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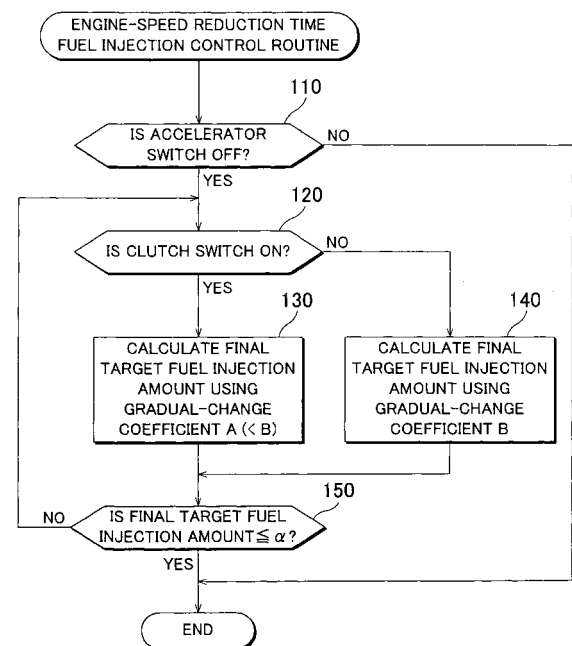
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(54) **Fuel injection control apparatus and method for internal combustion engine**

(57) A clutch switch (56) and an electronic control unit (61) are provided in a vehicle (11) in which transfer of torque output from an engine (12) to a manual transmission (39) can be interrupted by disengaging a clutch (38), provided between the engine (12) and the manual transmission (39), based on an operation of a clutch pedal (42). When an action to reduce the speed of the engine (12) is made ("YES" in step 110), the electronic control unit (61) determines, in step 120, the state of the clutch (38) based on the result of detection obtained by the clutch switch (56). If it is determined that the clutch (38) is engaged, the electronic control unit (61) gradually reduces the amount of fuel injected, in step 140. If it is determined that the clutch (38) is disengaged, the electronic control unit (61) gradually reduces the amount of fuel injected at a rate higher than that used if it is determined that the clutch (38) is engaged, in step 130.

FIG. 3



Description

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

[0001] The invention relates to a fuel injection control apparatus and method used in a vehicle in which transfer of torque output from an internal combustion engine to a transmission may be interrupted by disengaging a clutch, provided between the internal combustion engine and the transmission, based on the operation of the clutch operating portion.

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2. Description of the Related Art

[0002] Vehicles in which transfer of torque output from the internal combustion engine to a manual transmission can be interrupted by disengaging the clutch based on the operation of a clutch pedal are known. In such vehicles, after a driver's action to reduce the engine speed is made, the amount of fuel injected is gradually reduced, also known as "gradual-change control" or "smoothing control". Executing the gradual-change control reduces the torque output from the engine, and, therefore, suppresses rapid changes in torque output from the internal combustion engine (i.e., a torque shock), which tends to occur when the amount of fuel injected is rapidly reduced, or when fuel injection ceases.

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[0003] However, in the case where a driver's action to reduce the engine speed is made, if the gradual-change control is executed while the clutch is disengaged, the engine speed, which is supposed to decrease, may temporarily increase instead. This occurs because the execution of the gradual-change control does not cease fuel injection, it only reduces the amount of fuel injected. As such, the load, applied to the internal combustion engine from the drive system, is no longer applied because the clutch has been disengaged. To avoid such a problem, the gradual-change control should not be executed, namely, fuel injection ceases, if the clutch is disengaged when an action to reduce the engine speed is made. With this configuration, rapid increases in engine speed can be suppressed.

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[0004] For example, Japanese Patent Application Publication No. 63-140842 A discloses execution of fuel injection control in different manners depending on whether the clutch is disengaged or engaged. According to the technology disclosed in this publication, the threshold engine speed is set based on the operation of the accelerator pedal and the amount of fuel injected is controlled such that the engine speed does not exceed the threshold engine speed when the clutch is disengaged.

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[0005] Whether the clutch is engaged or disengaged is determined based on a signal from the clutch switch provided near the clutch pedal. This clutch switch is turned ON, when the clutch pedal is at a position in the depression side with respect to the predetermined position.

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[0006] However, the clutch switch is usually turned ON before the clutch is actually disengaged. Accordingly, in the state where an action to reduce the engine speed is made, if fuel injection ceases based on the determination that the clutch has been disengaged, which is made just because the clutch switch has been turned ON, another problem may arise. More specifically, negative torque may be generated in the internal combustion engine due to the cease of fuel injection. Such negative torque is continuously transferred to the components in the drive system until the clutch is actually disengaged. Accordingly, the components in the drive system are twisted such that the engine speed is reduced, and torsion torque accumulates. When the clutch is finally disengaged, the torsion torque thus accumulated is released all at once, and the components in the drive system may vibrate and rattle as a result.

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[0007] According to the technology disclosed in Japanese Patent Application Publication No. 63-140842 A, the amount of fuel injected is controlled such that the engine speed does not exceed the threshold engine speed corresponding to the accelerator pedal operation amount, when the clutch is disengaged. Accordingly, vibration does not occur easily among the components in the drive system. However, fuel injection continues, and, in addition, the amount of fuel injected is not reliably reduced. As a result, the engine speed may still increase.

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SUMMARY OF THE INVENTION

[0008] The invention is made in light of the above-mentioned circumstances. It is, therefore, an object of the invention to provide a fuel injection control apparatus for an internal combustion engine that can suppress both rapid increases in the engine speed when a clutch is disengaged and vibration among components in the drive system.

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[0009] Hereafter, means for achieving the above-mentioned object, and the effects thereof will be described in detail. According to an aspect of the invention, there is provided a fuel injection control apparatus for an internal combustion engine used in a vehicle in which transfer of torque output from the internal combustion engine to a transmission can be interrupted by disengaging a clutch, provided between the internal combustion engine and the transmission, based on the operation of a clutch operating portion. This fuel injection control apparatus includes engine-speed-reduction action determining means for determining whether an action to reduce the speed of the internal combustion engine is

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made; operation position detecting means for detecting the position of the clutch operating portion; clutch state determining means for determining the state of the clutch based on the result of detection obtained by the operation position detecting means; fuel injection amount gradual-change means that changes the amount of fuel injected in the internal combustion engine when the engine-speed-reduction action determining means determines that the action to reduce the speed of the internal combustion engine is made, by gradually reducing an amount of fuel injected in the internal combustion engine at a predetermined rate when the clutch state determining means determines that the clutch is engaged; and by gradually reducing the amount of fuel injected in the internal combustion engine at a rate that is higher than the predetermined rate when the clutch state determining means determines that the clutch is disengaged.

[0010] With such a configuration, the driver may engage or disengage the clutch through the operation of the clutch operating portion. Then, transfer of the torque output from the internal combustion engine to the transmission may be interrupted when the clutch is disengaged. When the clutch is engaged or disengaged through the operation of the clutch operating portion, the position of the clutch operating portion is detected by the operation position detecting means. Also, the clutch state determining means determines the state of the clutch (whether the clutch is engaged or disengaged) based on the position of the clutch operating portion, which is detected by the operation position detecting means.

