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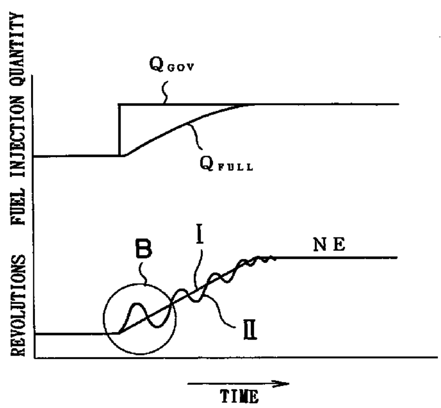
(54) Apparatus and method for controlling fuel injection in internal combustion engine

(57) An apparatus and a method for controlling fuel injection in an internal combustion engine (1) for preventing torsional vibrations of the engine without deteriorating the acceleration performance is disclosed. The apparatus is provided with a control unit (an ECU) (30) for controlling a fuel injection quantity for the diesel engine (1) of a vehicle (10). The ECU (30) calculates the change rate ΔNE of engine revolutions in accordance with an input from a crank angle sensor (35) and subtracts a value obtained by smoothing a variation component of ΔNE from the ΔNE so as to extract a torsional vibration component thereof. Moreover, the ECU (30) corrects the fuel injection quantity of the engine to reduce the torsional vibration component. Since the extracted torsional vibration component does not contain steady change in the revolutions during acceleration or the like, the steady change in the revolutions caused only by the acceleration is not affected by the correction of the fuel injection quantity. Therefore, deterioration in the acceleration performance caused by prevention of the torsional vibrations can be prevented.

FIG. 2A



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to an apparatus and a method for controlling fuel injection in an internal combustion engine, and more particularly to an apparatus and a method for controlling fuel injection in an internal combustion engine which is capable of preventing torsional vibration of an output shaft system of an internal combustion engine.

2. Description of the Related Art

[0002] Torsional vibrations of an output shaft of an internal combustion engine occurring in, for example, an engine for a vehicle cause fluctuation (such as a shock administered during acceleration or deceleration, jerk or the like) in the acceleration of the vehicle when the acceleration or deceleration is performed or surging when running in a steady state. Thus, the driveability of the vehicle deteriorates. In particular, a required fuel injection quantity for a diesel engine is determined in accordance with a state of the operation of the engine (for example, revolutions of the engine speed and an amount (the opening of the accelerator) of depression of an accelerator pedal performed by a driver). Therefore, the required fuel injection, quantity immediately varies with the opening of the accelerator. If a required quantity of fuel for injection is injected into the engine, the torque generated by the engine is rapidly changed, leading to increased torsional vibrations of the output shaft system. To prevent this, so-called smoothing control is adopted for the diesel engine when the required fuel injection quantity is rapidly increased when, for example, acceleration is performed. In the foregoing case, an actual fuel injection quantity is gently increased to the required fuel injection quantity.

[0003] On the other hand, a method has been known with which torsional vibrations of a shaft system are actually detected to control output torque of the internal combustion engine such that the torsional vibrations can be prevented. A control apparatus adapted to the above-mentioned method is disclosed in, for example, Japanese Patent Laid-Open No. 60-26142.

[0004] An apparatus of the foregoing type detects any one of quantities of state, such as an amount of fluctuation in the rotational speed of the diesel engine, an amount of fluctuation in the acceleration of a vehicle, in the longitudinal direction, having the engine mounted thereon and an amount of fluctuation in the torsional torque of the output shaft of the engine. A detected quantity of state is used as an amount of vibrations representing torsional vibrations. In accordance with the value of the detected amount of torsional vibrations, an actual fuel injection quantity of the engine is feedback-controlled to prevent torsional vibrations.

[0005] The apparatus of the foregoing type, however, encounters limitation of the increase in the fuel injection quantity at a rapid acceleration. Therefore, there is a possibility of deterioration in the acceleration performance.

[0006] As described above, each conventional apparatus detects a fluctuation amount as a value relating to the actual torsional vibrations such as the revolution speed of the engine, acceleration of the vehicle in the longitudinal direction, and the torsional torque of the output shaft of the engine. The fuel injection quantity is feedback controlled in accordance with the amount of torsional vibrations. As described above, the amount of torsional vibrations is calculated using the revolution speed of the engine, the acceleration of the vehicle in the longitudinal direction and the torsional torque of the output shaft of the engine. The foregoing factors, however, may rapidly vary during acceleration of vehicle even if no torsional vibration is created. If the detected value of the amount of fluctuation such as the revolution speed of the engine, the acceleration of the vehicle in the longitudinal direction and the torsional torque of the output shaft of the engine are employed for controlling the torsional vibrations, the change in, for example, the revolution speed of the engine accompanied with acceleration of the vehicle will be undesirably detected as the increase in the torsional vibrations. In the foregoing case, the fuel injection quantity is corrected to suppress the fluctuation. Therefore, required increase in the fuel injection quantity is limited, thus deteriorating the acceleration performance of the engine.

SUMMARY OF THE INVENTION

[0007] Accordingly, an object of the present invention is to provide a method and an apparatus for controlling fuel injection in an internal combustion engine which is capable of obtaining a satisfactory effect of preventing torsional vibrations without deteriorating the acceleration characteristic of the engine.

[0008] The above object is solved by combination of features of the independent claims, the dependent claims disclose further advantageous embodiments of the invention.

[0009] To achieve the above-mentioned object, according to one aspect of the present invention, there is provided an apparatus for controlling fuel injection in an internal combustion engine including vibrations detection means for detecting a quantity of state relating to the amplitude of torsional vibrations of an output shaft system of the internal combustion engine as a torsional vibration parameter, and a fuel injection quantity correction means for correcting a fuel injection quantity of the internal combustion engine to prevent torsional vibrations in accordance with said detected torsional vibration parameter, in which the fuel injection quantity correction means stores change in the torsional vibration parameter which has occurred until the present time as a hysteresis value, vibration component extracting means is provided to extract a torsional vibration component from the detected torsional vibration parameter using the hysteresis value, and the fuel injection quantity is corrected in accordance with the magnitude of the torsional vibration component.

[0010] According to the foregoing aspect, the vibration parameter relating to the amplitude of the torsional vibrations is detected. The hysteresis value of the torsional vibration parameter is used to extract only the torsional vibration component representing the torsional vibrations of the shaft system from the detected torsional vibration parameter. The torsional vibration parameter may be the change rate, for example, of engine revolutions, acceleration in an advancing direction (in the longitudinal direction), torsional torque of an engine output or the like. The hysteresis value of the torsional vibration parameter may be, for example, the magnitude of the torsional vibration parameter value within a predetermined past period. Accompanied with the increase in the engine revolutions, acceleration in the advancing direction and the torsional torque of the shaft during the acceleration of the engine, the parameter value of the torsional vibrations will increase. The torsional vibrations may add the resultant torsional vibration parameter value to the increased parameter of the torsional vibrations during the acceleration. Meanwhile the increase rate of the engine revolutions, the acceleration in the advancing direction or the torsional torque of the shaft is not considerably changed. That is, the increase amount of the parameter of vibrations during acceleration is substantially constant. On the other hand, the parameter value of the vibrations owing to the torsional vibrations usually assumes either a positive or a negative value. Thus, only the component relating to the torsional vibrations can be extracted from the torsional vibration parameter by comparing the magnitude of the torsional vibrations within a predetermined past period and that of the present torsional vibration parameter.

[0011] Correction of the fuel injection quantity in accordance with the magnitude of the torsional vibration component makes it possible to correct the fuel injection quantity to prevent torsional vibrations without limiting the fuel injection quantity required for acceleration. Therefore, torsional vibrations can be prevented without giving the adverse influence on the engine acceleration.

[0012] In the foregoing aspect, it is effective that the vibration component extracting means stores a value obtained by smoothing change in the torsional vibration parameter which has occurred until the present time as the hysteresis value, and the vibration component extracting means sets a value obtained by subtracting the hysteresis value from a change rate of the present torsional vibration parameter as a present torsional vibration component.

