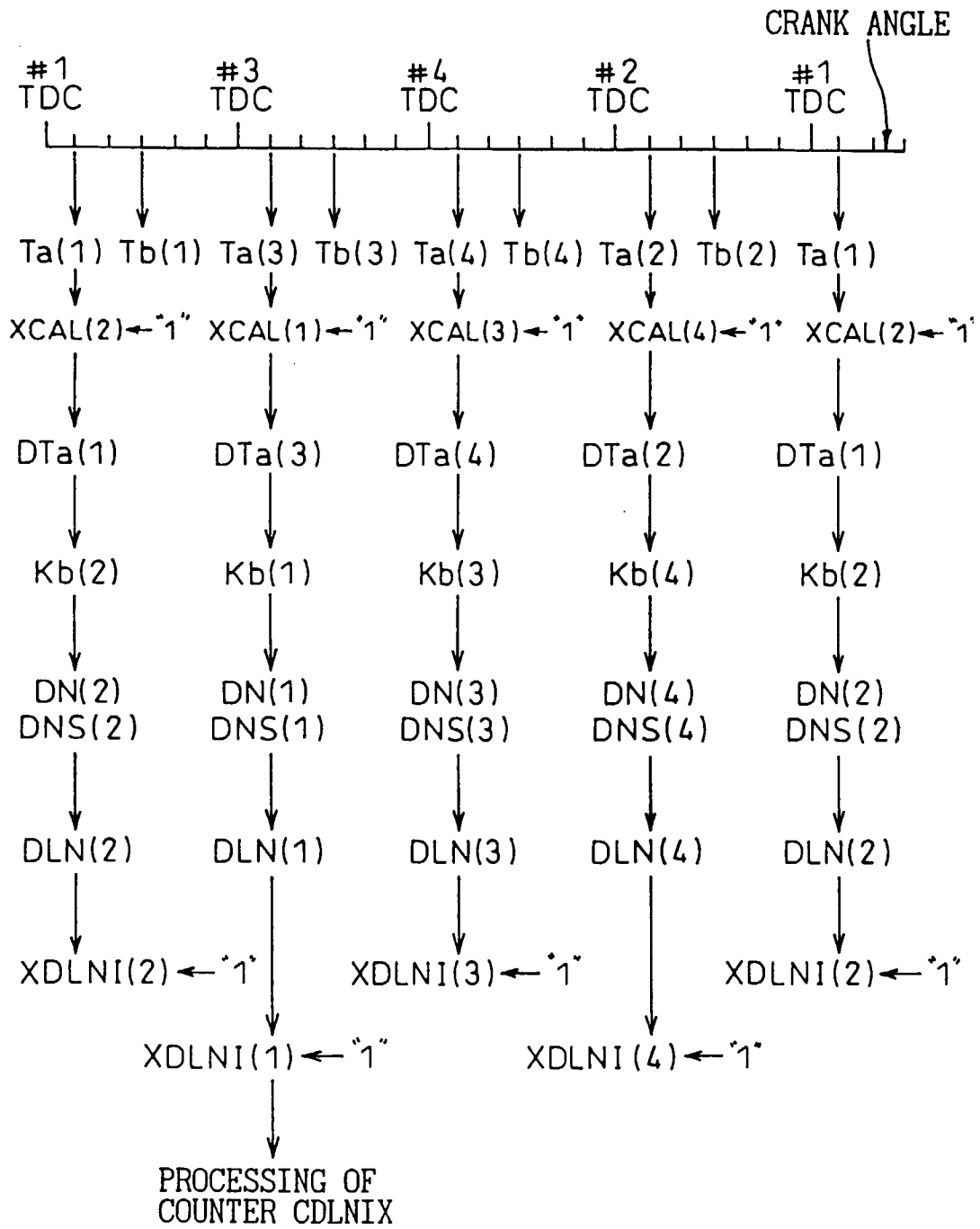


Fig. 29A

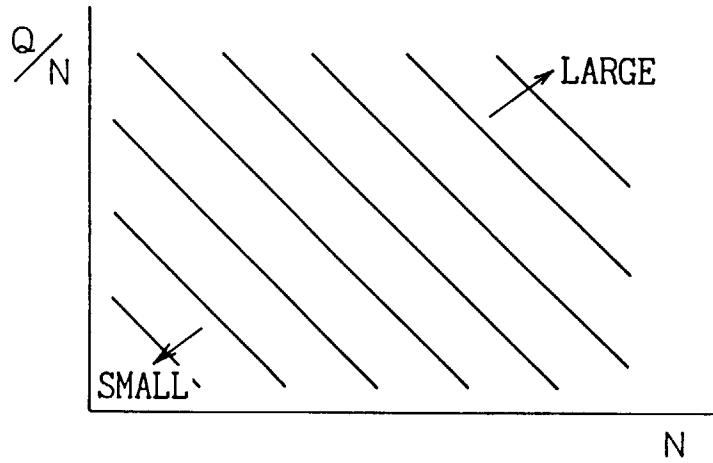


Fig. 29B

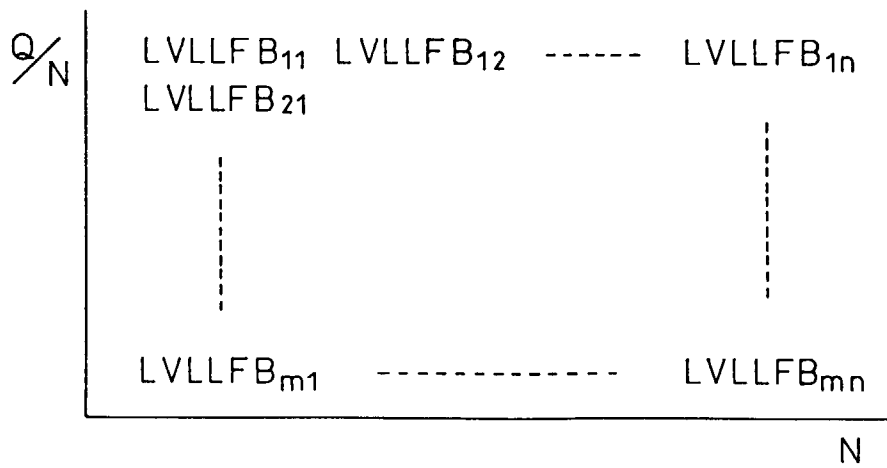


Fig. 30A

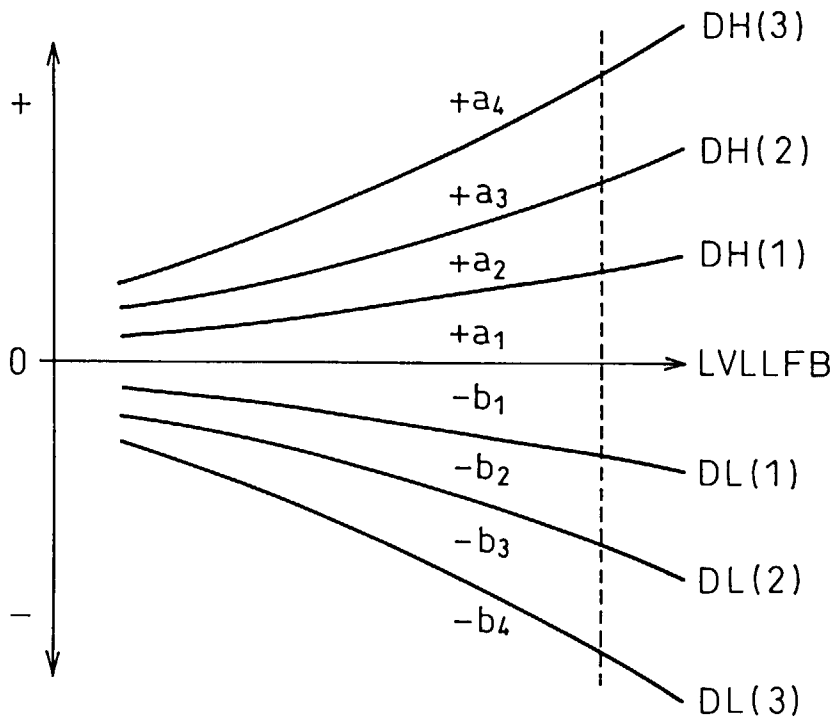


Fig. 30B

TORQUE FLUCTUATION LEVEL	FEEDBACK CORRECTION VALUE
LVLH (3)	+a ₄
LVLH (2)	+a ₃
LVLH (1)	+a ₂
LVLLFB	+a ₁
LVLL (1)	-b ₁
LVLL (2)	-b ₂
LVLL (3)	-b ₃
	-b ₄

