

[54] **ELECTRONIC FUEL INJECTION SYSTEM HAVING COARSE AND FINE SPEED COMPENSATION**

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[51] Int. Cl. **F02d 5/02, F02m 51/00**

[58] Field of Search..... **123/32 EA**

[56] **References Cited**

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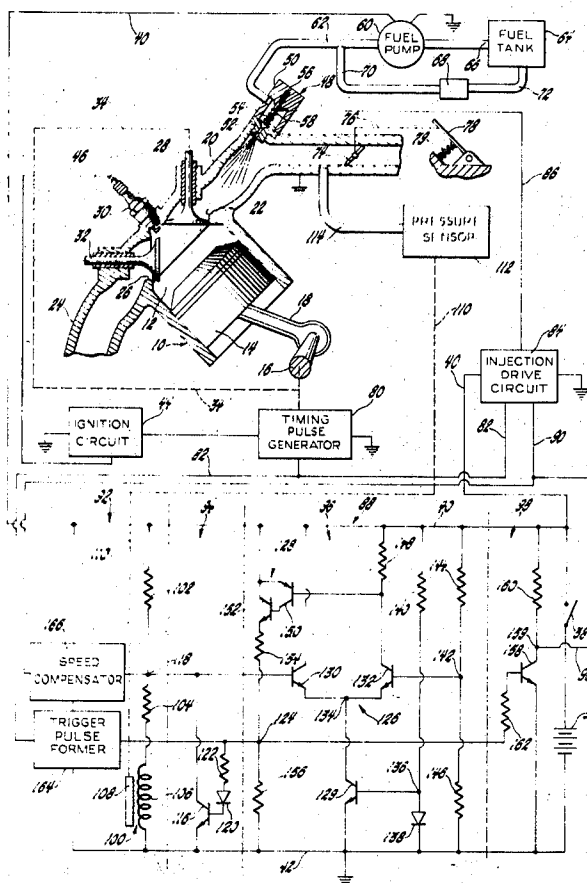
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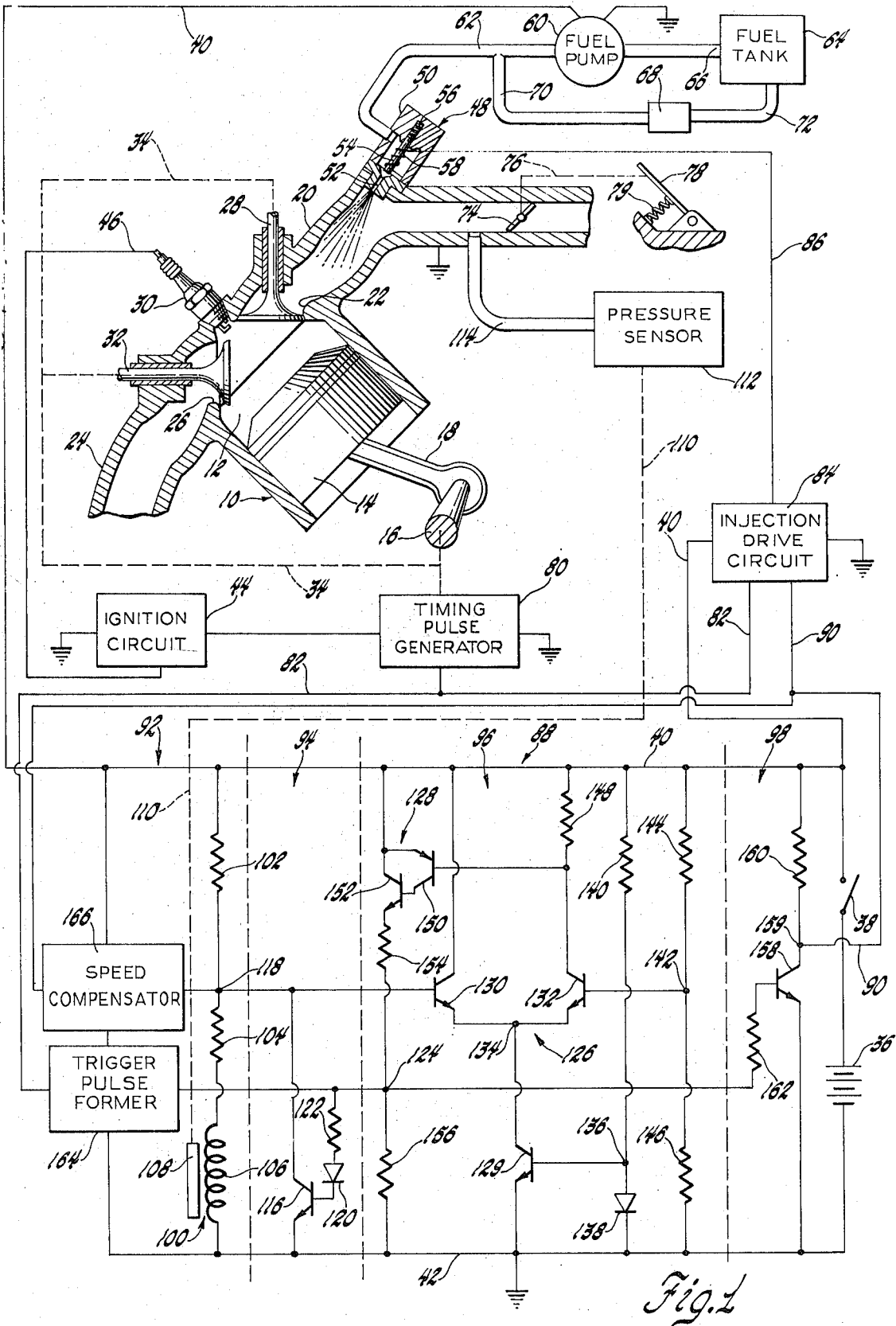
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[57] **ABSTRACT**