[0013] If the change rate of the engine revolutions is used as the vibration parameter, it is obtained by combining the change in the acceleration, deceleration or the like having a relatively long change cycle and the change in the torsional vibrations having a relatively short change cycle. Therefore, in the aforementioned structure, the fluctuation of the engine revolutions for a predetermined period is smoothed to calculate a value from which the fluctuation of the change rate of the revolutions owing to the torsional vibrations has been removed. The calculated value is used as the hysteresis value. Therefore, the hysteresis value represents the change rate of the revolutions during acceleration or deceleration, which is independent of the torsional value. When the hysteresis value is subtracted from the current torsional vibration parameter value, only the vibration component of the torsional vibration parameter can accurately be extracted. The change rate of the engine revolutions can be smoothed by using an arithmetic average of the change rate of the revolutions within a predetermined period or a value derived from the process to be described later.

[0014] It is effective that the above-mentioned aspect is structured such that the vibration component extracting means extracts the torsional vibration component at a predetermined time interval, and the fuel injection quantity correction means calculates a vibration correction quantity of the fuel injection quantity in accordance with the extracted torsional vibration component and adds the vibration correction quantity to a fuel injection quantity which is set in accordance with a state of the operation of the engine so as to correct the fuel injection quantity, and reduce the absolute value of the vibration correction quantity when an inverse timing pattern of the sign of the torsional vibration component coincides with a predetermined pattern.

[0015] With the aforementioned structure, when the inverse timing pattern of the sign of the extracted torsional vibration component becomes a predetermined one, hunting during the controlling operation can be prevented by decreasing the absolute value of the vibration correction amount.

[0016] The engine revolutions, the acceleration of the vehicle and the torsional torque of the output shaft are likely to generate a very small degree of vibration resulting from variation in the output torque among the cylinders of the engine and an influence of a mechanical element (for example, a gear) of the output shaft of the engine. The vibration component extracted by the vibration component extracting means contains the aforementioned variations. Therefore, if the aforementioned variation cycle coincides with the cycle for controlling to prevent the torsional vibrations, hunting is generated during the control. As a result, fluctuation in the inverse of the sign of the vibration correction amount might be amplified, resulting in divergence of the control. The hunting can be prevented by setting the control gain to a small value preliminarily. Setting the control gain to a small value, however, may retard the response of the control for preventing the torsional vibrations, thus failing to provide a satisfactory effect of preventing vibrations. Therefore, in the present invention, the inverse timing pattern of the sign of the torsional vibration component that causes the hunting is preliminarily stored. When the actual inverse timing pattern coincides with the stored pattern, the vibration correction amount is decreased (that is, the control gain is decreased). As a result, the control gain is decreased only when there is a possibility of the hunting. In case of no possibility of the hunting, the gain is not decreased. Therefore, the aforementioned structure provides a satisfactory effect for suppressing vibrations while preventing hunting.

[0017] Decreasing in the vibration correction amount in case of a possibility of hunting represents not only to decrease the vibration correction amount partially but also set the vibration correction amount to zero (i.e., interruption of the fuel injection correction).

[0018] This summary of the invention does not necessarily describe all necessary features so that the invention may also reside in a sub-combination of these described features.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

FIG. 1 is a schematic diagram of a structure of an embodiment in which the present invention is applied to a diesel engine for a vehicle;

FIGS. 2A and 2B are graphs each showing change in the engine revolutions during acceleration;

FIG. 3 is a flow chart of a process for preventing torsional vibrations;

Fig. 4 is a flow chart of a process for setting a fuel injection amount;

Fig. 5 is a flow chart of a process for preventing hunting; and

Fig. 6 is a map for use to determine occurrence of hunting.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] An embodiment of the present invention will now be described with reference to the drawings.

[0021] FIG. 1 is a diagram showing a schematic structure of an embodiment in which the present invention is applied to a diesel engine for a vehicle. Referring to FIG. 1, a diesel engine 1 (a 4-cylinder 4-cycle engine in this embodiment) is mounted on a vehicle 10. Driving wheels 9 are driven by an output shaft (not shown) of the engine 1 connected to a transmission unit 3 through a propeller shaft 5, a differential gear 7 and axles 8. A shaft system including shafts from a crank shaft of the engine 1 to the driving wheels 9 is hereinafter called as an "output shaft system for the engine 1".

[0022] An electronic control unit (ECU) 30 for controlling the engine 1 is formed as a microcomputer incorporating a RAM (Random Access Memory), a ROM (Read Only Memory), a CPU (which is a microprocessor) and input/output ports. In this embodiment, the ECU 30 performs a basic control, for example, control of the fuel injection of the engine 1 as well as correction of a fuel injection quantity for the purpose of preventing torsional vibrations to be described later.

[0023] The ECU 30 for performing the aforementioned controls has an input port to which an accelerator-opening sensor 31 is connected through an AD converter (not shown). Moreover, a crank-angle sensor 35 is connected to the input port of the ECU 30.

[0024] The accelerator-opening sensor 31 is disposed adjacent to an accelerator pedal (not shown) of the engine 1 to generate a voltage signal corresponding to an amount of depression of the accelerator pedal (the opening of the accelerator) ACCP operated by a driver of the vehicle 10. In this embodiment, the ACCP indicating the opening of the accelerator is used as a parameter representing an engine output required by the driver.

[0025] The crank-angle sensor 35 is formed of two sensors, a reference-position sensor and a crank rotation angle sensor. The reference-position sensor (not shown) is disposed adjacent to a cam shaft of the engine 1 to output a reference pulse signal whenever the cam shaft reaches the reference position (for example, whenever a first cylinder of the engine 1 reaches the top dead center in the intake stroke). That is, the reference pulse signal is output whenever the crank shaft rotates at 720°. The crank rotation angle sensor is disposed adjacent to the crank shaft to output a crank rotation angle pulse signal whenever the crank shaft rotates at a predetermined angle (for example, 15°).

[0026] In this embodiment, the ECU 30 calculates the revolutions (the revolution speed) ΔNE of the engine 1 in accordance with the interval of the crank rotation angle pulse signal and a current phase of rotation of the crank shaft in accordance with the number of the crank rotation angle pulse signal after the reference pulse signal has been supplied from the reference-position sensor.

[0027] Moreover, the ECU 30 according to this embodiment calculates a change rate (a differential value) of the engine revolutions. The change rate is used as a vibration torsional parameter indicating the magnitude of the torsional vibrations of the output shaft system of the engine 1. The torsional vibrations of the output shaft system occur as the fluctuation in the rotational speed of the crank shaft of the engine 1. Therefore, the change rate of the engine revolutions may be used as a parameter representing the magnitude (the amplitude) of the torsional vibrations. That is, the crank-angle sensor 35 employed in this embodiment also functions as the vibration detection means.

[0028] Although the change rate in the revolutions is used as the parameter representing the torsional vibrations in this embodiment, the amount of other factors may be used as the parameter representing the torsional vibrations. For example, the torsional vibrations of the output shaft system of the engine may occur as the change in the acceleration in an advancing direction (the longitudinal direction) of the vehicle. Therefore, an acceleration sensor for detecting the acceleration of the vehicle 10 in the advancing direction may be added to serve as vibration detection means to use the change in the acceleration in the advancing direction as the parameter representing the torsional vibrations. The torsional vibrations of the output shaft system of the engine may occur as the change in the torsional torque of the output shaft of the engine. Therefore, a torque sensor for detecting the torsional torque of the output shaft of the engine may be added to serve as the vibration detection means to use the change in the torsional torque as a parameter representing the torsional vibrations.

[0029] As described later, the ECU 30 calculates to set a value of fuel injection quantity Q_{BASE} for the engine 1 in accordance with an operation state thereof (for example, the engine revolutions NE or accelerator opening ACCP). Moreover, the ECU 30 performs control for preventing torsional vibrations by setting a correction value Q_{JRKFB} for the fuel injection quantity in accordance with the value of the detected parameter of the torsional vibrations.

