

[54] ELECTRONIC FUEL INJECTION SYSTEM

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[58] Field of Search 123/32 EA

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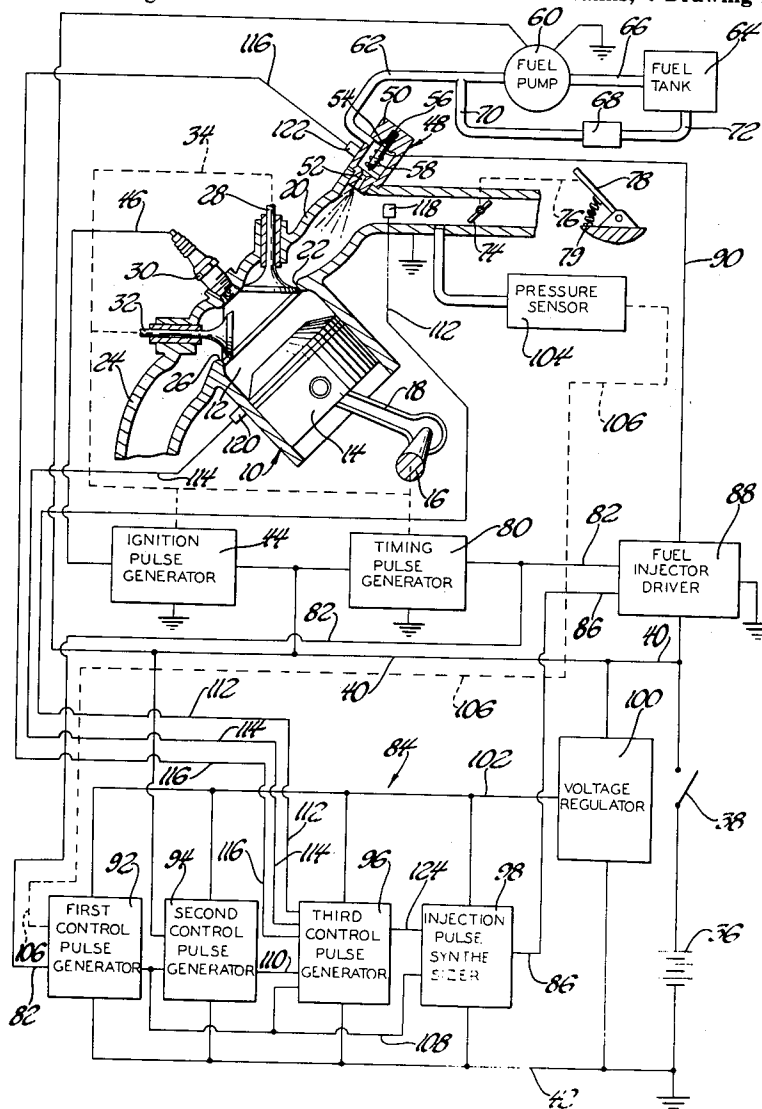
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[57]

ABSTRACT

Fuel is applied to an internal combustion engine in accordance with a linear fuel control curve characterized by a slope and an offset. The fuel control curve is primarily defined by a first time period initiated in synchronization with the operation of the engine and terminated at the expiration of a time duration determined as a preselected function of a first engine operating parameter. The offset of the fuel control curve is defined by a second time period initiated in response to initiation of the first time period and terminated before the termination of the first time period at the expiration of a time duration determined as a preselected function of a second engine operating parameter. The slope of the fuel control curve is defined by a third time period initiated in response to termination of the second time period and terminated after the termination of the first time period at the expiration of a time duration determined by the time duration of the first time period less the time duration of the second time period and determined as a preselected function of a third engine operating parameter.