[0011] The engine-speed-reduction action determining means determines whether the driver has made an action to reduce the speed of the internal combustion engine.

When the engine-speed-reduction determining means determines that an action to reduce the engine speed is made, and the clutch state determining means determines that the clutch is engaged, the fuel injection amount gradual-change means gradually reduces the amount of fuel injected in the internal combustion engine at the predetermined rate. Because the amount of fuel injected is gradually reduced, the torque output from the internal combustion engine is gradually reduced. As a result, a rapid change (a torque shock), which is likely to occur when the amount of fuel injected is rapidly reduced (fuel injection ceases), can be suppressed.

[0012] However, when the action to reduce the speed of the internal combustion engine is made, and it is determined that the clutch is disengaged and the amount of fuel injected is gradually reduced, fuel injection is continued even when the clutch is actually disengaged. Meanwhile, because the clutch has been disengaged, the load from the drive system is no longer applied to the internal combustion engine via the clutch. Therefore, in the state where such fuel injection is executed, if the clutch is disengaged and the load applied from the drive system to the internal combustion engine is reduced, the engine speed may rapidly increase. Such a rapid increase in the internal combustion engine is more likely to occur, as the amount of fuel injected when the clutch is disengaged becomes larger.

[0013] According to the above-mentioned aspect, however, when the engine-speed-reduction determining means determines that the action to reduce the engine speed is made, and the clutch state determining means determines that the clutch is disengaged, the amount of fuel injected is gradually reduced at a rate that is higher than the predetermined rate that is used if it is determined that the clutch is engaged. Namely, the amount of fuel injected is reduced at a lower rate than that used when the amount of fuel injected is not gradually but rapidly reduced (fuel injection ceases), but is higher than that used when the clutch is engaged. Accordingly, the rapid increase in the engine speed due to disengagement of the clutch is suppressed more effectively, than when the amount of fuel injected is reduced at the same rate as that used if it is determined that the clutch is engaged.

[0014] When the amount of fuel injected is reduced because it is determined that the action to reduce the speed of the internal combustion engine is made and the clutch is disengaged, negative torque is generated in the internal combustion engine. If the determination that the clutch is disengaged is made before the clutch is actually disengaged, the negative torque is continuously transferred to the components in the drive system from the time the above determination is made until the clutch is actually disengaged. Accordingly, the components in the drive system are twisted such that the engine speed is reduced, and torsion torque accumulates. Such accumulated torsion torque varies depending on the amount of fuel injected. The torsion torque increases as the amount of fuel injected decreases. When the fuel injection ceases (when the amount of fuel injected becomes "0"), the torsion torque becomes the maximum value.

[0015] According to the above-mentioned aspect, if it is determined that the action to reduce the engine speed is made and the clutch is disengaged, the amount of fuel injected is gradually reduced, as described above. Accordingly, the amount of fuel injected is larger, the negative torque generated in the internal combustion engine is lower, and the torsion torque accumulated in the components in the drive system is lower, than when the fuel injection ceases. Therefore, when the clutch is actually disengaged, although the accumulated torsion torque is released, the torsion torque is low. Therefore, the components in the drive system do not easily vibrate and rattle.

[0016] As described so far, according to the above-mentioned aspect, when the action to reduce the engine speed is made and the clutch is engaged, occurrence of a torque shock can be suppressed. Also, when the action to reduce the engine speed is made and the clutch is disengaged, a rapid increase in the engine speed and occurrence of vibration among the components in the drive system can be suppressed.

[0017] In the above-mentioned aspect, the engine-speed-reduction determining means may determine whether the action to reduce the speed of the internal combustion engine is made based on the operation of the accelerator operating portion. By using the operation, for example, the displacement and the position of the accelerator operating portion to

determine whether such an action is made, the intention of the driver (the action to reduce the engine speed) can be directly obtained. As a result, whether the fuel injection amount gradual-change means needs to gradually reduce the amount of fuel injected can be reliably determined, and the amount of fuel injected can be gradually changed only when required.

5 **[0018]** In the above-mentioned aspect, the clutch state determining means may determine that the clutch is disengaged, at a predetermined time that is before the clutch is actually disengaged. In addition, the operation position detecting means may be a switch, or a sensor that detects the position of the clutch operating portion (42).

[0019] In the above-mentioned aspect, the fuel injection amount gradual-change means may calculate a final target fuel injection amount based on a gradual-change coefficient, a target fuel injection amount in a control cycle presently being executed, and a final target fuel injection amount in an immediately preceding control cycle; and may gradually reduce the amount of fuel injected in the internal combustion engine based on the calculated final target fuel injection amount.

10 **[0020]** In the above-mentioned aspect, the fuel injection amount gradual-change means may calculate the final target fuel injection amount by subtracting the predetermined value from the final target fuel injection amount in the immediately preceding control cycle, and may gradually reduce the amount of fuel injected in the internal combustion engine based on the calculated final target fuel injection amount. In addition, the predetermined value that is used when the clutch state determining means determines that the clutch is disengaged may be greater than the predetermined value that is used when the clutch state determining means determines that the clutch is engaged.

20 BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

25 FIG. 1 illustrates the structure of a fuel injection control apparatus for an internal combustion engine according to an embodiment of the invention;

FIG. 2 illustrates the positional relationship among the engine, the clutch, the manual transmission, etc. in the vehicle;

FIG. 3 illustrates the flowchart including the step for gradually changing the amount of fuel injected when an action to reduce the engine speed is made;

30 FIG. 4 illustrates the time chart indicating how the final target fuel injection amount, the engine speed, etc. change when the clutch is engaged in the case where an action to reduce the engine speed is made; and

FIG. 5 (A to E) illustrate the time chat indicating how the final target fuel injection amount, the engine speed, etc. change when the clutch is disengaged in the case where an action to reduce the engine speed is made.

35 DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[0022] Hereafter, an embodiment of the invention will be described with reference to the accompanying drawings. As shown in FIG. 1 and FIG. 2, a gasoline engine (hereinafter, simply referred to as an "engine") 12 that serves as the drive power source is mounted in a vehicle 11. The gasoline engine 12 includes a cylinder block 14 provided with a plurality of cylinders 13. Pistons 15 are housed in the respective cylinders 13 so as to be able to reciprocate therein. Each piston 15 is connected to a crankshaft 17 that serves as the output shaft of the engine 12 via a connecting rod 16. The reciprocation of each piston 15 is converted into rotational movement by the connecting rod 16, and then transferred to the crankshaft 17.

40 **[0023]** Combustion chambers 18 formed in the respective cylinders 13 are connected to an intake passage 23 provided with a throttle valve 19, a surge tank 21, an intake manifold 22, and the like. The air present outside the engine 12 sequentially passes through the throttle valve 19, the surge tank 21, and the intake manifold 22 to be taken in the combustion chambers 18. The throttle valve 19, which is able to turn, is provided in the intake passage 23 at a position upstream of the surge tank 21, and driven by an actuator 24 such as an electric motor. An accelerator pedal 25 that serves as the acceleration control portion is provided in the vehicle compartment. The actuator 24 is actuated, for example, when the driver depresses the accelerator pedal 25, to turn the throttle valve 19. The amount of air flowing through the intake passage 23 (hereinafter, referred to as the "intake air amount") varies based on the turning angle of the throttle valve 19 (hereinafter, referred to as the "throttle valve opening-amount").