Fuel is applied to an internal combustion engine in an amount determined by the length of the control pulses produced at a frequency proportional to the speed of the engine. The length of the control pulses is determined as a function of at least one engine operating parameter. In addition, the length of the control pulses is determined in response to the amplitude of a speed voltage during each of the control pulses. The amplitude of the speed voltage linearly varies over a time period defined as a function of the total time interval between the termination of successive control pulses thereby to provide coarse speed compensation. Further, the slope or the rate of change in the amplitude of the speed voltage is defined as a function of engine speed thereby to provide fine speed compensation. Preferably, the rate of change in the amplitude of the speed voltage is altered such that the length of the control pulses is approximately linearly released to the speed of the engine.

8 Claims, 7 Drawing Figures





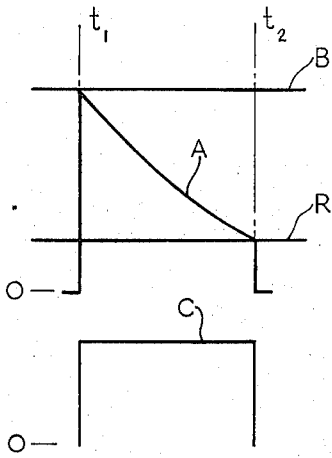


Fig. 2

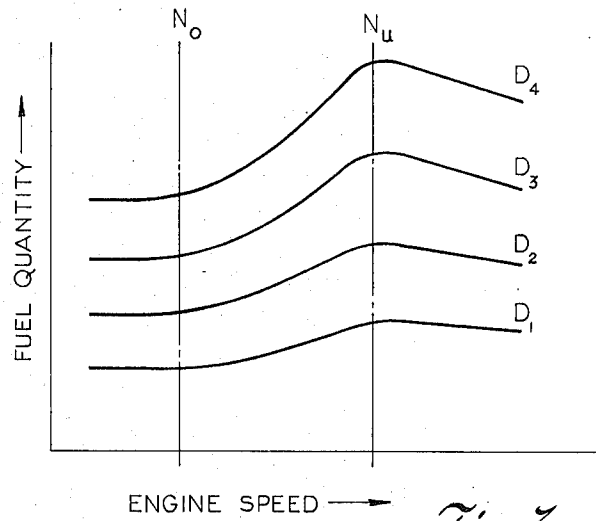


Fig. 3

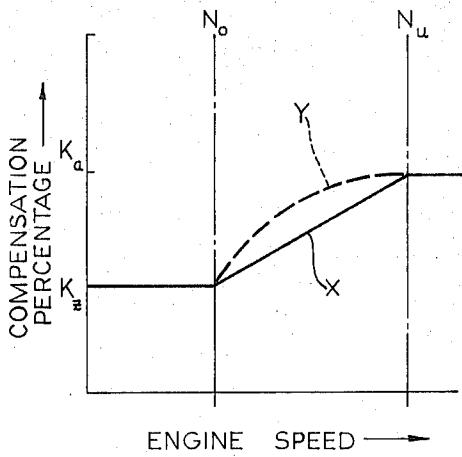


Fig. 4

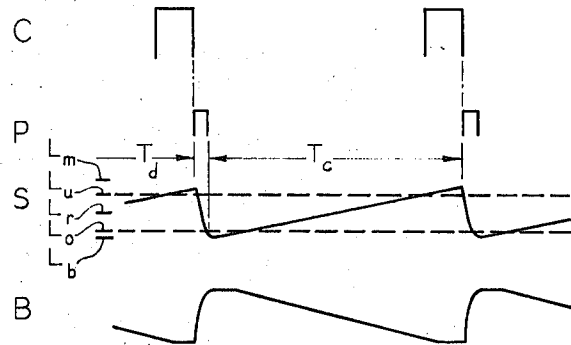


Fig. 5

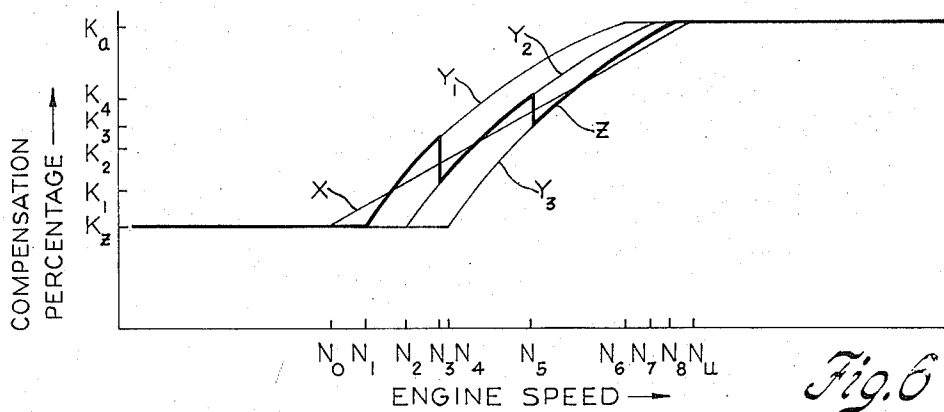
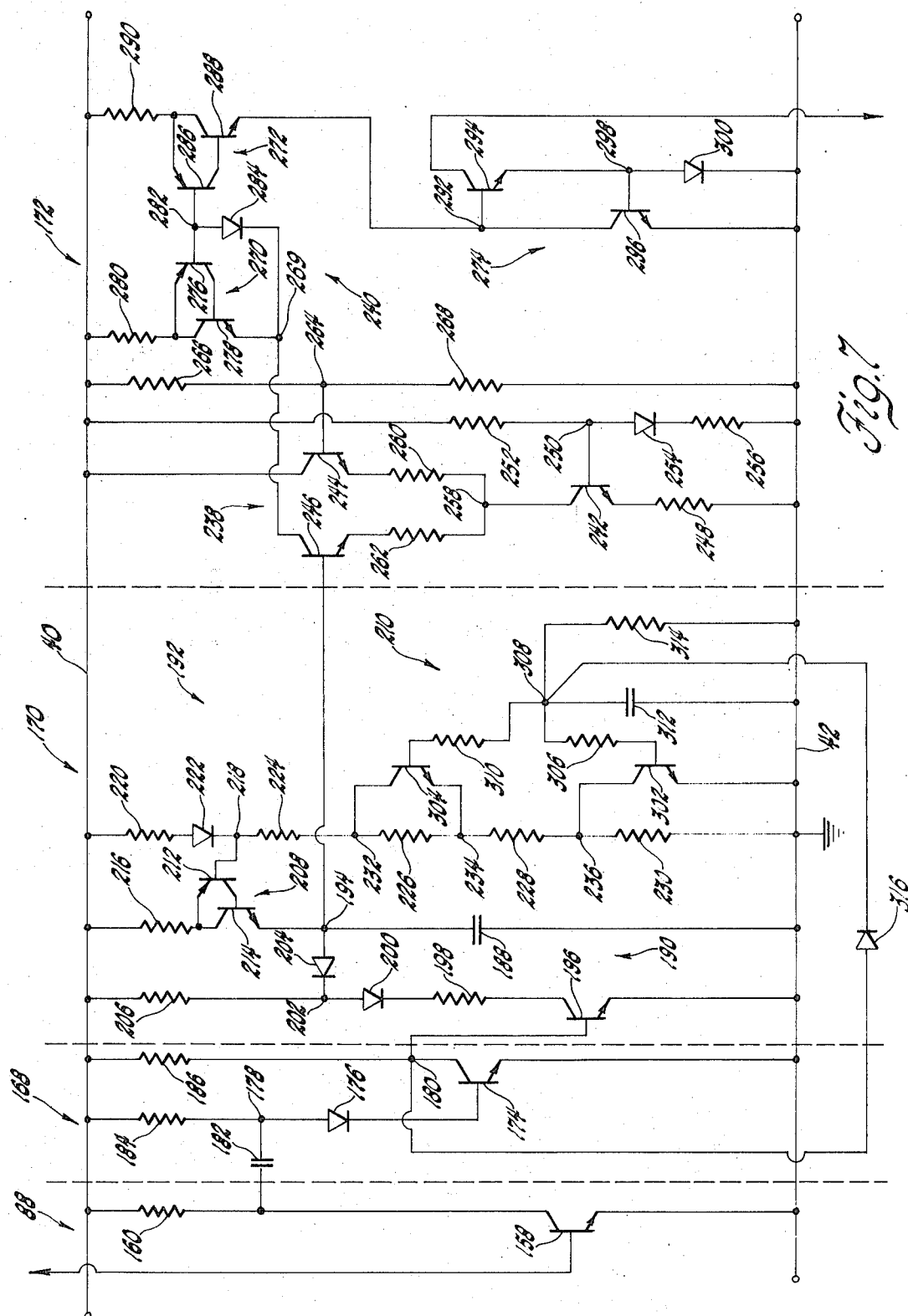


Fig. 6



ELECTRONIC FUEL INJECTION SYSTEM HAVING COARSE AND FINE SPEED COMPENSATION

This invention relates to a fuel supply system for an internal combustion engine. More particularly, the invention relates to an electronic fuel injection system for varying the amount of fuel applied to the engine in response to variations in engine speed.

In one well known type of an electronic fuel injection system, control pulses are produced in synchronization with the speed of the engine. The length of the control pulses is determined as a function of at least one engine operating parameter. Fuel is applied to the engine in an amount determined by the duration of each of the control pulses. Thus, since the control pulses are produced at a frequency proportional to the speed of the engine, the amount of fuel applied to the engine is inherently a function of engine speed. However, due to certain speed related fuel delivery phenomena, such as volumetric efficiency, it is often necessary that more or less fuel be applied to the engine to compensate for variations in the speed of the engine. In particular, it has been found that for optimum operation, some engines require that the length of the control pulses be an approximate linear function of engine speed. The present invention proposes an electronic fuel injection system for providing this desired speed compensation.