5 Claims, 4 Drawing Figures



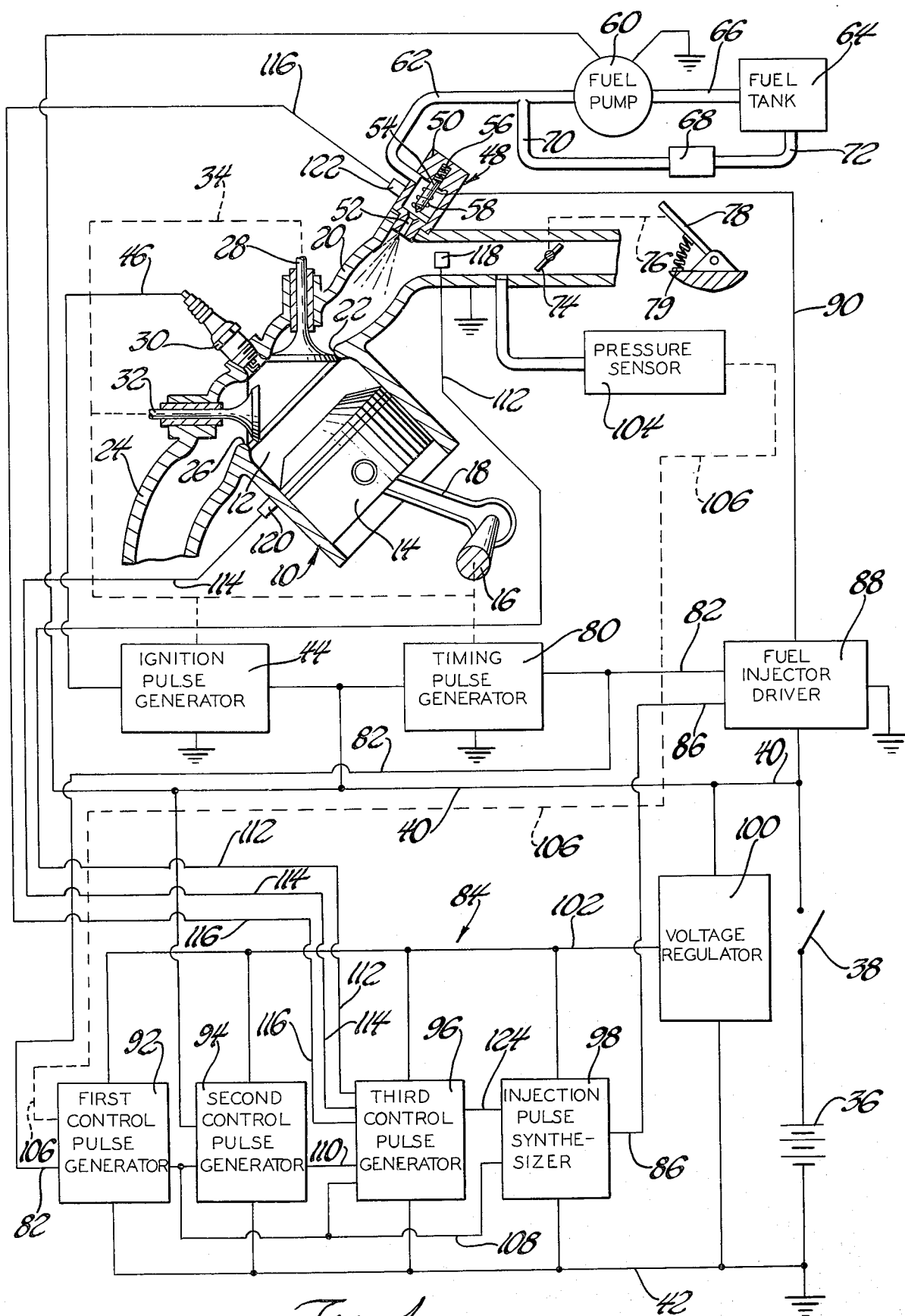


Fig. 1

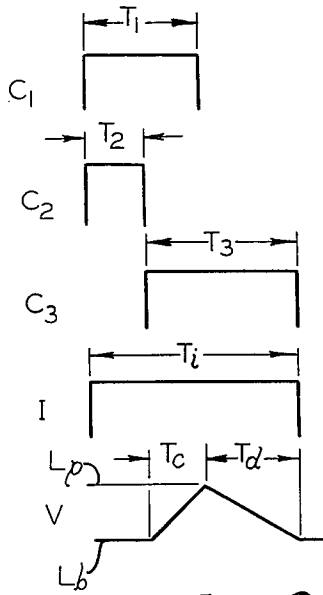


Fig. 2

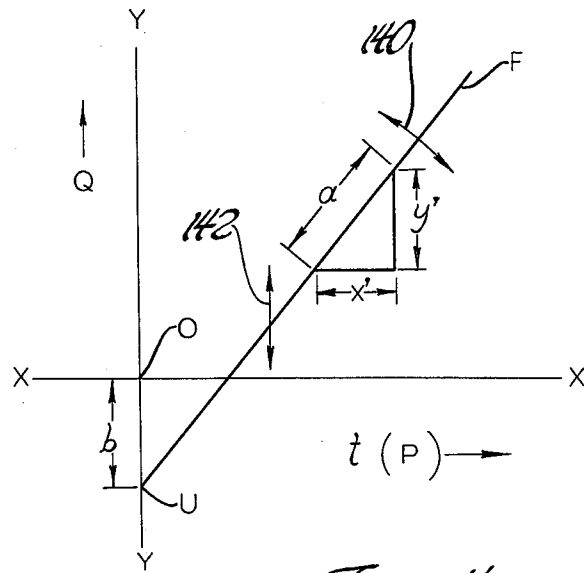


Fig. 4

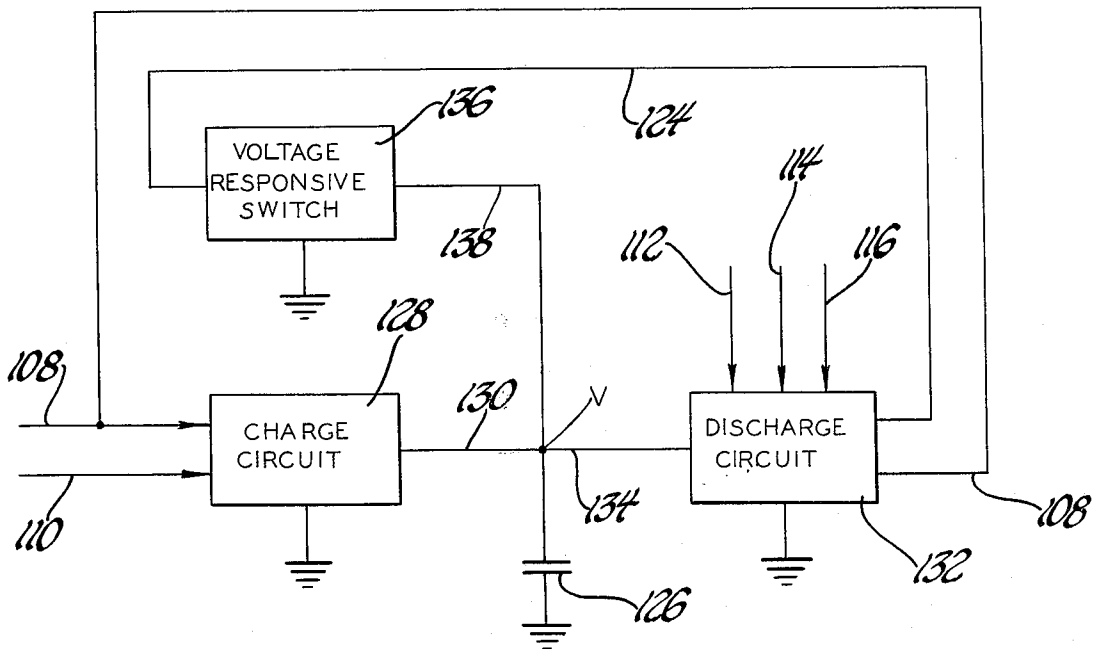


Fig. 3

ELECTRONIC FUEL INJECTION SYSTEM

This invention relates to a fuel supply system for an internal combustion engine. More particularly, the invention relates to an electronic fuel injection system.