[0024] Also, an exhaust passage 28 provided with an exhaust manifold 26, a catalytic converter 27 and the like is connected to the combustion chambers 18. The combustion gas generated in the combustion chambers 18 sequentially passes through the exhaust manifold 26 and the catalytic converter 27 to be discharged to the outside of the engine 12.

55 **[0025]** The engine 12 is provided with intake valves 29 that permit/interrupt communication between the intake passage 23 and the respective combustion chambers 18; and exhaust valves 31 that permit/interrupt communication between the exhaust passage 28 and the respective combustion chambers 18. The intake valves 29 and the exhaust valves 31 are provided so as to reciprocate. The intake valves 29 are driven by an intake camshaft 32 and the like that rotate in

accordance with the crankshaft 17. Also, the exhaust valves 31 are driven by an exhaust camshaft 33 and the like that rotate in accordance with the crankshaft 17.

5 [0026] The engine 12 is provided with electromagnetic fuel injection valves 34 that open, when supplied with electric power, to inject fuel. Each fuel injection valve 34 injects fuel to a portion (an intake port) at which the intake passage 23 and the combustion chamber 18 are communicated with each other. The fuel injection valve 34 may inject fuel directly into the combustion chamber 18.

10 [0027] The amount of fuel injected from each fuel injection valve 34 is basically determined based on the length of time electric power is supplied to the fuel injection valve 34, that is, the length of time the fuel injection valve 34 is open. The fuel injected from the fuel injection valve 34 and the air flowing through the intake passage 23 are mixed with each other to generate the air-fuel mixture.

15 [0028] In the engine 12, spark plugs 35 are provided for the respective cylinders 13. Each spark plug 35 is driven based on an ignition signal transmitted from an igniter 36. A high voltage output from an ignition coil 37 is applied to the spark plug 35. The air-fuel mixture is ignited by a spark made by the spark plug 35, and burned. The combustion gas having high temperature and high pressure generated at this time causes the piston 15 to reciprocate. Then, the crankshaft 17 rotates, and the engine 12 generates the driving force (i.e., torque is output from the engine 12). The gas (exhaust gas) generated by the combustion is discharged to the exhaust passage 28 when the exhaust valve 31 opens.

20 [0029] An input shaft 41 of a manual transmission 39 is connected to the crankshaft 17 of the engine 12 via a clutch 38. The clutch 38 is mechanically coupled with a clutch pedal 42 that serves as the clutch operating portion provided in the vehicle compartment. The driver may engage or disengage the clutch 38 through the operation of the clutch pedal 42. When the clutch 38 is engaged, the torque output from the crankshaft 17 is transferred to the input shaft 41 via the clutch 38. On the other hand, when the clutch 38 is disengaged, transfer of the torque from the crankshaft 17 to the input shaft 41 is interrupted. The clutch 38 is usually engaged. However, when the clutch pedal 42 is depressed, the clutch 38 is disengaged.

25 [0030] The manual transmission 39 is provided with the input shaft 41, an output shaft 43, a plurality of gears (not shown) that can be meshed with each other, a shift lever 44 operated by the driver, and a transfer mechanism (not shown) that transfers the operation of the shift lever 44 to the gears. In the manual transmission 39, the combination of the gears (shift speed) is changed based on the operation of the shift lever 44. As a result, the engine speed, the torque, and the like of the engine 12 are changed. Due to such changes, the speed ratio (gear ratio), which is the ratio of the rotational speed of the input shaft 41 to the rotational speed of the output shaft 43, corresponds to the combination of the gears.

30 [0031] The output shaft 43 of the manual transmission 39 is connected to drive wheels 48 via a drive shaft 45, a differential gear unit 46, an axle 47, and the like. The rotation of the output shaft 43 is transferred to the drive wheels 48 via these members 45, 46, and 47. In the embodiment, the components positioned between the engine 12 and the drive wheels 48 correspond to the components in the drive system, and these components constitute the drive system (power transmission system) of the vehicle 11.

35 [0032] The vehicle 11 is provided with various sensors that detect the states of various portions of the vehicle 11, for example, the operating state of the engine 12. For example, a crank angle sensor 51, which generates a pulse signal each time the crankshaft 17 is rotated predetermined degrees, is provided near the crankshaft 17. The signal generated by the crank angle sensor 51 is used to calculate the crank angle that is the turning angle of the crankshaft 17, the engine speed that is the rotational speed of the crankshaft 17 per unit time, and the like.

40 [0033] A throttle sensor 52 that detects the throttle valve opening-amount is provided near the throttle valve 19. An intake air amount sensor 53 such as an airflow meter that detects the intake air amount is provided in the intake passage 23 at a position upstream of the throttle valve 19. An accelerator switch 54 and an accelerator sensor 55 are provided in the vehicle compartment. The accelerator switch 54 is OFF when the driver has not depressed the accelerator pedal 25, and turned ON when the driver depresses the accelerator pedal 25. The accelerator sensor 55 detects the operation amount of the accelerator pedal 25 (hereinafter, referred to as the "accelerator pedal operation amount").

45 [0034] A clutch switch 56 is provided near the clutch pedal 42. The clutch switch 56 serves as the operation position detecting means for detecting the position of the clutch pedal 42. The clutch switch 56 is OFF when the clutch pedal 42 is at a position in the depression side with respect to the predetermined position, and turned ON when the clutch pedal 42 exceeds the predetermined position to the depression side. The clutch switch 56 is not configured to be turned ON when the clutch 38 is disengaged based on the operation of the clutch pedal 42. Like commonly used clutch switches, the clutch pedal 56 is configured to be turned ON before the clutch 38 is actually disengaged. More specifically, in the case where the clutch 38 is disengaged when the accelerator pedal 25 is depressed to the predetermined position, the clutch switch 56 is configured to be turned ON when the accelerator pedal 25 reaches a position at which the accelerator pedal operation amount is less than that at the predetermined position.

50 [0035] An electronic control unit (hereinafter, simply referred to as an "ECU") 61 formed mainly of a microcomputer is provided. The ECU 61 controls various portions of the engine 12 based on the values obtained by the sensors 51 to 56. In the ECU 61, a central processing unit (hereinafter, simply referred to as a "CPU") executes arithmetic processing

based on the control programs and the initial data stored in read-only memory (hereinafter, simply referred to as "ROM"), and executes various controls based on the results of the arithmetic processing. Random-access memory (hereinafter, simply referred to as "RAM") temporarily stores the results of arithmetic processing executed by the CPU.

[0036] The ECU 61 controls the ignition timing, the amount of fuel injected, etc. When the ECU 61 controls the ignition timing, the state of the engine 12 is detected based on the signals from the above-mentioned sensors, and the ignition timing that is the most suitable for the state of the engine 12 is calculated. When the crank angle calculated based on the signal from the crank angle sensor 51 matches the crank angle corresponding to the most suitable ignition timing, an ignition signal is output to the igniter 36. The igniter 36 intermittently supplies primary current to the ignition coil 37 based on the ignition signal. Due to such an intermittent supply of electric power, a high voltage is generated in the secondary coil of the ignition coil 37, and the spark plug 35 is actuated. The air-fuel mixture is ignited by a spark made by the spark plug 35, and burned.