According to one aspect of the invention, the length of the control pulses is altered in response to the amplitude of a speed voltage during each of the control pulses. The amplitude of the speed voltage linearly varies over a time period defined as a function of the total time interval between the termination of successive control pulses thereby to provide a first order or coarse speed compensation. In addition, the slope or the rate of change in the amplitude of the speed voltage is defined as a function of engine speed thereby to provide a second order or fine speed compensation. Preferably, the rate of change in the amplitude of the speed voltage is altered such that the length of the control pulses is approximately linearly related to the speed of the engine.

In another aspect of the invention, the speed voltage is developed across a capacitor. The capacitor is discharged at a rapid discharge rate over a discharge period to clamp the amplitude of the speed voltage at a base level at the termination of each discharge period which is initiated in response to the termination of each preceding control pulse. Further, the capacitor is charged at a constant charge rate to linearly increase the amplitude of the speed voltage from the base level toward a maximum level over a variable charge period initiated in response to the termination of each preceding discharge period and terminated in response to the termination of each succeeding control pulse. In response to the speed of the engine, the charge rate of the capacitor is shifted between at least two different values which are defined such that changes in the length of the control pulses are an approximate linear function of changes in the speed of the engine.

As contemplated by a further aspect of the invention, the charge period and the discharge period are defined by a series of speed pulses. The speed pulses are each initiated in response to the termination of a control pulse. In addition, the speed pulses each have a fixed length. The distance period is defined from the termi-

nation of each preceding control pulse until the termination of each succeeding speed pulse. The charge period is defined from the termination of each preceding speed pulse until the termination of each succeeding control pulse. Moreover, the charge rate of the capacitor is determined as a function of the frequency of the speed pulses. When the frequency of the speed pulses corresponds to a particular engine speed, the charge rate of the capacitor is shifted from a first value to a second value so as to linearize variations in the length of the control pulses with variations in the speed of the engine.

These and other aspects and advantages of the invention may be best understood by reference to the following detailed description of a preferred embodiment when considered in conjunction with the accompanying drawings.

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 diagram of several waveforms useful in explaining the operation of the electronic fuel injection system illustrated in FIG. 1.

FIGS. 3 and 4 are graphic diagrams of certain speed related fuel delivery phenomena useful in explaining the principles of the invention.

FIG. 5 is a graphic diagram of several waveforms useful in explaining the operation of the speed compensator illustrated in FIG. 7.

FIG. 6 is a graphic diagram depicting the operation of a preferred embodiment of the speed compensator illustrated in FIG. 7.

FIG. 7 is a schematic diagram of a speed compensator incorporating the principles of the invention.

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.

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 circuit 44 is electrically connected to the

power line 40 and is mechanically connected with the crankshaft 16 of the engine 10. Further, the ignition circuit 44 is connected through a spark cable 46 to the spark plug 30. In a conventional manner, the ignition circuit 44 energizes the spark plug 30 in synchroniza-
 5 tion with the rotation of the crankshaft 16 of the engine 10. Hence, the ignition circuit 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 driving 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 virtually any suitable constant flow rate 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.

A throttle valve 74 is rotatably mounted within the intake manifold 20 for regulating the flow of air into the intake manifold 20 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 pivotally 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 move 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 energiza-
 65 tion. The precise amount of fuel deposited within the

intake manifold 20 is regulated by a fuel supply control system which will be described later. The air enters the intake manifold 20 from the air intake 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. Alternatively, 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. At this point, it is to be understood that the illustrated internal combustion engine 10, together with all of its associated equipment, is shown only to facilitate a more complete understanding of the inventive electronic control system.

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 are applied to a timing line 82. Preferably, the timing pulse generator 80 is some type of inductive speed transducer coupled with a switching circuit. However, the timing pulse generator 80 may be provided by virtually any suitable pulse producing device such as a multiple contact rotary switch.