[0030] An output port of the ECU 30 is connected to a fuel injection valve of each cylinder of the engine 1 through a fuel injection circuit (not shown). Thus, the fuel in a quantity determined in accordance with Q_{BASE} and Q_{JRKFB} is injected into each cylinder at a predetermined fuel injection timing.

[0031] Prior to the description on the operation for preventing torsional vibrations according to this embodiment, setting of the fuel injection quantity for the engine 1 according to this embodiment will be described.

[0032] In this embodiment, the ECU 30 calculates a required fuel injection quantity Q_{GOV} in accordance with the accelerator opening ACCP detected by the accelerator-opening sensor 31 and the engine revolutions NE. As described above, the accelerator opening ACCP and the engine revolutions NE represent an engine output required by the driver. The required fuel injection quantity Q_{GOV} represents the fuel injection quantity required to achieve the required output, which is preliminarily stored in the ROM of the ECU 30 as a numeric map using the accelerator opening ACCP and the engine revolutions NE. Assuming that the value of the engine revolutions NE is constant, the value of Q_{GOV} is set to be larger as the acceleration opening ACCP increases. On the contrary, assuming that the value of the accelerator opening ACCP is constant, the value of Q_{GOV} is set to be larger as the engine revolutions NE decreases.

[0033] Then, the ECU 30 calculates a guard value Q_{FULL} for the fuel injection quantity in accordance with the engine revolutions NE. The value either the guard value Q_{FULL} or the required fuel injection quantity Q_{GOV} whichever smaller will be set as the value of a basic fuel injection quantity Q_{BASE}.

[0034] As described above, the accelerator opening ACCP will immediately increase with no time delay in accordance with an amount of depression of the accelerator pedal operated by the driver. Therefore, if the ACCP sharply increases during acceleration of the vehicle, the value of the required fuel injection quantity Q_{GOV} sharply increases accordingly. Actually, however, the engine revolutions NE increases relatively gently after the increase in the ACCP with a time delay. Therefore, if the required fuel injection quantity Q_{GOV} of the fuel is supplied to the engine, air in the combustion chamber may become insufficient, thus generation the exhaust smoke. In this embodiment, in order to prevent generation of the smoke at sharp increase in the load such as acceleration, the upper limit of the fuel injection quantity is limited with the guard value Q_{FULL} which is determined in accordance with the engine revolutions NE. The quantity of intake air into the engine varies depending on the revolutions. The guard value Q_{FULL} is set as a maximum fuel injection quantity with which no exhaust smoke is produced at the current engine revolutions. The guard value Q_{FULL} is obtained by experiments or the like so as to be stored as a numeric map in the ROM of the ECU 30. The guard value Q_{FULL} increases as the increase in the engine revolutions NE.

[0035] That is, the required fuel injection quantity Q_{GOV} sharply increases immediately at the initial acceleration. However, the guard value Q_{FULL} is kept at a relatively small value until the engine revolutions increase. Therefore, the actual fuel injection quantity Q_{BASE} is set to the Q_{FULL} ($Q_{BASE} = Q_{FULL}$). Since the Q_{FULL} increases as the increase in the engine revolutions NE, the Q_{BASE} is increased accordingly. When the engine revolution NE further increases to reach the relation $Q_{BASE} < Q_{FULL}$, the actual fuel injection quantity Q_{BASE} is kept equal to Q_{GOV} ($Q_{BASE} = Q_{GOV}$).

[0036] In this embodiment, the final fuel injection quantity Q_{FINC} is set in accordance with the following Equation (1) to prevent torsional vibrations. In the Equation (1), the value Q_{JRKFB} denotes a value of fuel injection quantity correction to prevent torsional vibrations to be described later. That is, in this embodiment, the actual fuel injection quantity during acceleration becomes either the guard value Q_{FULL} or the sum of the fuel injection quantity Q_{BASE} and the correction value Q_{JRKFB} whichever smaller.

$$Q_{FINC} = MIN(Q_{FULL}, (Q_{BASE} + Q_{JRKFB})) \qquad (1)$$

[0037] Described is a method of setting the fuel injection correction quantity Q_{JRKFB} for preventing torsional vibrations according to the present invention.

[0038] FIG. 2A is a diagram showing the change in the engine revolutions NE during acceleration of vehicle at an elapse of time in a case where the fuel injection correction is not performed to prevent torsional vibrations. When the required fuel injection quantity Q_{GOV} sharply increases during acceleration, the actual fuel injection quantity Q_{BASE} is limited by the guard value Q_{FULL} as shown in FIG. 2A. Therefore the Q_{BASE} is equal to the Q_{FULL} ($Q_{BASE} = Q_{FULL}$) and increases relatively gently as the increase in the engine revolutions NE. The sharp increase in the output torque owing to the increase in the fuel injection quantity will induce torsional vibration in the engine output shaft system. As a result, the engine revolutions NE further increases while varying in the form realized by adding the change in the revolutions caused by the torsional vibrations (as indicated by a curve II shown in FIG. 2A) to the uniform increase in the revolutions corresponding to the increase in the fuel injection quantity Q_{BASE} (Q_{FULL}) (as indicated by a straight line I shown in FIG. 2A).

[0039] The variation component caused by the torsional vibrations has a frequency as a resonant frequency (which is usually about several Hz in the case of a shaft system of a vehicle) of the torsional vibrations of the output shaft of the engine. The amplitude of the variation component is attenuated at an elapse of time. The variation in the engine revolutions which is caused by the torsional vibrations will vary the acceleration of the vehicle speed. Accordingly, the driveability of the vehicle deteriorates.

[0040] The torsional vibrations can be prevented by correcting the fuel injection quantity to cancel the variation in the engine revolutions. That is, when the engine revolutions are being raised (when the change rate of the engine revolutions assumes a positive value), the fuel injection quantity is corrected to be reduced. When the engine revolutions are being reduced (when the change rate of the engine revolutions assumes a negative value), the fuel injection quantity is corrected to be raised. If the fuel injection quantity is corrected in accordance only with the change rate of the engine revolutions, there may arise a problem. FIG. 2B is a graph showing an enlarged portion (portion B enclosed in a circle shown in FIG. 2A) of the change in the engine revolutions NE during acceleration. It is assumed that the engine revolutions NE were increased by ΔNE in unit time Δt during the acceleration as shown in FIG. 2B. In this case, if the fuel injection quantity is corrected in accordance only with the engine revolutions NE, the correction quantity will assume a negative value (reduction correction) corresponding to the change rate ΔNE of the engine revolutions ΔNE. Actually, the change rate ΔNE of the revolutions contains the increase in the revolutions caused by the acceleration of the engine in addition to the variation component caused by the torsional vibrations. If no torsional vibration is produced, the engine revolutions ΔNE will increase uniformly as indicated by the straight line I shown in FIGS. 2A and 2B. Therefore, the change rate ΔNE of the revolutions is equal to the sum of the change rate component ΔNE_{TV} caused by the torsional vibrations and steady acceleration component ΔNE_{BASE} as shown in the following Equation (2).

$$\Delta NE = \Delta NE_{TV} + \Delta NE_{BASE} \qquad (2)$$

[0041] Therefore, if the fuel injection quantity is corrected to be reduced corresponding to the value of the ΔNE when the revolutions have been raised during the acceleration, the fuel injection quantity corresponding to the increase in the revolutions caused by steady acceleration is undesirably reduced. As a result, the increase in the revolutions caused by the steady acceleration is undesirably prevented.

[0042] If the revolutions have been reduced, ΔNE_{TV} assumes negative values. However, the positive values of the steady acceleration component ΔNE_{BASE} are maintained as being the positive value. Since the absolute value of the ΔNE_{BASE} is smaller than the absolute value of ΔNE_{TV}, the absolute value of ΔNE (the negative value) undesirably becomes smaller than the absolute value of the ΔNE_{TV}. Therefore, if the fuel injection quantity is corrected to be increased corresponding to the value of ΔNE when the revolutions have been reduced during acceleration, the correction quantity equivalent to the increase in the revolutions caused by the steady acceleration is undesirably reduced, like the case in which the revolutions have been raised. As a result, the increase in the revolutions caused by the steady acceleration is undesirably prevented. That is, if the fuel injection quantity is corrected in accordance with the value of the change rate ΔNE of the revolutions, the acceleration performance of the vehicle is limited, thus causing such problem as deterioration in the acceleration performance.