According to one aspect of the invention, a first time period is initiated in synchronization with the operation of the engine and is terminated at the expiration of a time duration determined as a preselected function of a first engine operating parameter such as intake air pressure. A second time period is initiated in response to the initiation of the first time period and is terminated before the termination of the first time period at the expiration of a time duration determined as a function of a second engine operating parameter such as battery supply voltage. A third time period is initiated in response to the termination of the second time period and is terminated after the termination of the first time period at the expiration of a time duration determined by the time duration of the first time period less the time duration of the second time period and determined as a function of a third engine operating parameter such as engine temperature. Fuel is applied to the engine in an amount directly related to a composite time period defined between the initiation of the first time period and the termination of the third time period. Accordingly, the total quantity of fuel delivered to the engine is defined in relation to the preselected function of the first engine operating parameter by a linear fuel control curve having an offset determined by the preselected function of the second engine operating parameter and having a slope determined by the preselected function of the third engine operating parameter.

In another aspect of the invention, a control voltage is developed across a capacitor. The capacitor is charged at a charge rate to increase the control voltage from a base level to a peak level over a charge time period initiated in response to the termination of the second time period and terminated in response to the termination of the first time period. The capacitor is discharged at a discharge rate to decrease the control voltage from the peak level to the base level over a discharge time period initiated in response to termination of the charge time period and terminated when the control voltage reaches the base level. The third time period is defined by the sum of the charge time period and the discharge time period. At least one of the charge rate and the discharge rate of the capacitor is determined as a preselected function of one or more of the intake air temperature, the engine coolant temperature, and the injected fuel temperature.

These and other aspects of the invention may be best understood by reference to the following detailed description of a preferred embodiment of the invention when considered in conjunction with the accompanying drawings. As used in equations appearing in both the specifications and the claims, the symbol "=" means "is equal to" while the symbol " $\propto$ " means "is proportional to."

In the drawings:

FIG. 1 is a schematic diagram of an electronic fuel injection system incorporating the principles of the invention.

FIG. 2 is a graphic illustration of several waveforms useful in explaining the operation of the electronic fuel injection system shown in FIG. 1.

FIG. 3 is a block diagram of a portion of the electronic fuel injection system shown in FIG. 1.

FIG. 4 is a graphic illustration of a fuel control curve useful in explaining the operation of the electronic fuel injection system shown in FIG. 1.

Referring to FIG. 1, an internal combustion engine 10 for an automotive vehicle includes a combustion chamber or cylinder 12. A piston 14 is mounted for reciprocation within the cylinder 12. A crankshaft 16 is supported for rotation within the engine 10. A connecting rod 18 is pivotally connected between the piston 14 and the crankshaft 16 for rotating the crankshaft within the engine 10 when the piston 14 is reciprocated within the cylinder 12. Conventionally, a fluid coolant is circulated over the exterior wall of the cylinder 12 by a coolant system (not shown) to dissipate excessive heat generated within the combustion chamber 12.

An intake manifold 20 is connected with the cylinder 12 through an intake port 22. An exhaust manifold 24 is connected with the cylinder 12 through an exhaust port 26. An intake valve 28 is slidably mounted within the top of the cylinder 12 in cooperation with the intake port 22 for regulating the entry of combustion ingredients into the cylinder 12 from the intake manifold 20. A spark plug 30 is mounted in the top of the cylinder 12 for igniting the combustion ingredients within the cylinder 12 when the spark plug 30 is energized. An exhaust valve 32 is slidably mounted in the top of the cylinder 12 in cooperation with the exhaust port 26 for regulating the exit of combustion products from the cylinder 12 into the exhaust manifold 24. The intake valve 28 and the exhaust valve 32 are driven through a suitable linkage 34 which conventionally includes rocker arms, lifters, and a camshaft.

An electrical power source is provided by the vehicle battery 36. An ignition switch 38 connects the battery 36 between a power line 40 and a ground line 42. When the ignition switch 38 is closed, the battery 36 applies a supply voltage to the power line 40. A conventional ignition pulse generator 44 is electrically connected to the power line 40 and is mechanically connected with the crankshaft 16 of the engine 10. Further, the ignition pulse generator 44 is connected through a spark cable 46 to the spark plug 30. In the usual manner, the ignition pulse generator 44 energizes the spark plug 30 in synchronization with the rotation of the crankshaft 16 of the engine 10. Hence, the ignition pulse generator 44 combines with the ignition switch 38 and the spark plug 30 to form an ignition system.

A fuel injector 48 includes a housing 50 having a fixed metering orifice 52. A plunger 54 is supported within the housing 50 for reciprocation between a fully opened position and a fully closed position. In the fully opened position, the forward end of the plunger 54 is opened away from the orifice 52. In the fully closed position, the forward end of the plunger 54 is closed against the orifice 52. A bias spring 56 is seated between the rearward end of the plunger 54 and the housing 50 for normally maintaining the plunger 54 in the fully closed position. A solenoid or winding 58 is electromagnetically coupled with plunger 54 for retracting the plunger 54 to the fully opened position against the action of the bias spring 56 when the winding 58 is energized. The bias spring 56 drives the plunger 54 to the fully closed position when the winding 58 is deenergized. The fuel injector 48 is mounted on the intake manifold 20 of the engine 10 for injecting fuel into the

intake manifold 20 at a constant flow rate through the metering orifice 52 when the plunger 54 is in the fully opened position. Notwithstanding the illustrated structure, it is to be noted that the fuel injector 48 may be provided by any suitable voltage responsive valve.

A fuel pump 60 is connected to the fuel injector 48 by a conduit 62 and to the vehicle fuel tank 64 by a conduit 66 for pumping fuel from the fuel tank 64 to the fuel injector 48. Preferably, the fuel pump 60 is connected to the power line 40 to be electrically driven from the vehicle battery 36. Alternately, the fuel pump 60 could be connected to the crankshaft 16 to be mechanically driven from the engine 10. A pressure regulator 68 is connected to the conduit 62 by a conduit 70 and is connected to the fuel tank 64 by a conduit 72 for defining the pressure of the fuel applied to the fuel injector 48. Thus, the fuel injector 48 combines with the fuel tank 64, the fuel pump 60 and the pressure regulator 68 to form a fuel supply system.