An injector drive circuit 84 is connected to the power line 40 and to the timing line 82. Further, the injector drive circuit 84 is connected through an injection line 86 to the fuel injector 48. The injector drive circuit 84 is responsive to the timing pulses produced by the timing pulse generator 80 to energize the fuel injector valve 48 in synchronization with the rotating speed or frequency of the crankshaft 16 in much the same manner as the ignition circuit 44 energizes the spark plug 30. The time period for which the fuel injector 48 is energized by the drive circuit 84 is determined by the length or duration of rectangular control pulses produced by a modulator or control pulse generator 88 which will be more fully described later. The control pulses are applied by the control pulse generator 88 to the injector drive circuit 84 over a control line 90 in synchronization with the timing pulses produced by the timing pulse generator 80. In other words, the injector drive circuit 84 is responsive to the coincidence of a timing pulse and a control pulse to energize the fuel injector 48 for the length or duration of the control pulse.

The injector drive circuit 84 may be virtually any amplifier circuit capable of logically executing the desired coincident pulse operation. However, where additional fuel injectors 48 are provided, it may be necessary that the injector drive circuit 84 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 successive ones of the timing pulses. Conversely, the timing pulses may be applied to operate a counter circuit or a logic circuit which individually selects the fuel injectors 48 for energization.

The control pulse generator 88 includes a control network 92, a control switch 94, a switching circuit 96 and an output switch 98. The control network 92 includes a control transducer 100, a first control resistor 102 and a second control resistor 104. The control transducer 100 includes an inductor or control winding 106 connected in series with the control resistors 102 and 104 between the power line 40 and the ground line 42. Further, the control transducer 100 includes a movable magnetizable core 108 which is inductively coupled with the winding 106. The deeper the core 108 is inserted within the winding 106, the greater the inductance of the winding 106. The movable core 108 is mechanically connected through a suitable linkage 110 with a pressure sensor 112. The pressure sensor 112 communicates with the intake manifold 20 of the engine 10 downstream from the throttle valve 74 through a conduit 114 for monitoring the negative pressure or vacuum within the intake manifold 20. The pressure sensor 112 moves the core 108 within the winding 106 of the control transducer 100 to regulate the inductance of the winding 106 in direct relation to the pressure within the intake manifold 20. Therefore, as the pressure within the intake manifold 20 increases in response to opening of the throttle valve 74, the core 108 is inserted deeper within the winding 106 of the control transducer 100 to proportionally increase the inductance of the winding 106.

The control switch 94 is provided by an NPN junction transistor 116. The emitter electrode of the transistor 116 is connected directly to the ground line 42. The collector electrode of the transistor 116 is connected directly to a junction 118 between the first and second

control resistors 102 and 104 in the timing network 92. The base electrode of the transistor 116 is connected through a turnoff diode 120 and a biasing resistor 122 to a junction 124 in the switching circuit 96.

The switching circuit 96 includes a differential switch or differential amplifier 126 and a buffer switch 128. The differential amplifier 126 includes NPN junction transistors 129, 130 and 132. The emitter electrode of the transistor 129 is connected directly to the ground line 42. The collector electrode of the transistor 129 is connected to a junction 134 between the emitter electrodes of the transistors 130 and 132. The base electrode of the transistor 129 is connected to a junction 136 between a temperature compensating diode 138 and a biasing resistor 140 which are connected in series between the power line 40 and the ground line 42. The base electrode of the transistor 130 is connected directly to the junction 118 in the control network 92. The base electrode of the transistor 132 is connected to a junction 142 between a pair of biasing resistors 144 and 146 which are connected in series between the power line 40 and the ground line 42. The collector electrode of the transistor 130 is connected directly to the power line 40 and the collector electrode of the transistor 132 is connected through a biasing resistor 148 to the power line 40.

The buffer switch 128 includes a PNP junction transistor 150 and an NPN junction transistor 152. The emitter electrode of the transistor 150 and the collector electrode of the transistor 152 are connected together directly to the power line 40. The collector electrode of the transistor 150 is connected directly to the base electrode of the transistor 152. The base electrode of the transistor 150 is connected directly to the collector electrode of the transistor 132 in the differential amplifier 126. The emitter electrode of the transistor 152 is connected through a biasing resistor 154 to the junction 124. Further, a biasing resistor 156 is connected between the junction 124 and the ground line 42.