Fig. 31

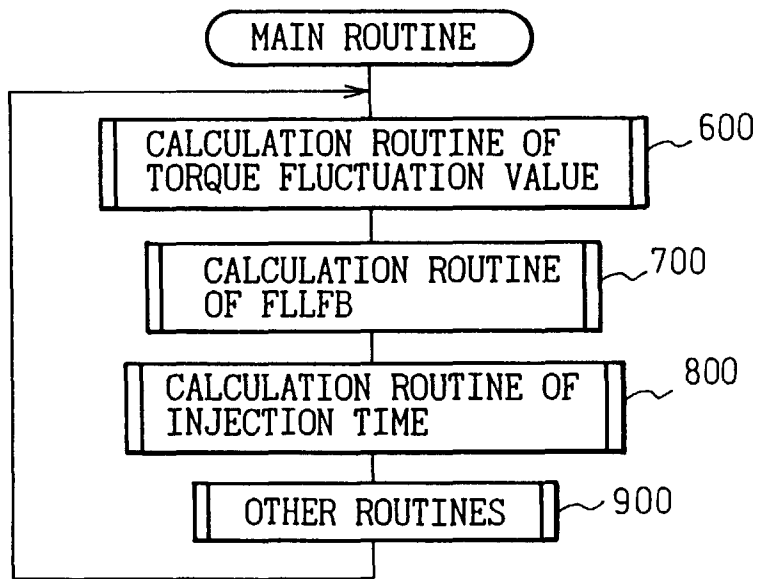


Fig. 32

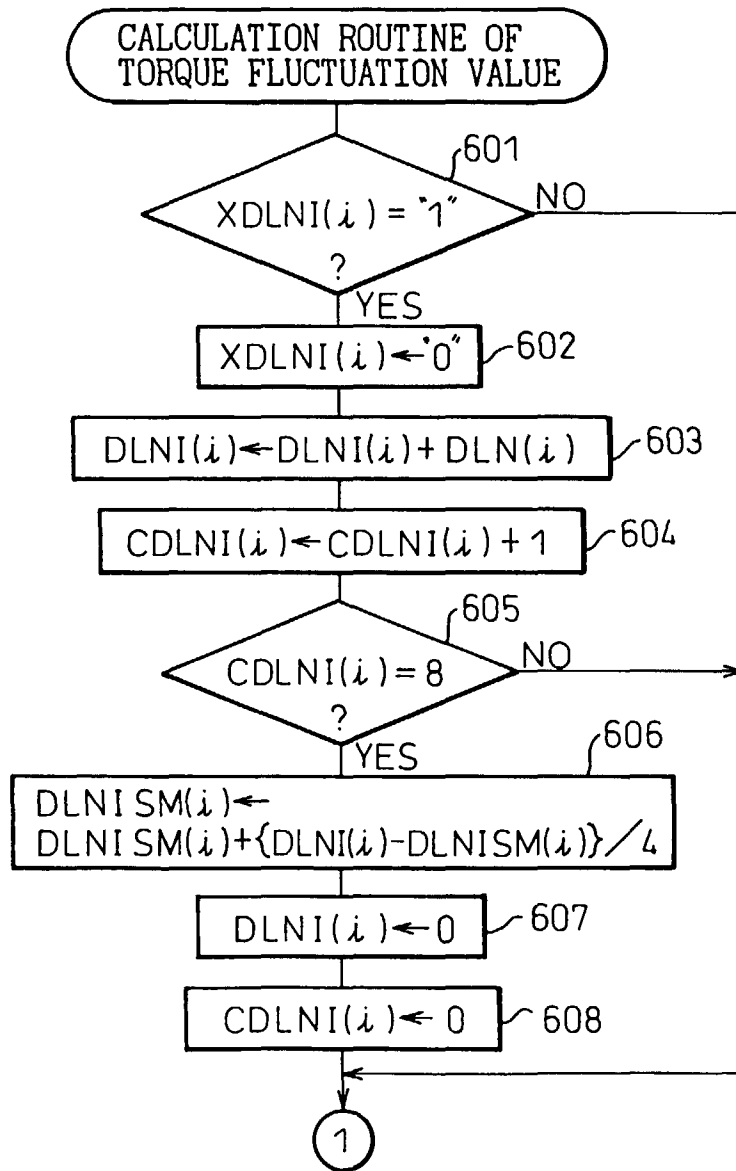