A throttle valve 74 is rotatably mounted within the intake manifold 20 for regulating the flow of air into the intake manifold 20 from an air supply system (not shown) in accordance with the position of the throttle valve 74. The throttle valve 74 is connected through a suitable linkage 76 with the vehicle accelerator pedal 78. The accelerator pedal 78 is pivotably mounted on a reference surface for movement against the action of a compression spring 79 seated between the accelerator pedal 78 and the reference surface. As the accelerator pedal 78 is depressed, the throttle valve 74 is moved to a more opened position to increase the flow of air into the intake manifold 20. Conversely, as the accelerator pedal 78 is released, the throttle valve 74 is moved to a less opened position to decrease the flow of air into the intake manifold 20.

In operation, fuel and air are combined within the intake manifold 20 to form an air/fuel mixture. The fuel is injected into the intake manifold 20 at a constant flow rate by the fuel injector 48 in response to energization. The precise amount of fuel deposited within the intake manifold 20 is regulated by an electronic fuel injection control system which will be described later. The air enters the intake manifold 20 from the air supply system (not shown) which conventionally includes an air filter. The precise amount of air admitted into the intake manifold 20 is determined by the position of the throttle valve 74. As previously described, the position of the accelerator pedal 78 controls the position of the throttle valve 74.

As the piston 14 initially moves downward within the cylinder 12 on the intake stroke, the intake valve 28 is opened away from the intake port 22 and the exhaust valve 32 is closed against the exhaust port 26. Accordingly, combustion ingredients in the form of the air/fuel mixture within the intake manifold 20 are drawn by negative pressure through the intake port 22 into the cylinder 12. As the piston 14 subsequently moves upward within the cylinder 12 on the compression stroke, the intake valve 28 is closed against the intake port 22 so that the air/fuel mixture is compressed between the top of the piston 14 and the top of the cylinder 12. When the piston 14 reaches the end of its upward travel on the compression stroke, the spark plug 30 is energized by the ignition circuit 44 to ignite the air/fuel mixture. The ignition of the air/fuel mixture starts a combustion reaction which drives the piston 14 downward within the cylinder 12 on the power stroke. As the

piston 14 again moves upward within the cylinder 12 on the exhaust stroke, the exhaust valve 32 is opened away from the exhaust port 26. As a result, the combustion products in the form of various exhaust gases are pushed by positive pressure out of the cylinder 12 through the exhaust port 26 into the exhaust manifold 24. The exhaust gases pass out of the exhaust manifold 24 into the exhaust system (not shown) which conventionally includes a muffler and an exhaust pipe.

Although the structure and operation of only a single combustion chamber or cylinder 12 has been described, it will be readily appreciated that the illustrated internal combustion engine 10 may include additional cylinders 12 as desired. Similarly, additional fuel injectors 48 may be provided as required. However, as long as the fuel injectors 48 are mounted on the intake manifold 20, the number of additional fuel injectors 48 need not necessarily bear any fixed relation to the number of additional cylinders 12. Alternately, the fuel injector 48 may be directly mounted on the cylinder 12 so as to inject fuel directly into the cylinder 12. In such instance, the number of additional fuel injectors 48 would necessarily equal the number of additional cylinders 12.

A timing pulse generator 80 is connected with the crankshaft 16 for developing rectangular timing pulses having a frequency which is proportional to and synchronized with the rotating speed of the crankshaft 16. The rectangular timing pulses produced by the timing pulse generator 80 are applied to a timing pulse line 82. Preferably, the timing pulse generator 80 is provided by an inductive speed transducer coupled with a bistable switch.

An injection pulse generator 84 is coupled with the engine 10 for developing rectangular injection pulses having a length determined as a function of several different engine operating parameters. The injection pulses produced by the injection pulse generator 84 are synchronized with the timing pulses produced by the timing pulse generator 80. The injection pulses are applied by the injection pulse generator 84 to the injection pulse line 86. The injection pulse generator 84 will be more fully described later.

A fuel injector driver 88 is connected with the timing pulse line 82 and with the injection pulse line 86. Further, the fuel injector driver is connected through an injection drive line 90 to the fuel injector 48 and is connected to the vehicle battery 36 through the power line 40 and the ignition switch 38. The fuel injector driver 88 is responsive to the occurrence of the timing pulses produced by the timing pulse generator 80 to energize the fuel injector 48. The time period for which the fuel injector 48 is energized by the fuel injector driver 88 is defined by the length or duration of the injection pulses produced by the injection pulse generator 84. In other words, the fuel injector driver 88 is responsive to the coincidence of a timing pulse and an injection pulse to energize the fuel injector 48 for the duration of the injection pulse.

The fuel injector driver 88 may be virtually any logic switch or amplifier capable of executing the desired coincident pulse operation. However, where additional fuel injectors 48 are provided, it may be necessary that the fuel injector driver 88 also select which one or ones of the fuel injectors 48 are to be energized in response to each respective timing pulse. As an example, the fuel injectors 48 may be divided into separate groups which

are successively energized in response to succeeding ones of the timing pulses. Conversely, the timing pulses may be applied to a logic network which selects the fuel injectors 48 for individual energization.

The injection pulse generator 84 comprises first, second and third control pulse generators 92, 94 and 96, and an injection pulse synthesizer 98. A voltage regulator 100 is connected between the unregulated power line 40 and the ground line 42 for providing a regulated supply voltage for the injection pulse generator 84 on a regulated power line 102. The first, second and third control pulse generators 92, 94 and 96, and the injection pulse synthesizer 98 are connected between the regulated power line 102 and the ground line 42. The voltage regulator 100 may be provided by virtually any suitable voltage regulating apparatus, such as a Zener diode.

Referring to FIGS. 1 and 2, the first control pulse generator 92 repetitively produces a first control pulse C_1 which is initiated in synchronization with the operation of the engine 10 and which is terminated at the expiration of a first control time period T_1 determined as a preselected function of a first engine operating parameter. The second control pulse generator 94 repetitively produces a second control pulse C_2 which is initiated in response to the initiation of the first control pulse C_1 and which is terminated before the termination of the first control pulse C_1 at the expiration of a second control time period T_2 determined as a preselected function of a second engine operating parameter. The third control pulse generator 96 repetitively produces a third control pulse C_3 which is initiated in response to the termination of the second control pulse C_2 and which is terminated after the termination of the first control pulse C_1 at the expiration of a third control time period T_3 determined as a function of the difference between the first control time period T_1 and the second control time period T_2 and determined as a preselected function of a third engine operating parameter.