[0043] Therefore, in this embodiment, the steady acceleration component ΔNE_{BASE} is subtracted from the torsional vibration parameter ΔNE to extract only torsional vibration component ΔNE_{TV} such that the fuel injection quantity is corrected in accordance with the vibration component ΔNE_{TV}.

[0044] The change rate indicated by the straight lines I shown in FIGS. 2A and 2B is used as the value of the ΔNE_{BASE}. The change rate ΔNE_{BASE} indicated by the straight line I can be obtained by removing the torsional vibration component (the variation component) from the revolution variation curve for smoothing. The smoothed change rate ΔNE_{BASE} may be used as a value obtained by arithmetically averaging a change rate ΔNE of the revolutions within a predetermined period of time. However, smoothing value $\Delta NEAV$ derived from Equation (3) is used in this embodiment.

$$\Delta NEAV = \Delta NEAV_{i-1} + (\Delta NE - \Delta NEAV_{i-1})/K \qquad (3)$$

where ΔNE is a change rate in the revolutions detected at the present time, $\Delta NEAV_{i-1}$ is a smoothing value calculated at a preceding time and K is a smoothing factor.

[0045] That is, the smoothing value $\Delta NEAV$ is sequentially calculated as a weighted average of the smoothing values $\Delta NEAV_{i-1}$ accumulated until the previous detection and ΔNE detected at the present time. The smoothing value K (K > 1) corresponds to the weighting factor for use in the weighted-averaging operation. The larger the K becomes, the greater the degree of smoothing of the variation in the revolutions is raised. The value of K is set to be an optimum value obtained from experiments using an actual output shaft system of the engine.

[0046] As described above, only the torsional vibration component is extracted from the value of the torsional vibration parameter to correct the fuel injection quantity in accordance with the torsional vibration component. Thus, torsional vibrations of the output shaft system of the engine can effectively be prevented without deteriorating the acceleration performance of the vehicle.

[0047] FIG. 3 is a flow chart of the operation for correcting the fuel injection quantity for the purpose of preventing torsional vibrations according to this embodiment. The foregoing operation is performed as a routine executed by the ECU 30 whenever the crank shaft of the engine 1 rotates at a predetermined rotational angle (180° in this embodiment).

[0048] Referring to FIG. 3, upon start of the operation, the latest engine revolutions NE calculated in response to the pulse signal from the crank-angle sensor 35 and stored in the RAM of the ECU 30 are read in step 301. Moreover, the accelerator opening ACCP detected by the accelerator opening sensor 31 is read.

[0049] In step 303, the change rate ΔNE of the engine revolutions NE is calculated from Equation (4), where ΔNE_{i-1} represents the engine revolutions read during execution of the operation at the preceding process, ΔNE_{i-1} represents a value which is updated in step 315 at every execution of the foregoing operation.

$$\Delta NE = \Delta NE - \Delta NE_{i-1} \qquad (4)$$

[0050] In step 305, the steady component ΔNEAV is subtracted from ΔNE calculated in step 303 in accordance with Equation (5) so that vibrations component ΔNE_{TV} is calculated. The steady component ΔNEAV can be obtained by using the smoothing factor K to sequentially smooth ΔNE (step 313).

$$\Delta NE_{TV} = \Delta NE - \Delta NEAV \qquad (5)$$

[0051] In step 307, the fuel injection correction quantity Q_{JRKFB} is calculated in accordance with the calculated torsional vibration component ΔNE_{TV}. In this embodiment, the Q_{JRKFB} is calculated as a value obtained by multiplying the torsional vibration component ΔNE_{TV} with a negative constant α as expressed in Equation (6):

$$Q_{JRKFB} = \alpha \times \Delta NE_{TV} \ (\alpha < 0) \qquad (6)$$

[0052] As a result, the value of the correction quantity Q_{JRKFB} is set as the value which is increased in proportion to the variation (the change rate) in the revolutions caused by the torsional vibrations and which is inverse in sign. That is, when the revolutions caused by the torsional vibrations are being raised, the foregoing value is set to be a negative value to cancel the change. When the revolutions are being reduced, the foregoing value is set to be a positive value.

[0053] After the fuel injection correction quantity Q_{JRKFB} has been calculated as described above, a hunting preventive operation is performed in step 309. In step 309, it is determined whether or not there is a possibility of hunting. If it is determined that there is a possibility of hunting, the value of the correction quantity Q_{JRKFB} is set to zero to inhibit correction of the fuel injection. The hunting preventive operation in step 309 will be described later.

[0054] After the hunting determination step has been completed, the correction quantity Q_{JRKFB} is used to set the final fuel injection quantity Q_{FINC} in step 311. In the subsequent step 313, the present value of the revolution change rate ΔNE is used to recalculate the value of the aforementioned steady component (the smoothing value) ΔNEAV. In step 315, the value of NE_{i-1} is updated for the xt operation, and thus the foregoing operation is completed.

[0055] FIG. 4 is a flow chart of an operation for setting the final fuel injection quantity Q_{FINC} which is performed in step 311.

[0056] In step 401, the engine revolutions NE and the accelerator opening ACCP read in step 301 shown in FIG. 3 are used to read the required fuel injection quantity Q_{GOV} from the numeric map stored in the ROM of the ECU 30. In step 403, the value of NE is likewise used to read the guard value Q_{FULL} for the fuel injection quantity from the numeric map stored in the ROM of the ECU 30.

[0057] In step 405, the basic fuel injection quantity Q_{BASE} is set to the value either Q_{GOV} or Q_{FULL} whichever smaller in accordance with Equation (7).

$$Q_{BASE} = MIN\,(Q_{GOV}, Q_{FULL}) \qquad (7)$$

[0058] In step 407, the fuel injection correction quantity Q_{JRKFB} which has been calculated in steps 307 and 309 shown in FIG. 3 and used to prevent torsional vibrations is used to set the fuel injection quantity Q_{FIN} in accordance with Equation (8).

$$Q_{FIN} = Q_{BASE} + Q_{JRKFB} \qquad (8)$$

[0059] Since the Q_{JRKFB} is set to be a great value when the torsional vibrations are relatively strong, this embodiment has a structure in which the value of Q_{FIN} calculated in Equation (8) is limited again in step 309 using the guard value Q_{FULL}. In accordance with Equation (9), the final fuel injection quantity Q_{FINC} is calculated.

$$Q_{FINC} = MIN\,(Q_{FIN}, Q_{FULL}) \qquad (9)$$

[0060] In step 411, the value of the final fuel injection quantity Q_{FINC} is set for the fuel injection circuit, and the foregoing operation is completed.

[0061] As a result, the fuel injection quantity to be supplied to the engine 1 is corrected to cancel the variation in the revolutions caused only by the torsional vibrations. Therefore, the torsional vibrations can be prevented without deteriorating the acceleration performance of the vehicle.

[0062] The hunting preventive operation performed in step 309 shown in FIG. 3 will now be described. In this embodiment, the torsional vibration preventive control is performed in accordance with a variation in the revolutions (which is a variation in the revolutions for each cylinder of a 4-cylinder and 4-cycle engine used in this embodiment) detected whenever the crank shaft of the engine rotates at 180. However, the combustion conditions of the actual engine slightly differ depending on the respective cylinders even if no torsional vibration is being produced. Therefore, the output torque from the respective cylinders is different. The variation in the torque may fluctuate the engine revolutions in the explosion strokes of the respective cylinders in spite of the steady operating state. Therefore, there is a possibility of hunting if the cycles for detecting the variation in the revolutions for preventing the torsional vibrations coincide with the cycles of the variations in the revolutions of the respective cylinders. If no torsional vibration is generated, the variation in the revolutions of the respective cylinders is undesirably detected as ΔNE during the control shown in FIG. 3. Therefore, the error in correcting the fuel injection quantity may cause the variation in the revolutions to undesirably be amplified.