[0037] In the fuel injection control, the amount of fuel that is required to operate the engine 12 is calculated based on the signals from the sensors that detect the state of the engine 12, and the amount of fuel injected is controlled such that the air-fuel ratio of the air-fuel mixture becomes the optimum value.

[0038] When the fuel injection control is executed, the amount of fuel injected that is required to match the air-fuel ratio of the air-fuel mixture with the predetermined value (e.g. the stoichiometric air-fuel ratio) is calculated as the base fuel injection amount, based on the operating state of the engine such as the engine speed and the engine load. The engine load is calculated based on, for example, the amount of air taken in by the engine 12, or the parameters related to the amount of air taken in by the engine 12 (e.g. the throttle valve opening-amount and the accelerator pedal operation amount). Then, the target fuel injection amount is calculated by correcting the thus calculated base fuel injection amount based on the signals from the above-mentioned sensors. The final target fuel injection amount, which is the command value for the fuel injection valve 34, is set based on the target fuel injection amount. Then, electric power is supplied to the fuel injection valve 34 for the length of time corresponding to the final target fuel injection amount. The fuel injection valve 34 is opened by being supplied with electric power, and the fuel whose amount corresponds to the final target fuel injection amount is injected. As a result, the air-fuel ratio matches the value corresponding to the operating state of the engine 12.

[0039] As a part of the above-mentioned fuel injection control, the ECU 61 executes so-called gradual-change (smoothing) control for gradually reducing the amount of fuel injected when an action to reduce the engine speed of the engine 12 is made, according to the engine-speed-reduction-time fuel injection control routine shown in FIG. 3.

[0040] In the engine-speed-reduction-time fuel injection control routine, the ECU 61 first determines in step 110 whether the accelerator switch 54 is OFF. The ECU 61 executes step 110 to determine whether the driver has made an action to reduce the speed of the engine 12.

[0041] When an affirmative determination is made in step 110, namely, when the driver has made an action to reduce the speed of the engine 12 by releasing the accelerator pedal 25, the ECU 61 determines in step 120 whether the clutch 38 is engaged or disengaged based on the signal from the clutch switch 56. In this routine, the ECU 61 determines whether clutch switch 56 is ON. If a negative determination is made in step 120 (namely, if the clutch switch 56 is OFF), that is, the clutch pedal 42 has not been depressed to the predetermined position, the ECU 61 determines that the clutch 38 is engaged, and executes step 140. At this time, the clutch 38 is actually engaged, and the torque output from the engine 12 is transferred to the manual transmission 39 via the clutch 38. When the clutch switch 38 is OFF, the target fuel injection amount is set to "0" or a value close to "0".

[0042] In step 140, the ECU 61 executes the gradual-change (smoothing) process for gradually reducing the amount of fuel injected (the final target fuel injection amount). The final target fuel injection amount is calculated according to the following equation (1).

$$\text{Final target fuel injection amount} = \{(\text{gradual-change coefficient} - 1) \times (\text{previous final target fuel injection amount}) + \text{target fuel injection amount}\} / (\text{gradual-change coefficient}) \dots \text{Equation (1)}$$

In the equation (1), the "final target fuel injection amount" in the left side indicates the final target fuel injection amount in the control cycle presently being executed, and the "previous final target fuel injection amount" in the right side indicates the final target fuel injection amount obtained in the immediately preceding control cycle. In the equation (1), the final target fuel injection amount obtained in the immediately preceding control cycle is multiplied by "(gradual-change coefficient - 1) / gradual-change coefficient", and the target fuel injection amount in the control cycle presently being executed is multiplied by "1 / gradual-change coefficient", and then the sum of the values obtained by the above multiplication is used as the final target fuel injection amount in the control cycle presently being executed. The gradual-change coefficient

influences the rate at which the final target fuel injection amount is reduced. As the gradual-change coefficient decreases, the reduction in the amount of the fuel injected per unit time (hereinafter, referred to as the "rate of gradual-change") increases. In this case, a predetermined value B that is greater than 1 ($B > 1$) is used as the gradual-change coefficient. Then, electric power is supplied to the fuel injection valve 34 for the length of time corresponding to the final target fuel injection amount in the control cycle presently being executed, which is obtained according to the equation (1), such that the fuel injection valve 34 opens. Because the fuel injection valve 34 is thus opened, the fuel whose amount corresponds to the final target fuel injection amount is injected.

[0043] Next, in step 150, the ECU 61 determines whether the final target fuel injection amount obtained in step 140 is less than a predetermined value α . The predetermined value α is "0" or a value close to "0". When a negative determination is made in step 150, the ECU 61 executes step 120 and the following steps again. When a negative determination is made in step 150, the gradual-change process in step 140 is repeatedly executed at predetermined intervals while an affirmative determination has not been made in step 120 (the clutch switch is OFF). On the other hand, when an affirmative determination is made in step 150, namely, when the final target fuel injection amount is sufficiently reduced by the gradual-change process, the ECU 61 ends the engine-speed-reduction-time fuel injection control routine.

[0044] On the other hand, when an affirmative determination is made in step 120 (the clutch switch is ON), the ECU 61 executes step 130. In step 130, the ECU 61 calculates the final target fuel injection amount according to the above-mentioned equation (1). Note that, as the gradual-change coefficient, a value A that is greater than "1" and less than B ($1 < A < B$) is used. Accordingly, in step 130, the final target fuel injection amount is reduced at a higher rate than that in step 140. Then, the fuel injection valve 34 is supplied with electric power to be opened for the length of time corresponding to the final target fuel injection amount in the control cycle presently being executed, which is obtained according to the equation (1). Because the fuel injection valve 34 is thus opened, the fuel whose amount corresponds to the final target fuel injection amount is injected.

[0045] In step 150, the ECU 61 determines whether the final target fuel injection amount obtained in step 130 is equal to or less than the predetermined value α . When a negative determination is made in step 150, the ECU 61 executes step 120 and the following steps again. When a negative determination is made in step 150, the ECU 61 executes the gradual-change process in step 130 at predetermined intervals while an affirmative determination is made in step 120 (the clutch switch is ON). On the other hand, when an affirmative determination is made in step 150, namely, when the final target fuel injection amount is sufficiently reduced by the gradual-change process, the ECU 61 ends the engine-speed-reduction-time fuel injection control routine.

[0046] When a negative determination is made in step 110 (the accelerator switch is ON), namely, when the driver has not made an action to reduce the speed of the engine 12, the ECU 61 ends the engine-speed-reduction-time fuel injection control routine without executing steps 120 to 150.

[0047] In the engine-speed-reduction-time fuel injection control routine, step 110 corresponds to the "engine-speed-reduction action determining means", step 120 correspond to the "clutch state determining means", and steps 130 and 140 correspond to the "fuel injection amount gradual-change means".

[0048] When the step in the engine-speed-reduction-time fuel injection control routine are executed, for example, as shown in FIG. 4 and FIG. 5, the final target fuel injection amount and the engine speed change based on the operation of the accelerator pedal 25 and the clutch pedal 42.

[0049] FIG. 4 shows the case where the accelerator switch 54 is turned OFF at time t_1 because the driver releases the accelerator pedal 25, but the clutch pedal 42 has not been depressed. Accordingly, the clutch switch 56 is OFF, and the clutch 38 is engaged.