The injection pulse synthesizer 98 repetitively develops an injection pulse I extending over an injection time period T_i which is initiated in response to the initiation of the first control pulse C_1 and which is terminated in response to the termination of the third control pulse C_3 . Consequently, the duration T_i of the injection pulse I is directly related to the duration T_1 of the first control pulse C_1 , is inversely related to the duration T_2 of the second control pulse C_2 , and is directly related to the duration T_3 of the third control pulse C_3 . As previously described, the amount of fuel applied to the engine 10 by the fuel injector 48 is proportional to the duration T_i of the injection pulse I.

The first control pulse generator 92 is connected to the timing pulse generator 80 through the timing pulse line 82 and is connected to a pressure sensor 104 through a suitable linkage 106. The pressure sensor 104 communicates with the intake manifold 20 of the engine 10 downstream from the throttle 74 for monitoring the pressure of the air within the intake manifold 20. The first control pulses C_1 produced by the first control pulse generator 92 are applied to a first control pulse line 108. The first control pulses C_1 are each initiated in response to the initiation of a timing pulse as received from the timing pulse generator 80. The first control pulses C_1 each have a length or duration T_1 defined as a preselected function of the air pressure

within the intake manifold 20 of the engine 10 as measured by the pressure sensor 104.

The principal function of the illustrated electronic fuel injection system is to regulate the amount of fuel delivered to the engine 10 in response to the amount of air delivered to the engine 10 thereby to maintain a predetermined air-fuel ratio. The pressure of the air within the intake manifold 20 is directly related to the amount of air delivered to the engine 10 as regulated by the throttle 74. The amount of fuel delivered to the engine 10 is directly related to the length T_i of the injection pulses I, which in turn is directly related to the length T_1 of the first control pulses C_1 . Accordingly, the length T_1 of the first control pulses C_1 is defined by the first control pulse generator 92 as a preselected direct function of the air pressure within the intake manifold 20 as measured by the pressure sensor 104. Thus, as the intake air pressure increases, the first control time period T_1 increases to increase the injection time period T_i . Conversely, as the intake air pressure decreases, the first control time period T_1 decreases to decrease the injection time period T_i . Preferably, the duration T_1 of the first control pulses C_1 is a linear or straight-line function of the air pressure within the intake manifold 20. However, it is to be understood that the first control time period T_1 may be virtually any desired function of the intake air pressure.

The first control pulse generator 92 may be provided by a switching circuit including a resistance-inductance timing network for defining the duration T_1 of the first control pulses C_1 in accordance with the L/R time constant of the timing network. The inductance of the timing network may be mechanically varied by the pressure sensor 104 acting through the linkage 106 in response to changes in the air pressure within the intake manifold 20 thereby to define the length T_1 of the first control pulses C_1 as a direct function of the intake air pressure. A more detailed description of one embodiment of the first control pulse generator 92 may be had by reference to U.S. Pat. No. 3,623,459.

The second control pulse generator 94 is connected to the first control pulse generator 92 through the first control pulse line 108 and is connected to the vehicle battery 36 through the unregulated power line 40 and the ignition switch 38. The second control pulses C_2 produced by the second control pulse generator 94 are applied to a second control pulse line 110. The second control pulses C_2 are each initiated in response to the initiation of a first control pulse C_1 as received from the first control pulse generator 92. The second control pulses C_2 each have a length or duration T_2 defined as a preselected function of the supply voltage of the vehicle battery 36 as received via the unregulated power line 40.

As priorly discussed, the fuel injector 48 includes a plunger 54 which is electromagnetically coupled with a winding 58. The winding 58 is energized for the duration T_i of the injection pulses I. Due to the inherent inductive properties of the plunger 54 and the winding 58, the plunger 54 arrives at a fully opened position some "pull-in" time interval after energization of the winding 58 in response to the initiation of an injection pulse I. Similarly, the plunger 54 arrives at a fully closed position some "drop-out" time interval after de-energization of the winding 58 in response to the termination of an injection pulse I. Both the pull-in time interval and the drop-out time interval are dependent

upon the supply voltage of the vehicle battery 36 in such a manner that, assuming an injection pulse I of constant length T_i , the amount of fuel applied to the engine 10 is directly related to the magnitude of the battery voltage. The length T_i of the injection pulses I is inversely related to the length T_2 of the second control pulses C_2 . Accordingly, the duration T_2 of the second control pulses C_2 is defined by the second control pulse generator 94 as a preselected direct function of the supply voltage of the vehicle battery 36. Hence, as the battery voltage increases, the second control time period T_2 increases to decrease the injection time period T_i . Conversely, as the battery voltage decreases, the second control time period T_2 decreases to increase the injection time period T_i . The length T_2 of the second control pulses C_2 may be virtually any desired function of the battery supply voltage.

The second control pulse generator 94 may be provided by a switching circuit including a resistance-capacitance timing network for defining a timing voltage in accordance with the RC time constant of the timing network. The duration T_2 of the second control pulses C_2 may be defined by the switching circuit as the time interval between the departure of the timing voltage from a base level and the arrival of the timing voltage at a reference level. Either the base level or the reference level may be controlled in response to the supply voltage of the vehicle battery 36. In addition, the battery supply voltage may be directly applied to energize the timing network of the switching circuit so that the relative magnitude of the timing voltage is defined in proportion to the magnitude of the battery voltage.