[0063] In this embodiment, it is determined whether or not there is a possibility of hunting in accordance with an inverse timing pattern of the sign of the torsional vibration component ΔNE_{TV} and calculated in step 305 shown in FIG. 3. If it is determined that the pattern for causing the hunting is formed, the correction of the fuel injection quantity is interrupted (that is, the correction quantity Q_{JRKFB} is set to zero, $Q_{RKFB} = 0$) so that hunting caused by an error in correcting the fuel injection quantity is prevented.

[0064] The determination of hunting according to this embodiment will now be described. In this embodiment, the variation component ΔNE_{TV} is calculated whenever the crank shaft rotates at 180°. Since the 4-cylinder 4-cycle engine is used in this embodiment, the fuel injection is performed at an angular interval of 180°. Therefore, if the sign of ΔNE_{TV} is inverted at each calculating operation (at each 180°), the fuel injection quantity has been corrected excessively, thus it is determined that the fuel injection quantity has been corrected excessively. As a result, it is determined that hunting has occurred. If the sign of ΔNE_{TV} is positive in the previous calculating operation, the correction is performed to reduce the fuel injection quantity to decrease the revolutions. In this case, when the sign of the present ΔNE_{TV} is negative in the present calculating operation, an excessively large quantity has been reduced in the previous correction of the fuel injection quantity. This means that the engine revolutions have been excessively decreased. Therefore, the fuel injection quantity Q_{BASE} is corrected to be raised at the present correction. Therefore, when the sign of ΔNE_{TV} is inverted at each calculating operation (at each 180°), the fuel injection quantity is alternately corrected to be reduced and raised. Accordingly, the controlling operation is likely to become unstable, and thus, there is a possibility of hunting.

[0065] In the following case, hunting will occur:

> when the sign of ΔNE_{TV} is inverted at intervals of two calculating operations (that is, one revolution of the engine ($180° \times 2 = 360°$)) (for example, in the case where the following reverse is repeated in which a positive value is assumed during one revolution of the engine and a negative value is assumed during the subsequent one revolution of the engine); and
> when the following reverse is repeated in which the sign of ΔNE_{TV} successively assumes a positive (or negative) value three times and then the sign in the next time assumes a negative (or positive) value.

[0066] Therefore, in this embodiment, an influence of an error in detection exerted from influences of noise and disturbance is added to the foregoing patterns so that the hunting pattern as shown in FIG. 6 is preliminarily set. The hunting pattern shown in FIG. 6 will be described later.

[0067] FIG. 5 is a flow chart showing the hunting preventive operation which is performed in step 309 as shown in FIG. 3.

[0068] In step 501, it is determined whether or not the sign of ΔNE_{TV} calculated in step 305 shown in FIG. 3 has been inverted from that calculated in the previous operation (whether or not the sign has been inverted). If the sign has not been inverted, the operation proceeds to step 505 where the count of a counter C_1 is increased by one. Steps 507 and 509 execute the limiting operation such that the value of the C_1 does not exceed the maximum value C_{MAX}. As a result, the count of the counter C_1 is increased to the maximum value C_{MAX} if the sign of the ΔNE_{TV} is kept as being either positive or negative.

[0069] If it is determined in step 501 that the sign of ΔNE_{TV} has been inverted, the operation proceeds to step 503 where the values of counters C_2 and C_1 are substituted for the values of the counters C_3 and C_2. Moreover, the value of the counter C_1 is set to one.

[0070] As a result, the hysteresis of the reverse of the sign of ΔNE_{TV} in the three previous operations is stored in the counters C_3, C_2 and C_1.

[0071] For example, the relation $C_3 = C_2 = C_1 = 1$ represents that the sign of ΔNE_{TV} is inverted at each operation. The relation $C_3 = C_2 = 2$ represents that the sign of ΔNE_{TV} is inverted once in two operations. The relation $C_3 = 3$ and $C_2 = 1$, or $C_3 = 1$ and $C_2 = 3$ represents the variation cycle in which the ΔNE_{TV} repeatedly assumes the value with the same sign three times and then assumes the value with the inverted sign.

[0072] In step 511, hunting is determined in accordance with the counters C_1, C_2 and C_3. In step 511, it is determined whether or not there is a possibility of hunting in accordance with a map shown in FIG. 6.

[0073] FIG. 6 shows the map having an axis of ordinate as the values of the counter C_2 and an axis of abscissa as the values of the counter C_3. Points A to D shown in the map correspond as follows:

A: $C_3 = C_2 = 1$

B: $C_3 = C_2 = 2$

C: $C_3 = 3, C_2 = 1$

D: $C_3 = 1, C_2 = 3$

[0074] That is, the point A indicates reverse of the sign of ΔNE_{TV} in each operation, B indicates reverse of the sign of ΔNE_{TV} once in two operations and C and D indicate continuation of the same sign in three successive operations followed by the inverted sign only once. The above conditions are shown as the representative examples under which hunting occurs. That is, the points A to D on the map are basic conditions for determining occurrence of hunting. Therefore, in this embodiment, if the combination of the counters C_3 and C_2 satisfies any one of the points A to D, it is determined that the hunting has occurred. In an actual operation, the detection of the engine revolutions NE encounters an error owing to noise or disturbance. Therefore, determination on the possibility of hunting in accordance only with the basic conditions may not be accurately performed. Therefore, in this embodiment, influences of noise and the like are considered and thus a possibility of hunting is determined when the values of C_2 and C_3 fall in the diagonal-line region on the map shown in FIG. 6. The diagonal-line region shown in FIG. 6 is defined by lines expressed by the following equations: $C_2 = C_3 + 2$ (line I), $C_2 = C_3 - 2$ (line II) and $C_2 = -C_3 + 8$ (line III). That is, the conditions for determining hunting according to this embodiment are as follows:

$$C_3 - 2 \le C_2 \le C_3 + 2; \text{ and}$$

$$C_2 + C_3 \le 8$$

[0075] The values of C_2 and C_3 are kept unchanged during proceeding of the operation from step 501 to step 505. Therefore, if hunting is determined once under the aforementioned determining conditions, the determination of hunting is not canceled even if the sign of ΔNE_{TV} is no longer inverted. Therefore, in this embodiment, a condition in which the value of the counter C_1 is, in step 511, smaller than the value of the counter C_2 or C_3 is added to the conditions for determining hunting. The fact that the value of C_1 is smaller than the value of C_2 or C_3 represents that the number of times at which the ΔNE_{TV} is kept to have the same sign has been decreased as compared with the previous number of times. That is, hunting is being strengthened. When the value of C_1 is larger than both values of C_2 and C_3, it is determined that hunting has been eliminated.

[0076] That is, conditions under which occurrence of hunting is determined in step 511 shown in FIG. 5 are as follows:

$$C_3 - 2 \le C_2 \le C_3 + 2; \text{ and}$$

$$C_2 + C_3 \le 8; \text{ and}$$

$$C_1 \le C_2 \text{ or } C_1 \le C_3$$

[0077] When the counters C_1, C_2 and C_3 satisfy the aforementioned conditions in step 511, that is, when there is a possibility of hunting at present, the operation proceeds to step 513 where the value of the correction quantity Q_{JRKFB} set in step 307 shown in FIG. 3 is set to zero. As a result, the value of the final fuel injection quantity Q_{FINC} set in step 409 shown in FIG. 4 coincides with the Q_{BASE}. In the foregoing case, hunting is caused by the correction of the fuel injection quantity for the purpose of preventing torsional vibrations, resulting in a possibility of strengthened vibrations or unstable control. Therefore, the correction of the fuel injection quantity is not executed. If the values of the counters do not satisfy the aforementioned conditions in step 511 and there is no possibility of hunting, the value of the correction quantity Q_{JRKFB} is kept unchanged and the operation is completed in this state. As a result, the correction of the fuel injection quantity for the purpose of preventing torsional vibrations is executed.

[0078] It is preferable that the diagonal-line region shown in FIG. 6 is determined by experiments using an actual engine and an output shaft system.