[0050] When the accelerator switch 54 is turned OFF at time t_1 , an affirmative determination is made in step 110. At this time, because the clutch switch 56 is OFF, a negative determination is made in step 120. Accordingly, in the engine-speed-reduction-time fuel injection control routine, steps 110, 120, and 130 are executed in this order. The value that is smaller than the value obtained in the immediately preceding control cycle is calculated as the final target fuel injection amount, by the gradual-change process in step 140. Then, the supply of electric power to the fuel injection valve 34 is controlled based on the final target fuel injection amount. Because an affirmative determination has not been made in step 150 at time t_1 , the ECU 61 executes step 120 after executing step 150, and then executes step 140 again. The ECU 61 repeatedly executes steps 120 and 140 until an affirmative determination is made in step 150. Because steps 120 and 140 are repeatedly executed, the final target fuel injection amount is gradually reduced. When an affirmative determination is made in step 150 because the final target fuel injection amount is sufficiently reduced, the ECU 61 ends the engine-speed-reduction-time fuel injection control routine. Because the final target fuel injection amount is reduced, the engine speed gradually reduces from time t_1 . The torque output from the engine 12 is also reduced gradually from time t_1 .

[0051] Accordingly, when the accelerator switch 54 is turned OFF at time t_1 , if the final target fuel injection amount is rapidly reduced to "0" or a value close to "0", the torque output from the engine 12 is rapidly reduced, and a torque shock may occur. In the embodiment, however, such a torque shock does not occur easily, because the final target fuel injection amount is gradually changed.

[0052] FIG. 5 ((A) to (E)) shows the case where the accelerator switch 54 is turned OFF at time t11 because the driver releases the accelerator pedal 25, and then, the driver starts depressing the clutch pedal 42.

5 [0053] When the accelerator switch 54 is turned OFF at time t11, in the engine-speed-reduction-time fuel injection control routine, step 110, step 120, and step 140 are executed in this order, as in the case shown in FIG. 4 where the accelerator switch 54 is turned OFF at time t1. In step 140, the ECU 61 calculates the final target fuel injection amount according to the equation (1), using the value B as the gradual-change coefficient. The calculated final target fuel injection amount is smaller than the final target fuel injection amount obtained in the immediately preceding control cycle. Then, the supply of electric power to the fuel injection valve 34 is controlled based on the calculated final target fuel injection amount. Because an affirmative determination has not been made in step 150 at time t11, the ECU 61 executes step 10 120 again after executing step 150, and executes step 140 again.

15 [0054] If the clutch switch 56 is turned ON at time t12 while the final target fuel injection amount is gradually reducing, an affirmative determination is made in step 120. Accordingly, the ECU 61 executes step 120 and then step 130 after executing step 150. In step 130, the ECU 61 calculates the final target fuel injection amount according to the equation (1), using the value A as the gradual-change coefficient. The calculated final target fuel injection amount is less than the final target fuel injection amount obtained in the immediately preceding control cycle. However, because the value A is smaller than the value B, the final target fuel injection amount calculated in step 130 is less than the final target fuel injection amount calculated in step 140. Then, the supply of electric power to the fuel injection valve 34 is controlled based on the calculated final target fuel injection amount. At this time, the clutch 38 is still engaged.

20 [0055] Because an affirmative determination has not been made in step 150 at time t12, the ECU 61 executes step 120 again after executing step 150, and then executes step 130. The ECU 61 repeatedly executes steps 120 and 130 until an affirmative determination is made in step 150. Because steps 120 and 130 are repeatedly executed, the final target fuel injection amount is gradually reduced. When an affirmative determination is made in step 150 because the final target fuel injection amount is sufficiently reduced, the ECU 61 ends the engine-speed-reduction-time fuel injection control routine. As the final target fuel injection amount is reduced, the engine speed is gradually reduced from time t12. 25 The clutch 38 is then disengaged at time t13 that is slightly later than time t12 at which the clutch switch 56 is turned ON. As a result, the torque output from the engine 12 is no longer transferred to the manual transmission 39.

30 [0056] Accordingly, when an action to reduce the speed of the engine 12 is made, if it is determined that the clutch 38 is disengaged at time t12 and the final target fuel injection amount is gradually reduced because the clutch switch 56 is turned ON at time t12, fuel is continuously injected even at time t13 at which the clutch 38 is actually disengaged. Meanwhile, the load from the drive system to the engine 12 is no longer applied to the engine 12, because the clutch 38 is disengaged. Accordingly, in the state where fuel is injected, if the clutch 38 is disengaged and the load applied from the drive system to the engine 12 is rapidly reduced, the engine speed may rapidly increase, as shown by the chain double-dashed line in FIG. 5 (E). Such an increase is more likely to occur, as the amount of fuel injected when the clutch 38 is disengaged at time t13 becomes larger.

35 [0057] In the embodiment, however, when an action to reduce the speed of the engine 12 is made, if it is determined in step 120 that the clutch 38 is disengaged because the clutch switch 56 is ON (YES in step 120), a rate of the gradual change in the final target fuel injection amount is made higher than when the clutch 38 is engaged. Namely, the final target fuel injection amount is reduced (see the solid line in FIG. 5 (D)) at a rate that is lower than when the final target fuel injection amount is reduced rapidly, not gradually (see the chain line in FIG. 5 (D)), but higher than when the clutch 40 38 is engaged (see the chain double-dashed line in FIG. 5 (D)). Accordingly, the rapid increase in the engine speed due to disengagement of the clutch 38 can be suppressed more effectively (see the solid line in FIG. 5 (E)), than when the amount of fuel injected is reduced at the same rate as that if it is determined that the clutch 38 is engaged (see the chain double-dashed line in FIG. 5 (E)).

45 [0058] When an action to reduce the speed of the engine 12 is made, if it is determined that the clutch 38 is disengaged and the amount of fuel injected is reduced because the clutch switch is ON, negative torque is generated in the engine 12. The determination that the clutch 38 is disengaged is made before the clutch 38 is actually disengaged. Accordingly, the negative torque is transferred to the components in the drive system from the time the above-mentioned determination is made until the clutch 38 is actually disengaged (from time t12 to time t13). Then, the components in the drive system are twisted such that the engine speed is reduced, and the torsion torque accumulates. The torsion torque accumulated varies depending on the amount of fuel injected (the final target fuel injection amount). The torsion torque increases as the amount of fuel injected increases. When the fuel injection ceases (when the amount of fuel injected becomes "0"), the torsion torque reaches the maximum value.

50 [0059] In the embodiment, however, when an action to reduce the engine speed is made, if it is determined that the clutch 38 is disengaged, the amount of fuel injected is gradually reduced (see the solid line in FIG. 5 (D)). Therefore, the amount of fuel injected is larger, the negative torque generated in the engine 12 is smaller, and the torsion torque accumulated in the components in the drive system is smaller, than when the fuel injection ceases (see the chain line in FIG. 5 (D)). Accordingly, when the clutch 38 is actually disengaged at time t13, although the accumulated torsion torque is released, the components in the drive system do not easily vibrate or rattle, because the torsion torque is small.

[0060] The embodiment that has been described in detail produces the following effects.