The third control pulse generator 96 is connected to the first control pulse generator 92 through the first control pulse line 108 and is connected to the second control pulse generator 94 through the second control pulse line 110. Further, the third control pulse generator 96 is connected with a plurality of temperature sensor lines 112, 114 and 116. The first sensor line 112 is connected to an intake air temperature sensor provided by a thermistor 118 mounted within the intake manifold 20 of the engine 10 downstream from the throttle 74 for monitoring the temperature of the intake air. The second sensor line 114 is connected to an engine coolant temperature sensor provided by a thermistor 120 immersed within the cooling fluid surrounding the outer surface of the combustion chamber 12 for monitoring the overall temperature of the engine 10 as manifested by the temperature of the engine coolant. The third sensor line 116 is connected to an injected fuel temperature sensor provided by a thermistor 122 mounted to the fuel injector 48 for monitoring the temperature of the injected fuel.

The third control pulses C_3 produced by the third control pulse generator 96 are applied to a third control pulse line 124. The third control pulses C_3 are each initiated in response to the termination of a second control pulse C_2 as received from the second control pulse generator 94. The third control pulses C_3 each have a length or duration T_3 defined by the difference between the duration T_1 of the associated first control pulse C_1 and the duration T_2 of the associated second control pulse C_2 and defined as preselected function of the temperature of the engine 10. More specifically, the third control time period T_3 is defined as a function of the temperature of the intake air as measured by the thermistor 118, the temperature of the engine coolant

as measured by the thermistor 120, and the temperature of the injected fuel as measured by the thermistor 122.

Assuming a constant mass of air is delivered to the engine 10, the pressure of the air within the intake manifold 20 is directly related to the temperature of the intake air. In addition, when the engine 10 is relatively cold, the quantity of fuel which is condensed upon the surfaces of the intake manifold 20, the intake valve 22, etc. is inversely related to the temperature of these engine parts as manifested by the temperature of the engine coolant. Further, when the engine 10 is very hot, the quantity of fuel which is vaporized within the intake manifold 20 is directly related to the temperature of the injected fuel, especially the fuel temperature at the nozzle of the fuel injector 48. Therefore, to accurately maintain a predetermined air-fuel ratio, the amount of fuel injected into the intake manifold 20 must be compensated for the effects of temperature upon intake air pressure, fuel condensation, and fuel vaporization.

The amount of fuel applied to the engine 10 is directly related to the length T_i of the injection pulses I, which in turn is directly related to the length T_3 of the third control pulses C_3 . Accordingly, the length T_3 of the third control pulses C_3 is defined by the third control pulse generator 96 as a preselected inverse function of the intake air temperature, as a preselected inverse function of the engine coolant temperature, and as a preselected direct function of the injected fuel temperature. Preferably, the temperature of the engine coolant is effective to lengthen the injection time period T_i only when such temperature is below a value at which appreciable amounts of fuel are condensed. Similarly, the temperature of the injected fuel is effective to lengthen the injection time period T_i only when such temperature is above a value at which appreciable amounts of fuel are vaporized.

The structure and operation of one embodiment of the third control pulse generator 96 is illustrated in FIGS. 2 and 3. A control voltage V is developed across a capacitor 126. A charge circuit 128 is connected to the capacitor 126 through a charge line 130 and is connected to the first control pulse line 108 and to the second control pulse line 110. The charge circuit 128 charges the capacitor 126 with a constant charge current I_c to increase the control voltage V from a base level L_b to a peak level L_p over a charge time period T_c which is initiated in response to the termination of a second control pulse C_2 and which is terminated in response to the termination of a first control pulse C_1 . A discharge circuit 132 is connected to the capacitor 126 through a discharge line 134 and is connected to the first control pulse line 108 and the third control pulse line 124. The discharge circuit 132 discharges the capacitor 126 with a constant discharge current I_d to decrease the control voltage V from the peak level L_p to the base level L_b over a discharge time period T_d which is initiated in response to the termination of a first control pulse C_1 and which is terminated when the control voltage V reaches the base level L_b .

A voltage responsive switch 136 is connected to the capacitor 126 through a monitor line 138 and is connected to the third control pulse line 124. Preferably, the voltage responsive switch 136 is provided by a differential amplifier of the type shown and described in U.S. Pat. No. 3,712,990. The differential amplifier 136 is responsive to the control voltage V as received via

the monitor line 138 to develop third control pulses C_3 on the third control pulse line 124. The third control pulses C_3 are each initiated when the control voltage V initially departs from the base level L_b and are each terminated when the control voltage V subsequently arrives back at the base level L_b . Between the termination of each preceding discharge time period T_d and the initiation of each succeeding charge time period T_c , the control voltage V is clamped at the base level L_b by the differential amplifier 136.

The duration T_3 of the third control pulses C_3 may be expressed by the following equation:

$$T_3 = T_c + T_d$$

which indicates that the third control time period T_3 is equal to the summation of the charge time period T_c and the discharge time period T_d . The charge time period T_c may be expressed by the following equation:

$$T_c = T_1 - T_2$$

which indicates that the charge time period T_c is equal to the first control time period T_1 less the second control time period T_2 . The discharge time period T_d may be expressed by the following equation:

$$T_d = (T_1 - T_2) I_c / I_d$$

which indicates that the discharge time period T_d is equal to the difference between the first control time period T_1 and the second control time period T_2 multiplied by the ratio I_c / I_d of the charge current I_c to the discharge current I_d . The simultaneous solution of equations 1-3 for the third control time period T_3 yields the following equation:

$$T_3 = (T_1 - T_2) (1 + I_c / I_d)$$

which indicates that the duration T_3 of the third control pulses C_3 is directly related to the magnitude of the charge current I_c and is inversely related to the magnitude of the discharge current I_d . Thus, the third control time period T_3 increases when either the charge current I_c increases or the discharge current I_d decreases. Conversely, the third control time period T_3 decreases when either the charge current I_c decreases or the discharge current I_d increases.

Preferably, the discharge circuit 132 is connected to the temperature sensor lines 112, 114 and 116 for defining the magnitude of the discharge current I_d in direct relation to the intake air temperature as sensed by the thermistor 118, in direct relation to the engine coolant temperature as sensed by the thermistor 120, and in inverse relation to the injected fuel temperature as sensed by the thermistor 122. Alternately, the temperature sensor lines 112, 114 and 116 may be connected to the charge circuit 128 for defining the magnitude of the charge current I_c in inverse relation to the intake air temperature, in inverse relation to the engine coolant temperature, and in direct relation to the injected fuel temperature. Between the extremes of these two examples, it will be apparent that either the charge

current I_c or the discharge current I_d may be appropriately varied in response to any desired combination of the intake air temperature, the engine coolant temperature, and the injected fuel temperature. The charge circuit 128 and the discharge circuit 132 may be provided by virtually any suitable thermistor controlled constant current sources.