[0079] In step 513 shown in FIG. 5, the correction quantity Q_{JRKFB} is set to zero and the correction of the fuel injection quantity is not executed in case of a possibility of hunting. The value of the correction quantity Q_{JRKFB} may be reduced in accordance with Equation (10) in place of the setting $Q_{JRKFB} = 0$. Thus, the control gain is reduced and the torsional vibrations are controlled to a certain degree while preventing hunting.

$$Q_{JRKFB} = Q_{JRKFB} \times \beta \; (\beta < 1) \qquad (10)$$

[0080] As described above, according to the present invention, torsional vibrations can effectively be prevented without deteriorating the engine acceleration characteristics.

[0081] An apparatus and a method for controlling fuel injection in an internal combustion engine (1) for preventing torsional vibrations of the engine without deteriorating the acceleration performance is disclosed. The apparatus is provided with a control unit (an ECU) (30) for controlling a fuel injection quantity for the diesel engine (1) of a vehicle (10). The ECU (30) calculates the change rate ΔNE of engine revolutions in accordance with an input from a crank angle sensor (35) and subtracts a value obtained by smoothing a variation component of ΔNE from the ΔNE so as to extract a torsional vibration component thereof. Moreover, the ECU (30) corrects the fuel injection quantity of the engine to reduce the torsional vibration component. Since the extracted torsional vibration component does not contain steady change in the revolutions during acceleration or the like, the steady change in the revolutions caused only by the acceleration is not affected by the correction of the fuel injection quantity. Therefore, deterioration in the acceleration performance caused by prevention of the torsional vibrations can be prevented.

Claims

1. An apparatus for controlling fuel injection in an internal combustion engine (1) including vibrations detection means for detecting a quantity of state relating to the amplitude of torsional vibrations of an output shaft system (5, 8) of a vehicle (10) as a torsional vibration parameter, and a fuel injection quantity correction means for correcting a fuel injection quantity of the internal combustion engine (1) to prevent torsional vibrations in accordance with said detected torsional vibration parameter, characterized in that:

   said fuel injection quantity correction means is adapted to determine and store a change rate of said torsional vibration parameter which has occurred within a predetermined period as a hysteresis value;
   a vibration component extracting means is provided to extract a torsional vibration component from said detected torsional vibration parameter using said hysteresis value; and
   in that said fuel injection quantity correction means is further adapted to correct the fuel injection quantity in accordance with the magnitude of said torsional vibration component.

2. An apparatus for controlling fuel injection according to claim 1, characterized in that:

   said vibration component extracting means is provided to store a value obtained by smoothing change in said torsional vibration parameter which has occurred within the predetermined period as said hysteresis value; and
   said vibration component extracting means is adapted to set a value obtained by subtracting said hysteresis value from a change rate of the present torsional vibration parameter as a present torsional vibration component.

3. An apparatus for controlling fuel injection according to claim 1 or 2, characterized in that:

   said fuel injection quantity correction means is adapted to calculate a vibration correction quantity of the fuel injection quantity in accordance with said extracted torsional vibration component and to add said vibration correction quantity to a fuel injection quantity which is set in accordance with a state of the operation of the engine so as to correct the fuel injection quantity, and to reduce the absolute value of said vibration correction quantity when an inverse timing pattern of the sign of said torsional vibration component coincides with a predetermined pattern.

4. An apparatus for controlling fuel injection according to claim 3, characterized in that said fuel injection quantity correction means is adapted to interrupt the correction of the fuel injection when the reverse timing pattern of the sign of said torsional vibration component coincides with the predetermined pattern.

5. Method for controlling fuel injection in an internal combustion engine (1) including vibrations detection means for detecting a quantity of state relating to the amplitude of torsional vibrations of an output shaft system (5, 8) of a vehicle (10) as a torsional vibration parameter, and a fuel injection quantity correction means for correcting a fuel injection quantity of the internal combustion engine (1) to prevent torsional vibrations in accordance with said detected torsional vibration parameter, characterized by the following steps:

   said fuel injection quantity correction means (30) stores a change rate of said torsional vibration parameter which has occured within a predetermined period as a hysteresis value;
   vibration component extracting means (30) extract a torsional vibration component from said detected torsional vibration parameter using said hysteresis value; and
   the fuel injection quantity is corrected in accordance with the magnitude of said torsional vibration component.

6. Method for controlling fuel injection according to

claim 5, characterized in that:

said vibration component extracting means stores a value obtained by smoothing change in said torsional vibration parameter which has occurred within the predetermined period as said hysteresis value; and

said vibration component extracting means sets a value obtained by subtracting said hysteresis value from a change rate of the present torsional vibration parameter as a present torsional vibration component.

7. Method for controlling fuel injection according to claim 5 or 6, characterized in that:

said vibration component extracting means extracts said torsional vibration component at a predetermined time interval; and

said fuel injection quantity correction means calculates a vibration correction quantity of the fuel injection quantity in accordance with said extracted torsional vibration component and adds said vibration correction quantity to a fuel injection quantity which is set in accordance with a state of the operation of the engine so as to correct the fuel injection quantity, and to reduce the absolute value of said vibration correction quantity when an inverse timing pattern of the sign of said torsional vibration component coincides with a predetermined pattern.

8. Method for controlling fuel injection according to claim 7, characterized in that said fuel injection quantity correction means interrupts the correction of the fuel injection when the reverse timing pattern of the sign of said torsional vibration component coincides with the predetermined pattern.