Fig. 33

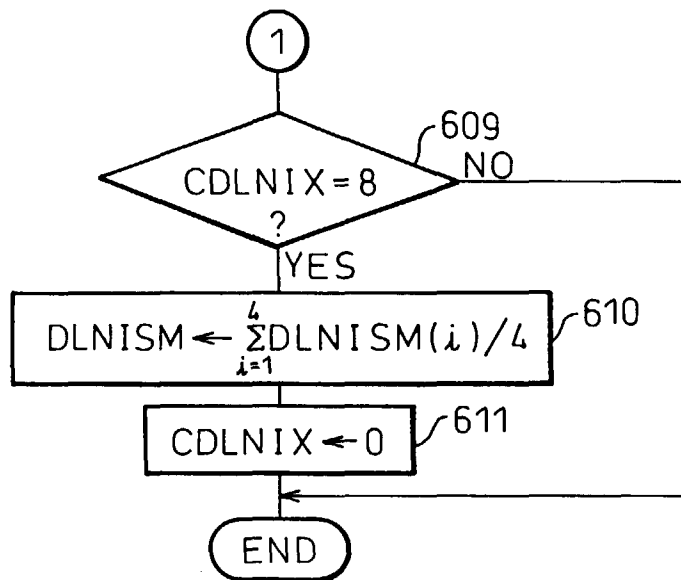


Fig. 34

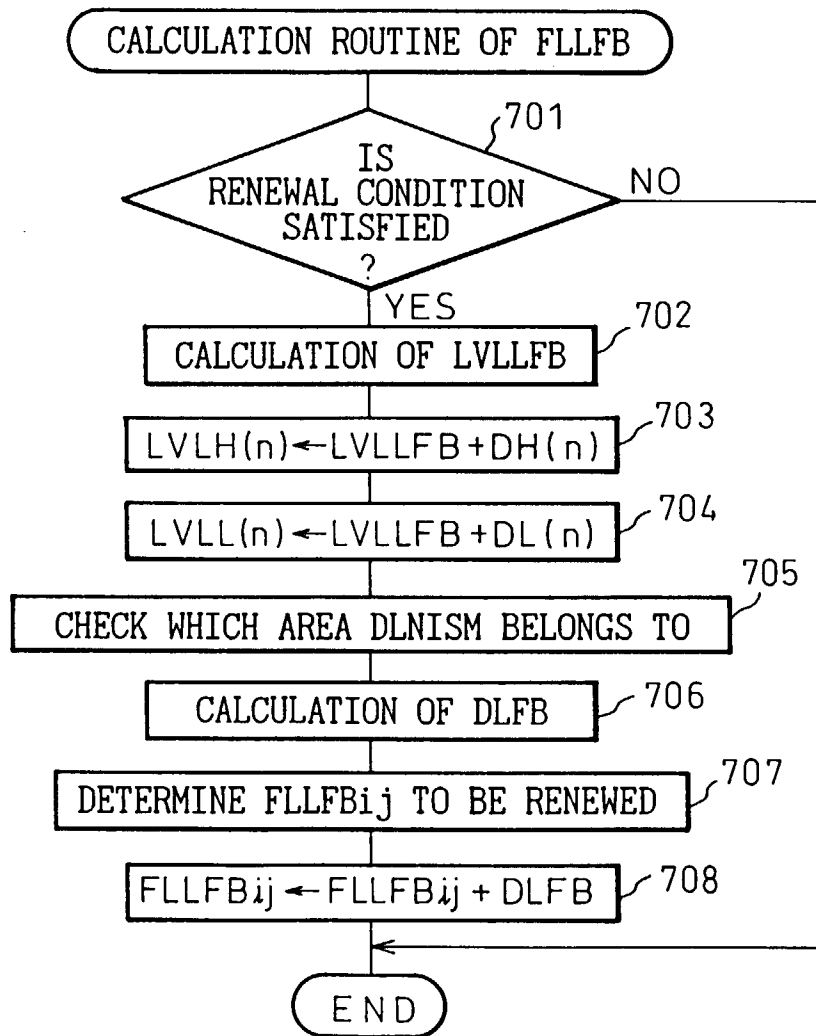


Fig.35