The injection pulse synthesizer 98 is connected to the first control pulse generator 92 through the first control pulse line 108 and is connected to the third control pulse generator 94 through the third control pulse line 124. The injection pulse synthesizer 98 is responsive to the receipt of a first control pulse C_1 via the first control pulse line 108 and a third control pulse C_3 via the third control pulse line 124 to develop an injection pulse I on the injection pulse line 86. As previously described, the injection pulses I each extend over an injection time period T_i which is initiated in response to the initiation of a first control pulse C_1 and which is terminated in response to the termination of a third control pulse C_3 . In other words, the injection pulse synthesizer 98 develops injection pulses I in response to the presence of a first control pulse C_1 or a third control pulse C_3 . The fuel injector driver 88 energizes the fuel injector 48 for the duration T_i of the injection pulses I emitted by the injection pulse synthesizer 98. Consequently, the amount of fuel applied to the engine 10 is proportional to the length T_i of the injection pulses I .

The total quantity of fuel Q delivered to the engine 10, which is proportional to the duration T_i of the injection pulses I , may be expressed by the following equation:

$$Q \propto T_2 + T_3$$

The simultaneous solution of equations 4 and 5 for the fuel quantity Q , yields the following equation:

$$Q \propto T_1 (1 + I_c / I_d) - T_2 (I_c / I_d)$$

The duration T_1 of the first control pulses C_1 may be expressed by the following equation:

$$T_1 = f(P)$$

which indicates that the first control time period T_1 is defined as a preselected function f of the intake air pressure P . The duration T_2 of the second control pulses C_2 may be expressed by the following equation:

$$T_2 = f(B)$$

which indicates that the second control time period T_2 is defined as a preselected function f of the battery voltage B . The ratio I_c / I_d of the charge current I_c to the discharge current I_d may be expressed by the following equation:

$$I_c / I_d = f(H)$$

which indicates that the ratio I_c / I_d is a preselected function f of the engine temperature H which comprises one

or more of the intake air temperature H_1 , the engine coolant temperature H_2 , or the injected fuel temperature H_3 . The simultaneous solution of equations 6-9 for the fuel quantity Q yields the following equation:

$$Q \neq f(P) [f(H) + 1] - [f(B)f(H)] \quad (10)$$

which defines a linear or straight-line fuel control curve F as shown in FIG. 4.

Referring to FIG. 4, the fuel control curve F is described within a two-dimensional coordinate system defined by a horizontally disposed X-axis and a vertically disposed Y-axis which perpendicularly intersect at an origin 0. The preselected function of intake air pressure $f(P)$ is plotted along the X-axis while the fuel quantity Q is plotted along the Y-axis. The fuel control curve F is characterized by a slope and an offset. The slope of the fuel control curve F is given by the ratio (y'/x') of the distance y' traced along the Y-axis to the distance x' traced along the X-axis when an imaginary point is moved a distance a along the fuel control curve F . The offset of the fuel control curve F is given by the distance b between the origin 0 and the intersection U of the fuel control curve F with the Y-axis. This intersection is only theoretical since the function of intake air pressure $f(P)$ is never zero in actual practice.

Referring to equation 10, the slope of the fuel control curve F is defined by the term $[f(H) + 1]$. Changes in the function of engine temperature $f(H)$ have the effect of rotating the fuel control curve F about the Y-axis intercept U as depicted by the double-headed arrow 140. The offset of the fuel control curve F is defined by the term $-[f(B)f(H)]$. Changes in the function of battery voltage $f(B)$ or in the function of temperature $f(H)$ have the effect of vertically shifting the Y-axis intercept U of the fuel control curve F as depicted by the double-headed arrow 142. However, it will be noted that since the sign of the offset term $-[f(B)f(H)]$ is always minus $(-)$, the Y-axis intercept U of the fuel control curve F cannot be shifted above the origin 0.

The net change in the amount of fuel delivered to the engine 10 as a result of variations in the temperature of the engine 10 is dependent upon the pressure of the air within the intake manifold 20. Given a constant air mass within the intake manifold 20, the intake air pressure is directly proportional to the intake air temperature. Further, the amount of fuel condensation and the amount of fuel vaporization are directly proportional to the quantity of fuel injected into the intake manifold 20 as primarily determined by the intake air pressure. Thus, the engine temperature and the intake air pressure are multiplicatively related as engine operating parameters. Ideally, the slope (y'/x') of the fuel control curve F is determined by the function of engine temperature $f(H)$ only. The slope term $[f(H) + 1]$ of equation 10 satisfies this criteria.

The net change in the amount of fuel delivered to the engine 10 as a result of variations in the supply voltage of the vehicle battery 36 is independent of the pressure of the air within the intake manifold 20. Hence, the battery voltage and the intake air pressure are additively related as engine operating parameters. Ideally, the offset b of the fuel control curve F should be determined by the function of battery voltage $f(B)$ only. Unfortunately, the offset term $-[f(B)f(H)]$ does not satisfy this criteria. However, the criteria may be conveniently sat-

isfied by multiplying the offset term $-[f(B)f(H)]$ by the reciprocal of the function of engine temperature $1/f(B)$, or the ratio I_d/I_c of the discharge current I_d to the charge current I_c .