FIG. 1

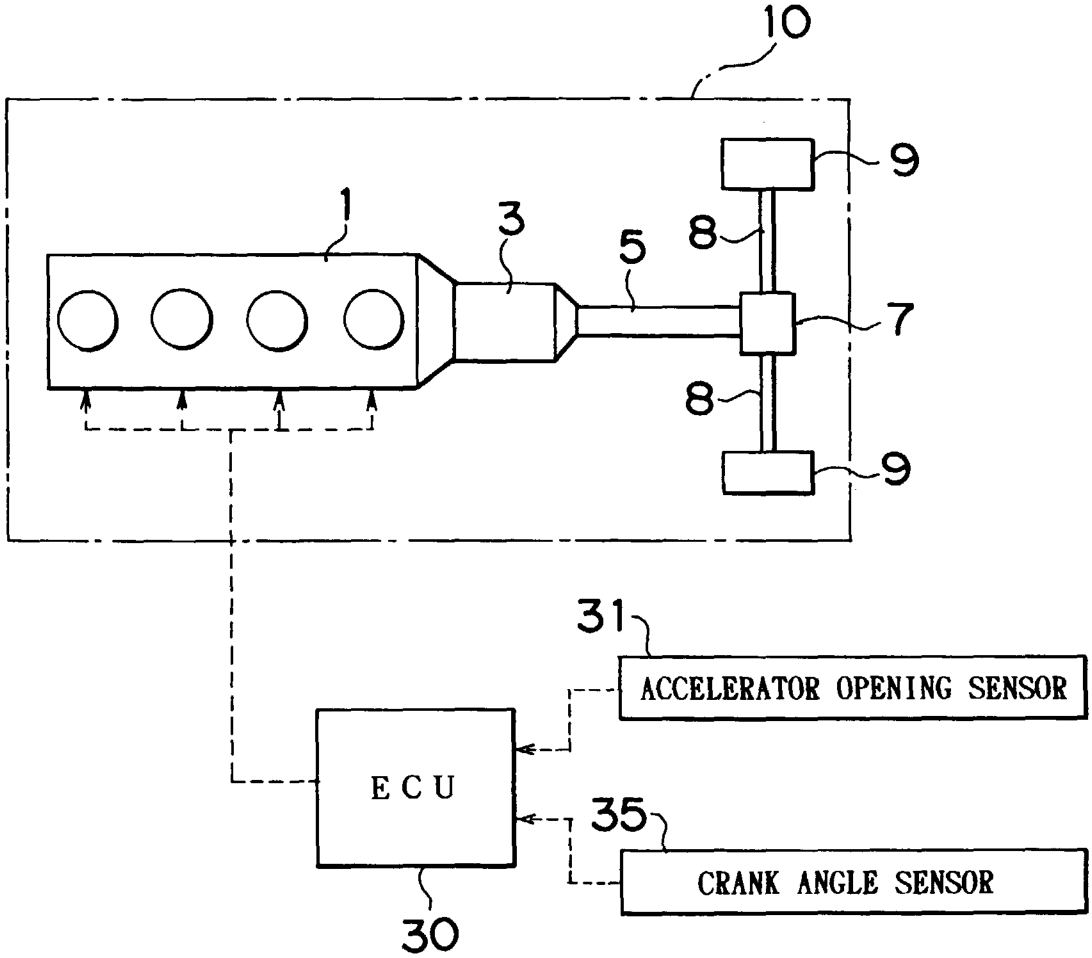
10
9
1
3
5
8
7
8
9
31
ACCELERATOR OPENING SENSOR
ECU
35
CRANK ANGLE SENSOR
30

FIG. 2A

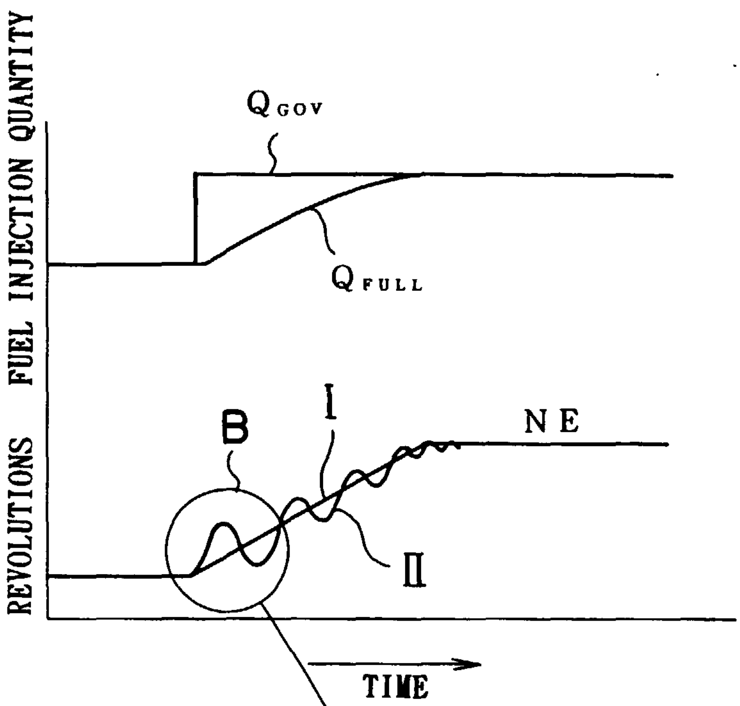
FUEL INJECTION QUANTITY
REVOLUTIONS
Q_{GOV}
Q_{FULL}
B
I
NE
II
TIME

FIG. 2B

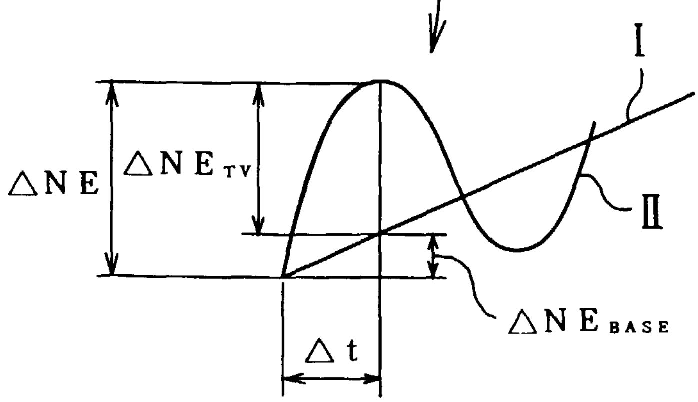
I
ΔNE
ΔNE_{TV}
II
ΔNE_{BASE}
Δt

FIG. 3

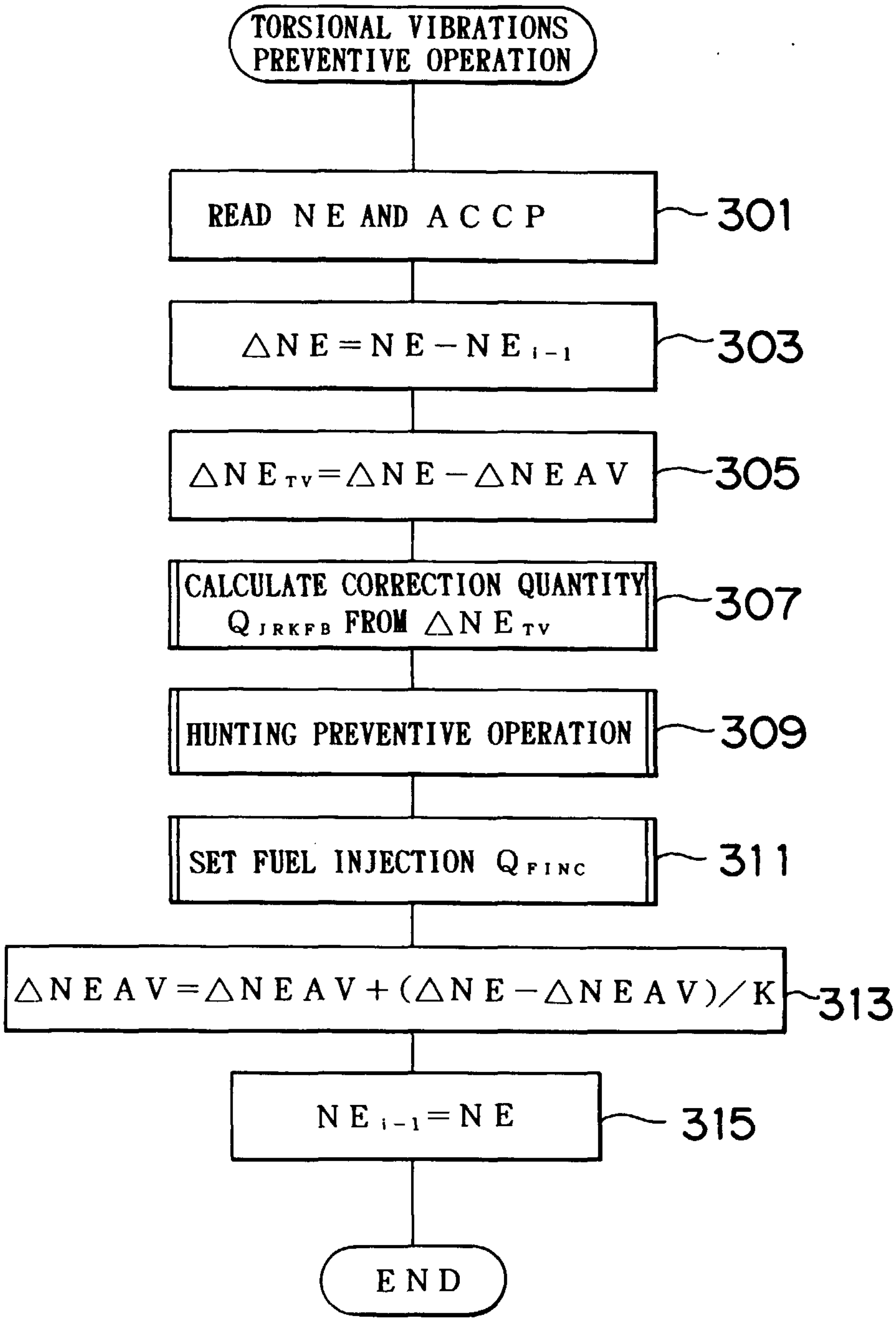
TORSIONAL VIBRATIONS PREVENTIVE OPERATION
READ NE AND ACCP
301
ΔNE=NE−NE i−1
303
ΔNE TV=ΔNE−ΔNEAV
305
CALCULATE CORRECTION QUANTITY Q JRKFB FROM ΔNE TV
307
HUNTING PREVENTIVE OPERATION
309
SET FUEL INJECTION Q FINC
311
ΔNEAV=ΔNEAV+(ΔNE−ΔNEAV)/K
313
NE i−1=NE
315
END