(1) In step 110, it is determined whether an action to reduce the speed of the engine 12 is made, and in step 120 it is determined whether the clutch 38 is engaged or disengaged based on the signal from the clutch switch 56. If it is determined that the action to reduce the engine speed is made (YES in step 110), and it is determined that the clutch 38 is engaged (NO in step 120), the final target fuel injection amount is calculated according to the equation (1) using the value B as the gradual-change coefficient. The supply of electric power to the fuel injection valve 34 is controlled based on the final target fuel injection amount in step 140.

[0061] Accordingly, the torque output from the engine 12 can be gradually reduced by gradually reducing the amount of fuel injected when the action to reduce the speed of the engine 12 is made. As a result, a torque shock, which occurs when the amount of fuel injected is rapidly reduced or when fuel injection ceases, can be suppressed.

[0062] (2) If it is determined that the action to reduce the speed of the engine 12 is made (YES in step 110), and it is determined that the clutch 38 is disengaged (YES in step 120), the final target fuel injection amount is calculated according to the equation (1) using the value A, which is smaller than the value B, as the gradual-change coefficient. The supply of electric power to the fuel injection valve 34 is then controlled based on the final target fuel injection amount in step 130 instead.

[0063] As a result, rapid increases in the engine speed due to disengagement of the clutch 38 can be suppressed more effectively, than when the amount of fuel injected is reduced at the same rate as that if it is determined that the clutch 38 is engaged.

[0064] Also, the amount of fuel injected can be increased, the negative torque generated in the engine 12 can be reduced, and the torsion torque accumulated in the components in the drive system can be made smaller, than when fuel injection ceases. As a result, when the torsion torque is released due to disengagement of the clutch 38, the components in the drive system do not easily vibrate or rattle.

[0065] (3) The position of the accelerator pedal 25 is detected by the accelerator switch 54, and based on the result of detection in step 110, it is determined whether an action to reduce the speed of the engine 12 is made. By using the result of detection executed by the accelerator switch 54 for the determination, the intention of the driver (the action to reduce the engine speed) can be directly detected. As a result, whether the gradual-change process for the amount of fuel injected (steps 130 and 140) needs to be executed is accurately determined, and the amount of fuel injected is gradually changed only when required.

[0066] The invention may be realized in the following embodiments.

(1) The final target fuel injection amount in steps 130 and 140 in FIG. 3 may be calculated without using the equation (1). For example, the value that is obtained by subtracting a constant amount C from the final target fuel injection amount obtained in the immediately preceding control cycle may be used as the final target fuel injection amount in the control cycle presently being executed. Thus, the final target fuel injection amount is reduced in increments of the constant amount C with the lapse of time.

[0067] The constant amount C in step 130 is set to a value greater than the constant amount C in step 140. Even in this state, if it is determined that the clutch 38 is disengaged, based on the result of detection executed by the clutch switch 56, the rate of gradual change in the amount of fuel injected is increased over the rate used when it is determined that the clutch 38 is engaged. As a result, the same effects in the above-mentioned embodiment can be obtained.

[0068] (2) Instead of the clutch switch 56, a sensor that detects the position of the clutch pedal 42 may be used as the operation position detecting means.

(3) Whether an action to reduce the speed of the engine 12 is made is determined based on the change in the position of the accelerator pedal, which is detected by the accelerator sensor 55. For example, the difference between the accelerator pedal operation amount in the immediately preceding control cycle and the accelerator pedal operation amount in the control cycle presently being executed is obtained, and the absolute value of the difference is compared with the predetermined value. When the difference is greater than the predetermined value, it may be determined that the action to reduce the engine speed is made.

Claims

1. A fuel injection control apparatus for an internal combustion engine (12) used in a vehicle (11) in which transfer of torque output from the internal combustion engine (12) to a transmission (39) can be interrupted by disengaging a clutch (38), provided between the internal combustion engine (12) and the transmission (38), based on an operation

of a clutch operating portion (42), **characterized by** comprising:

engine-speed-reduction action determining means for determining whether an action to reduce a speed of the internal combustion engine (12) is made;

operation position detecting means for detecting a position of the clutch operating portion (38);

clutch state determining means for determining a state of the clutch (38) based on a result of detection obtained by the operation position detecting means; and

fuel injection amount gradual-change means that changes the amount of fuel injected in the internal combustion engine when the engine-speed-reduction action determining means determines that the action to reduce the speed of the internal combustion engine (12) is made, by gradually reducing an amount of fuel injected in the internal combustion engine (12) at a predetermined rate when the clutch state determining means determines that the clutch (38) is engaged; and by gradually reducing the amount of fuel injected in the internal combustion engine (12) at a rate that is higher than the predetermined rate when the clutch state determining means determines that the clutch (38) is disengaged.

2. The fuel injection control apparatus for an internal combustion engine (12) according to claim 1, wherein the engine-speed-reduction action determining means determines whether the action to reduce the speed of the internal combustion engine (12) is made based on an operation state of an accelerator operating portion.

3. The fuel injection control apparatus for an internal combustion engine (12) according to claim 1 or 2, wherein the clutch state determining means determines that the clutch (38) is disengaged, at a predetermined time that is before the clutch (38) is actually disengaged.

4. The fuel injection control apparatus for an internal combustion engine (12) according to claim 3, wherein the operation position detecting means is a switch (56).

5. The fuel injection control apparatus for an internal combustion engine (12) according to claim 3, wherein the operation position detecting means is a sensor that detects a position of the clutch operating portion (42).

6. The fuel injection control apparatus for an internal combustion engine (12) according to any one of claims 1 to 5, wherein the fuel injection amount gradual-change means calculates a final target fuel injection amount based on a gradual-change coefficient, a target fuel injection amount in a control cycle presently being executed, and a final target fuel injection amount in an immediately preceding control cycle; and gradually reduces the amount of fuel injected in the internal combustion engine (12) based on the calculated final target fuel injection amount.

7. The fuel injection control apparatus for an internal combustion engine (12) according to any one of claims 1 to 5, wherein the fuel injection amount gradual-change means calculates a final target fuel injection amount by subtracting a predetermined value (c) from a final target fuel injection amount in an immediately preceding control cycle, and gradually reduces the amount of fuel injected in the internal combustion engine (12) based on the calculated final target fuel injection amount.

8. The fuel injection control apparatus for an internal combustion engine (12) according to claim 7, wherein the predetermined value (c) that is used when the clutch state determining means determines that the clutch (38) is disengaged is greater than the predetermined value (c) that is used when the clutch state determining means determines that the clutch (38) is engaged.

9. A fuel injection control method for an internal combustion engine (12) used in a vehicle (11) in which transfer of torque output from the internal combustion engine (12) to a transmission (39) can be interrupted by disengaging a clutch (38), provided between the internal combustion engine (12) and the transmission (38), based on an operation of a clutch operating portion (42), **characterized by** comprising:

determining whether an action to reduce a speed of the internal combustion engine (12) is made;

detecting a position of the clutch operating portion (38);

determining a state of the clutch (38) based on a result of detection obtained by the operation position detecting means; and

changing the amount of fuel injected in the internal combustion engine when the engine-speed-reduction action

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determining means determines that the action to reduce the speed of the internal combustion engine (12) is made, by gradually reducing an amount of fuel injected in the internal combustion engine (12) at a predetermined rate when the clutch state determining means determines that the clutch (38) is engaged; and by gradually reducing the amount of fuel injected in the internal combustion engine (12) at a rate that is higher than the predetermined rate when the clutch state determining means determines that the clutch (38) is disengaged.