- 5 It is to be understood that the illustrated embodiment of the invention is shown for demonstrative purposes only and that various alterations and modifications may be made to the illustrated embodiment without departing from the spirit and scope of the invention.
- 10 What is claimed is:

1. In an internal combustion engine, the combination comprising: means for defining a first time period initiated in synchronization with the operation of the engine and terminated at the expiration of a time duration determined as a preselected function of a first engine operating parameter; means for defining a second time period initiated in response to the initiation of the first time period and terminated before the termination of the first time period at the expiration of a time duration determined as a preselected function of a second engine operating parameter; means for defining a third time period initiated in response to termination of the second time period and terminated after the termination of the first time period at the expiration of a time duration determined by the time duration of the first time period less the time duration of the second time period and determined as a preselected function of a third engine operating parameter; and means for applying fuel to the engine in an amount directly related to a composite time period defined between the initiation of the first time period and the termination of the third time period so that the total quantity of fuel delivered to the engine is defined in relation to the preselected function of the first engine operating parameter by a linear fuel control curve having an offset determined by the preselected function of the second engine operating parameter and having a slope determined by the preselected function of the third engine operating parameter.

2. In an internal combustion engine system, the combination comprising: means for defining a first time period T_1 initiated in synchronization with the operation of the engine and terminated at the expiration of a time duration determined as a preselected function of a first engine operating parameter; means for defining a second time period T_2 initiated in response to the initiation of the first time period and terminated before the termination of the first time period at the expiration of a time duration determined as a preselected function of a second engine operating parameter; a capacitor for developing a control voltage thereacross; means for charging the capacitor with a charge current I_c to increase the control voltage from a base level to a peak level over a charge time period initiated in response to the termination of the second time period and terminated in response to the termination of the first time period; means for discharging the capacitor with a discharge current I_d to decrease the control voltage from the peak level to the base level over a discharge time period initiated in response to the termination of the first time period and terminated when the control voltage reaches the base level; means for defining at least one of the charge current I_c and the discharge current I_d as a preselected function of a third engine operating parameter; and means for applying fuel to the engine in an amount proportional to the time interval defined between the initiation of the first time period T_1 and the

termination of the discharge time period so that the total quantity of fuel Q delivered to the engine is defined by the following equation:

$$Q \neq T_1(1 + I_c/I_d) - T_2(I_c/I_d).$$

3. In an internal combustion engine including an air supply system for providing intake air to the engine, a battery for providing a supply voltage, and a fuel supply system including at least one voltage responsive fuel injector for applying fuel to the engine when energized by the supply voltage, the combination comprising: means including a first pulse generator for producing a first control pulse initiated in synchronization with the operation of the engine and terminated at the expiration of a time duration determined as a preselected function of the pressure of the intake air; means including a second pulse generator for producing a second control pulse initiated in response to the initiation of the first control pulse and terminated before the termination of the first control pulse at the expiration of a time duration determined as a preselected function of the magnitude of the supply voltage; means including a third pulse generator for producing a third control pulse initiated in response to the termination of the second control pulse and terminated after the termination of the first control pulse at the expiration of a time duration determined by the time duration of the first control pulse less the time duration of the second control pulse and determined as a preselected function of the temperature of the engine; and means for energizing the fuel injector with the supply voltage between the initiation of the first control pulse and the termination of the third control pulse so that the total amount of fuel applied to the engine is defined in relation to the preselected function of the intake air pressure by a linear fuel control curve having an offset determined by the preselected function of the battery supply voltage and having a slope determined by the preselected function of the engine temperature.

4. In an internal combustion engine including a coolant supply system for providing coolant to the engine, an air supply system for providing intake air to the engine, a battery for providing a supply voltage, and a fuel supply system including at least one voltage responsive fuel injector for applying fuel to the engine when energized by the supply voltage, the combination comprising: means including a first pulse generator for producing a first control pulse initiated in synchronization with the operation of the engine and terminated at the expiration of a time duration determined as a preselected direct function of the pressure of the intake air; means including a second pulse generator for producing a second control pulse initiated in response to the initiation of the first control pulse and terminated before the termination of the first control pulse at the expiration of a time duration determined as a preselected direct function of the magnitude of the battery supply voltage; means including a third pulse generator for producing a third control pulse initiated in response to the termination of the second control pulse and terminated after the termination of the first control pulse at the expiration of a time duration determined by the time duration of the first control pulse less the time du-

ration of the second control pulse and determined as a preselected inverse function of the temperature of the intake air and a preselected inverse function of the temperature of the engine coolant and a preselected direct function of the temperature of the injected fuel; and means for energizing the fuel injector with the supply voltage between the initiation of the first control pulse and the termination of the third control pulse so that the total quantity of fuel applied to the engine is defined in relation to the preselected direct function of the intake air pressure by a straight-line fuel control function having an offset determined by the preselected direct function of the battery supply voltage and having a slope determined by the preselected inverse function of the intake air temperature and the preselected inverse function of the engine coolant temperature and the preselected direct function of the injected fuel temperature.

5. In an internal combustion engine system including an air supply system for providing intake air to the engine, a battery for providing a supply voltage, and a fuel supply system including at least one electromagnetic fuel injector for applying fuel to the engine when energized by the supply voltage, the combination comprising: means including a timing pulse generator for producing timing pulses at a frequency proportional to the speed of the engine; means including a first pulse generator for producing first control pulses each initiated in response to the occurrence of a timing pulse and each terminated after a time duration T_1 determined as a preselected function of the pressure of the intake air; means including a second control pulse generator for producing second control pulses each initiated in response to the initiation of a first control pulse and each terminated before the termination of the first control pulse after a time duration T_2 determined as a preselected function of the magnitude of the supply voltage; a capacitor for developing a control voltage thereacross; means for charging the capacitor with a charge current I_c to increase the control voltage from a base level to a peak level over a charge time period initiated in response to the termination of the second control pulse and terminated in response to the termination of the first control pulse; means for discharging the capacitor with a discharge current I_d to decrease the control voltage from the peak level to the base level over a discharge time period initiated in response to the termination of the first control pulse and terminated when the control voltage reaches the base level; means for defining at least one of the charge current I_c and the discharge current I_d as a preselected function of the temperature of the intake air, as a preselected function of the temperature of the engine coolant, and as a preselected function of the temperature of the injected fuel; and means for energizing the fuel injector with the supply voltage between the initiation of the first time duration T_1 and the termination of the discharge time period so that the total quantity of fuel Q delivered to the engine is defined by the following equation:

$$Q \neq T_1(1 + I_c/I_d) - T_2(I_c/I_d).$$

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