FIG. 4

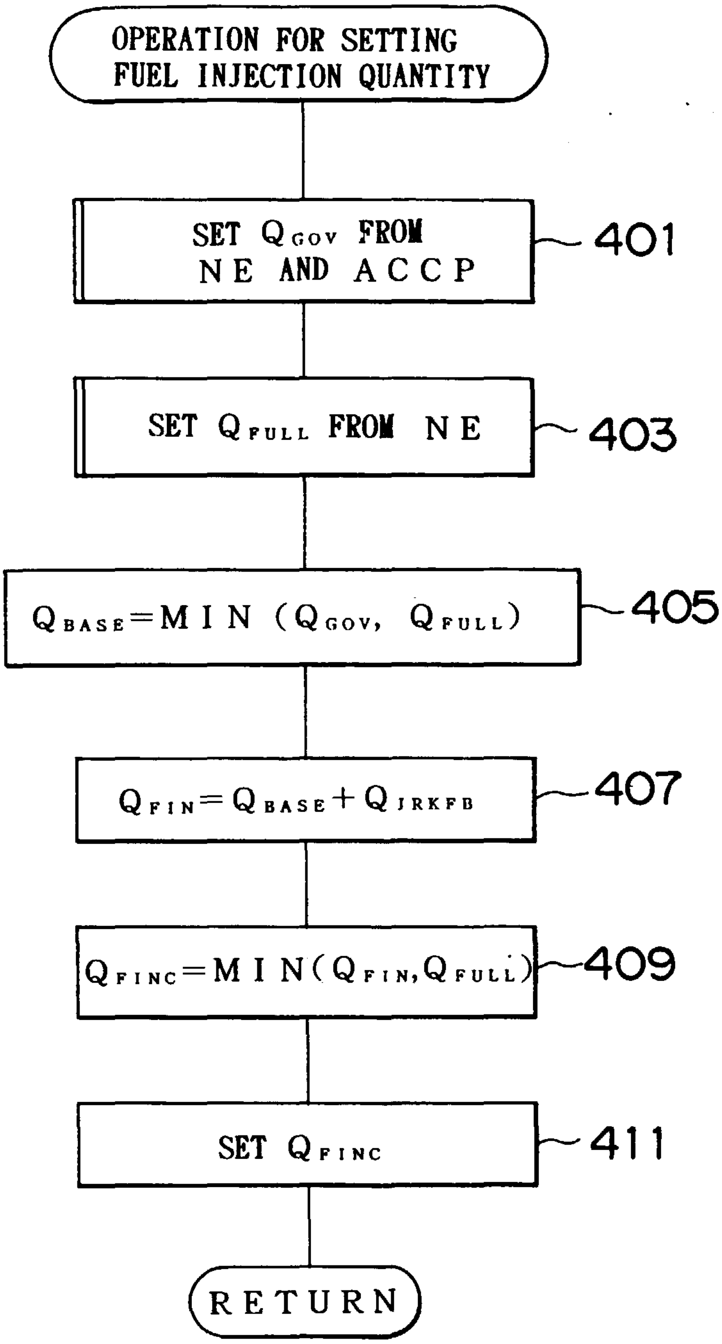
OPERATION FOR SETTING FUEL INJECTION QUANTITY
SET Q GOV FROM NE AND ACCP
401
SET Q FULL FROM NE
403
Q BASE=MIN (Q GOV, Q FULL)
405
Q FIN=Q BASE+Q JRKFB
407
Q FINC=MIN(Q FIN,Q FULL)
409
SET Q FINC
411
RETURN

FIG. 5

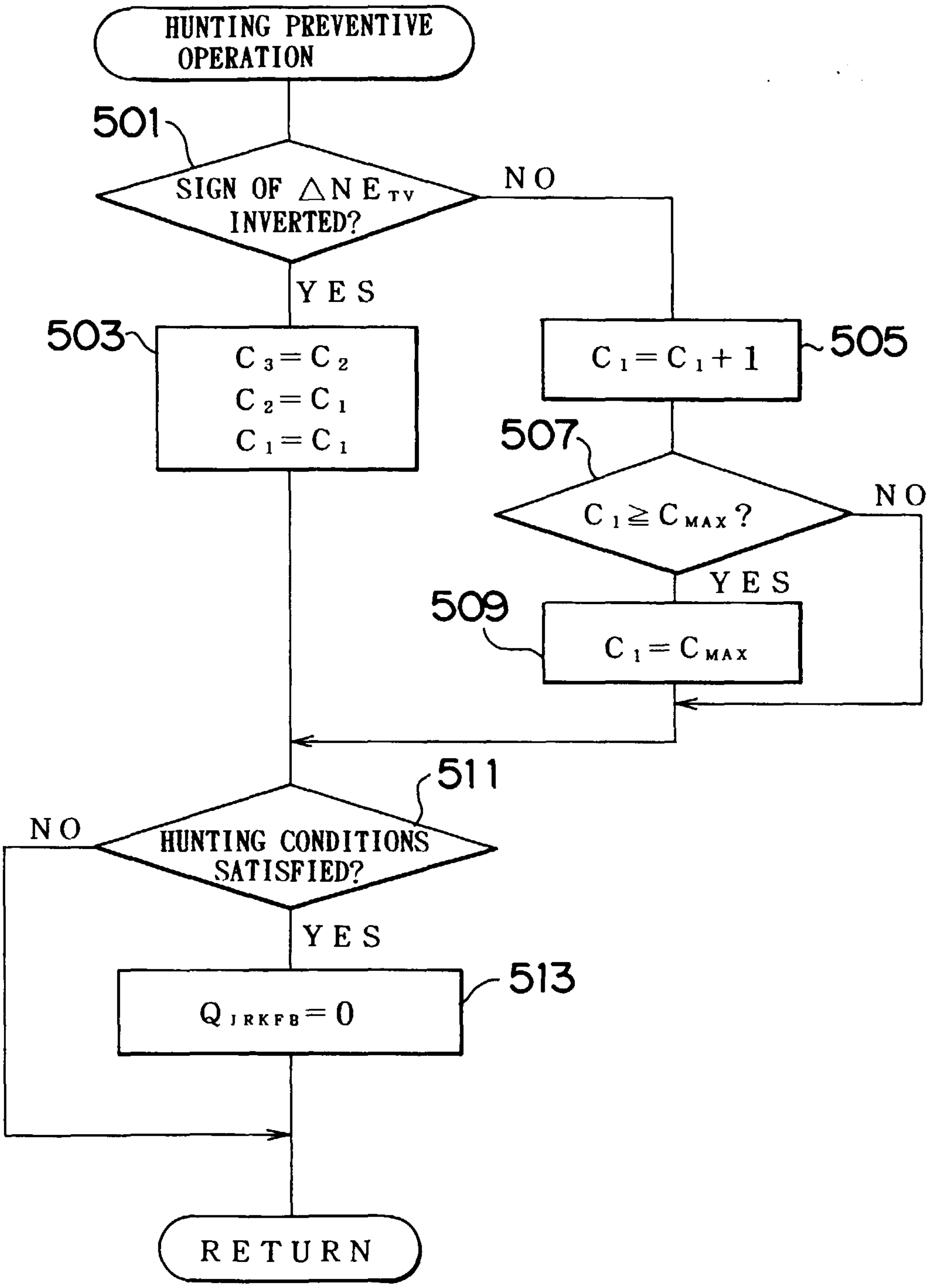
HUNTING PREVENTIVE OPERATION
501
SIGN OF △NE TV INVERTED?
NO
YES
503
C3=C2
C2=C1
C1=C1
C1=C1+1
505
507
C1≧CMAX?
NO
YES
509
C1=CMAX
511
HUNTING CONDITIONS SATISFIED?
NO
YES
513
QJRKFB=0
RETURN

FIG. 6