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FIG. 1

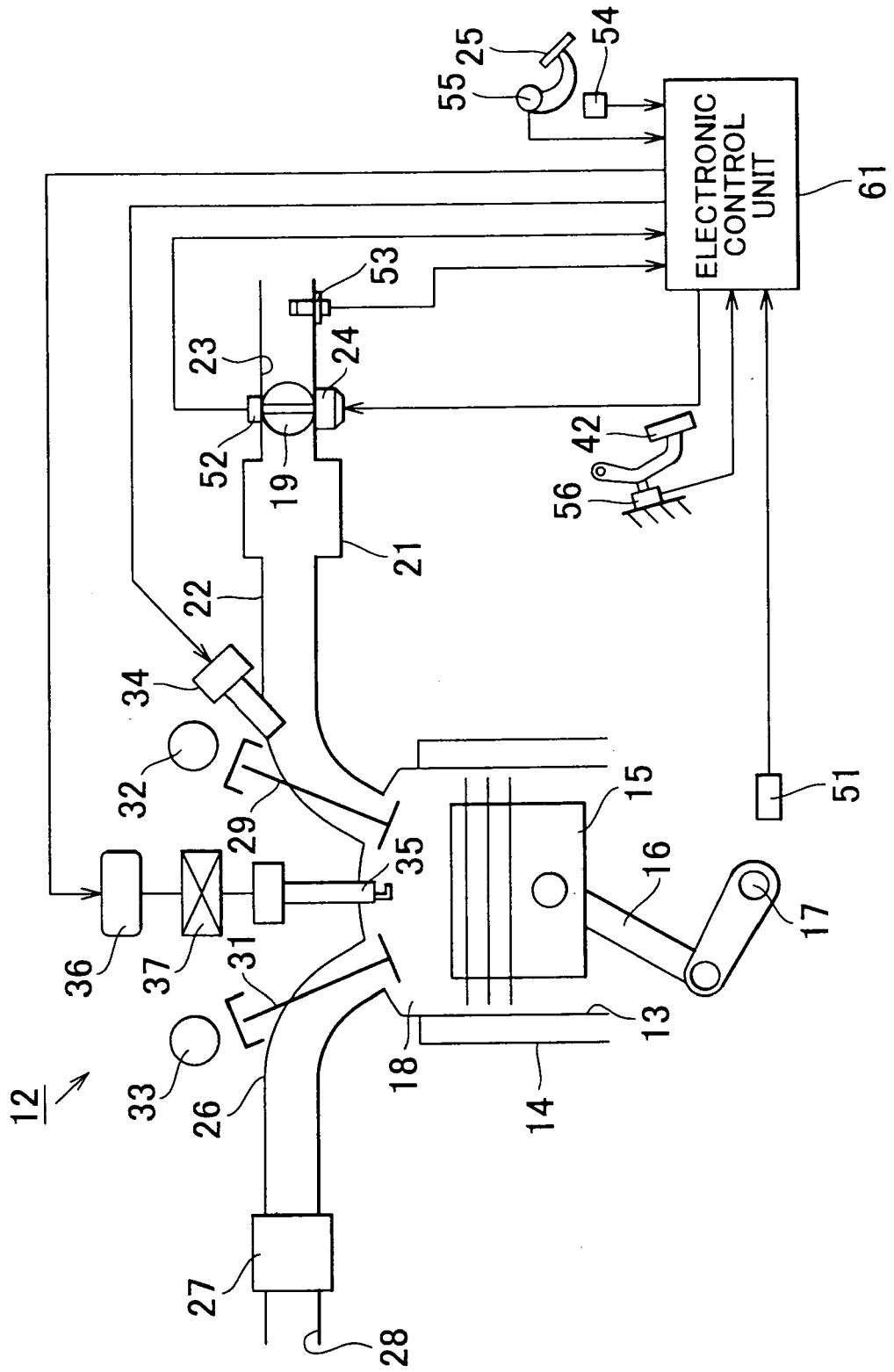


FIG. 2

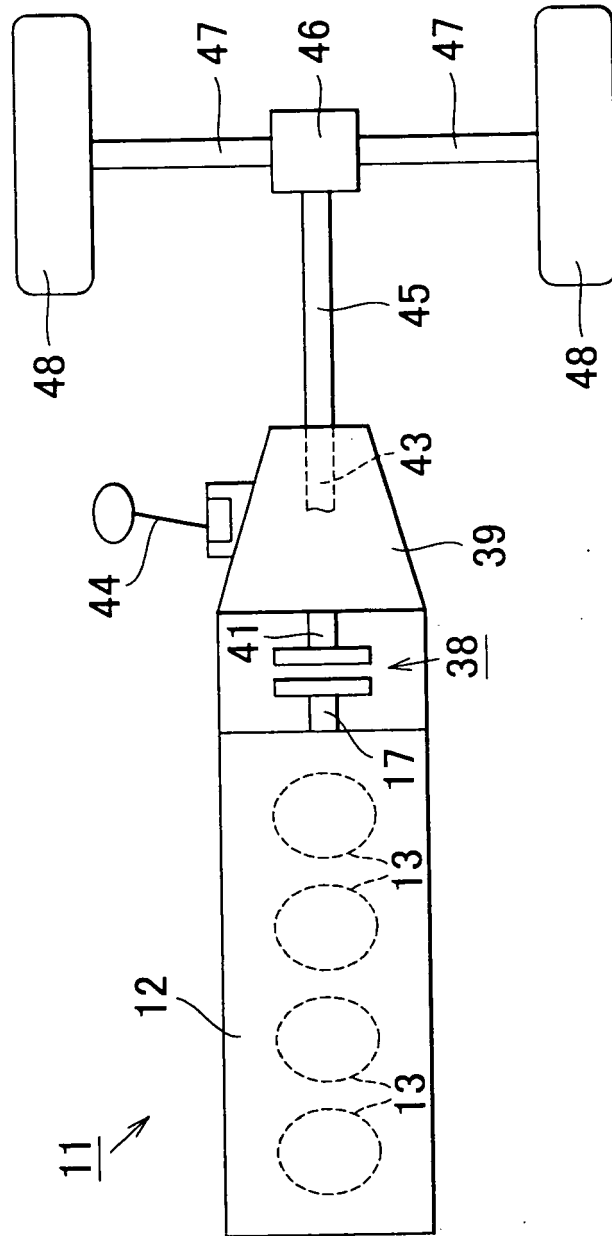


FIG. 3

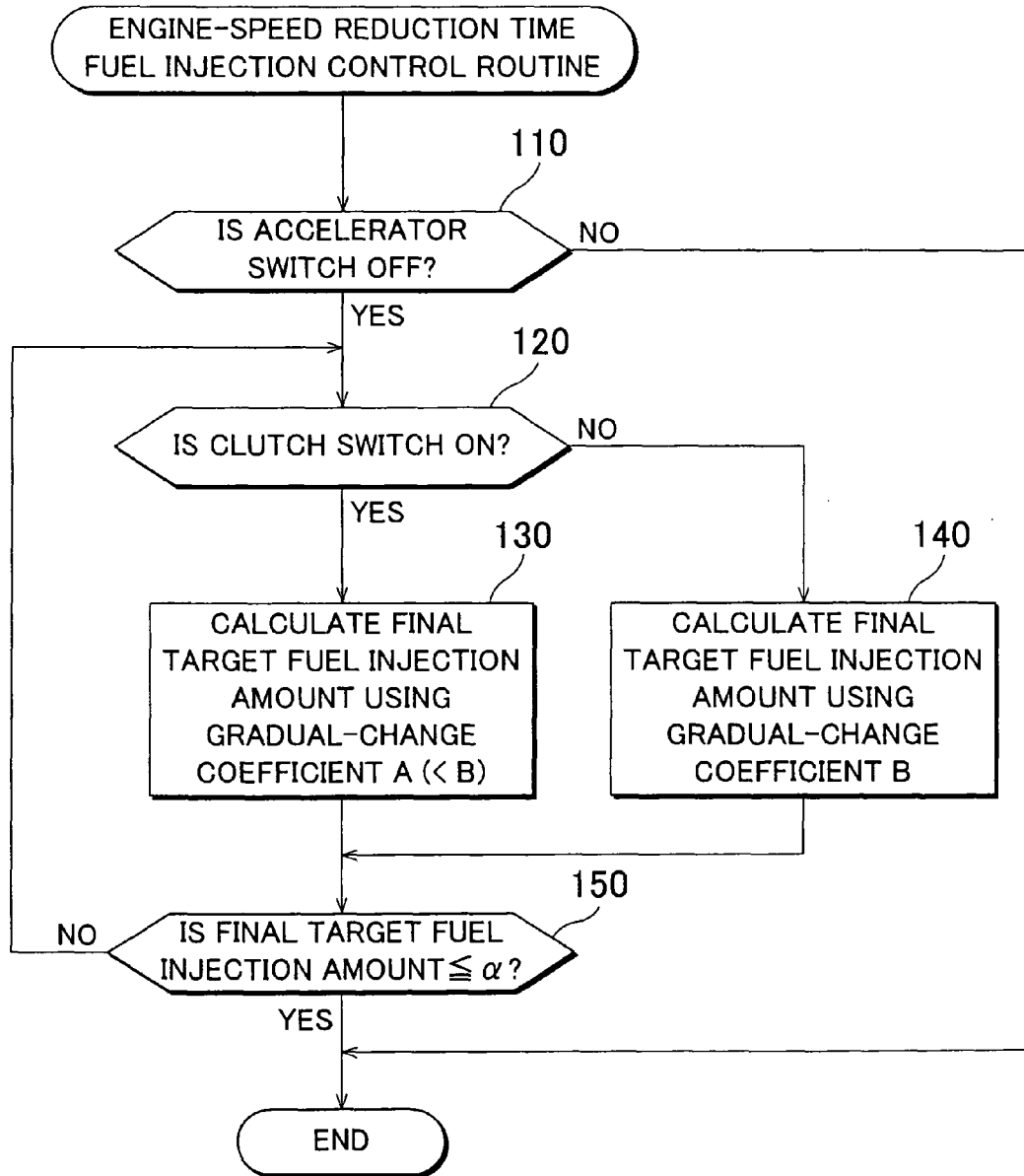


FIG. 4

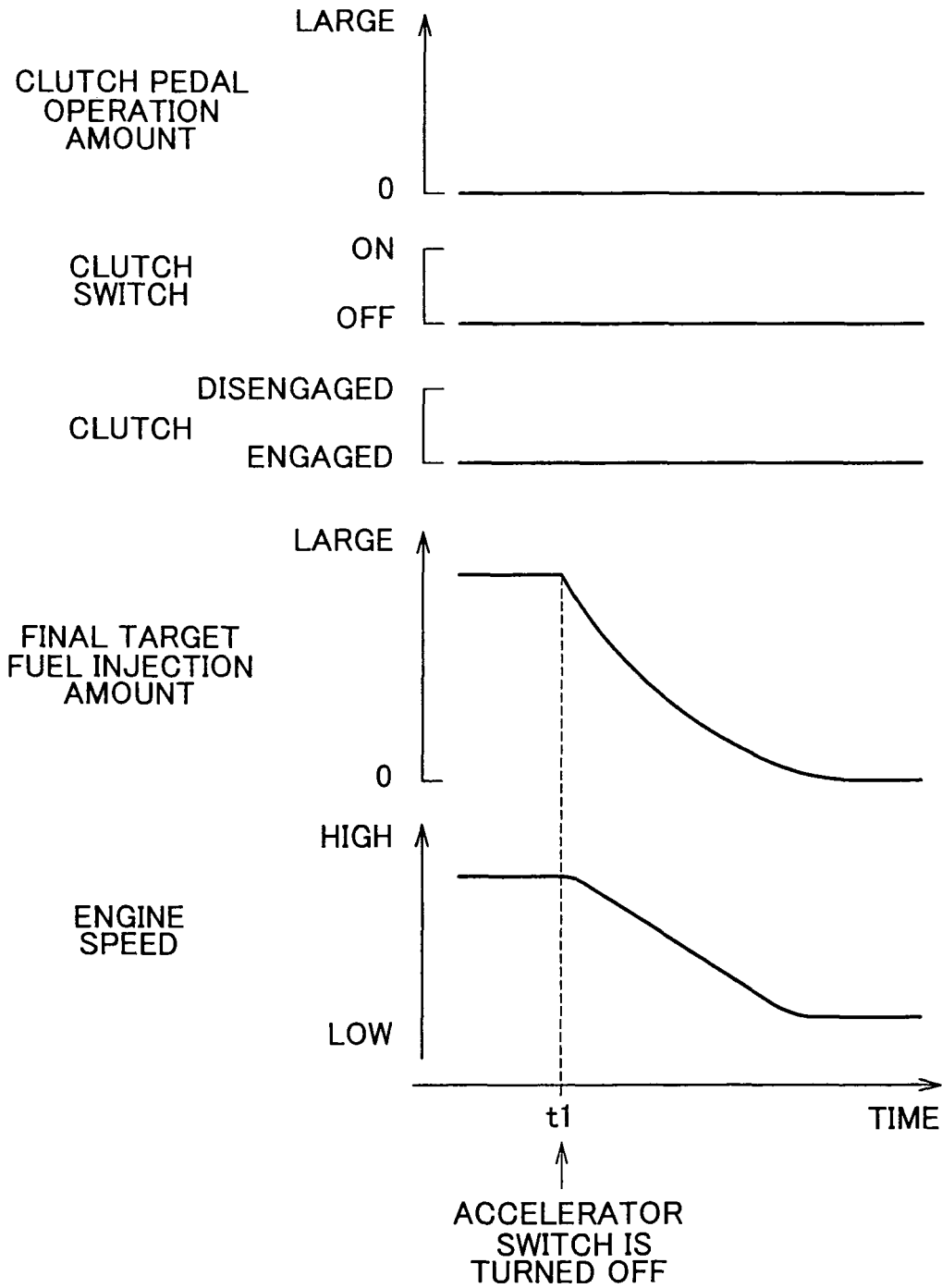


FIG. 5