The output switch 98 is provided by an NPN junction transistor 158. The emitter electrode of the transistor 158 is connected directly to the ground line 42. The collector electrode of the transistor 158 is connected directly to a junction 159. A biasing resistor 160 is connected between the junction 159 and the power line 40. In addition, the collector electrode of the transistor 158 is connected directly to the control line 90. The base electrode of the transistor 158 is connected through a biasing resistor 162 to the input junction 124 in the bistable circuit 96.

A trigger pulse former 164 is connected between the timing line 82 and the junction 124 of the control pulse generator 88 for developing negative trigger pulses or voltage spikes in response to conductive, rectangular timing pulses produced by the timing pulse generator 80. More specifically, the trigger pulse former 164 provides a trigger pulse in coincidence with the initiation of each of the timing pulses on the timing line 82. Thus, the trigger pulses have the same frequency as the connected pulses. The trigger pulse former 164 may be provided by a simple RC differentiator or any other suitable trigger pulse forming circuit. Together, the trigger pulse former 164 and the timing pulse generator 80 comprise a timing apparatus for producing trigger pulses having a trigger frequency proportional to the output speed of the engine 10.

Referring to FIGS. 1 and 2, the control network 92 produces a control voltage A at the junction 118. The amplitude of the control voltage A varies in a manner which will be more fully described later. In the switching circuit 96, the resistors 144 and 146 form a voltage divider network for providing a reference voltage R at the junction 142. The amplitude of the reference voltage R is substantially constant at a reference level determined by the ratio of the resistances of the resistors 144 and 146. Further, in the switching circuit 96, the transistor 129 combines with the diode 138 and a resistor 140 to provide a constant current sink for the differential amplifier 126 at the junction 134.

In the conventional manner, the differential amplifier 126 is operable between first and second states. More particularly, the differential amplifier 126 switches to the second state when the voltage at the junction 118 exceeds the voltage at the junction 142 and switches to the first state when the voltage at the junction 142 exceeds the voltage at the junction 118. Hence, the differential amplifier 126 switches from the first state to the second state when the amplitude of the control voltage A initially increases above the amplitude of the reference voltage R and switches from the second state to the first state when the amplitude of the control voltage A subsequently decreases below the amplitude of the reference voltage R.

When the differential amplifier 126 is in the first state, the transistor 132 is rendered fully conductive and the transistor 130 is rendered fully nonconductive. With the transistor 132 turned on, the transistor 150 and 152 in the buffer switch 128 are rendered fully conductive through the biasing action of the resistor 148 and the transistors 128 and 132. When the differential amplifier 126 is in the second state, the transistor 130 is rendered fully conductive and the transistor 132 is rendered fully nonconductive. With the transistor 132 turned off, the transistors 150 and 152 in the buffer switch 128 rendered fully nonconductive through the biasing action of the resistor 148.

Before time t_1 , it is assumed that the differential amplifier 126 is in the first state. Consequently, the transistor 132 is turned on to render the buffer switch 128 fully conductive. With the buffer switch transistors 150 and 152 turned on, the control switch transistor 116 is rendered fully conductive through the biasing action of the resistors 122, 154 and 156. With the transistor 116 turned on, the control junction 118 in the control network 92 is effectively connected to the ground line 42 through the transistor 116. As a result, the amplitude of the control voltage A is clamped to the ground potential on the ground line 42. Further, with the buffer switch transistors 150 and 152 turned on, the output switch transistor 158 is rendered fully conductive through the biasing action of the resistors 154, 156 and 162. With the transistor 158 turned on, the control line 90 is effectively connected to the ground line 42 through the transistor 158. Hence, before time t_1 , a control pulse C is absent from the control line 90.

As previously described, the trigger pulse former 164 applies negative trigger pulses to the junction 124 in the control pulse generator 88 at a trigger frequency defined in direct relation to the speed of the engine 10. Assuming a trigger pulse arrives at the junction 124 at time t_1 , it instantaneously renders both the control switch transistor 116 and the output switch transistor 158 fully nonconductive. With the transistor 158

turned off, the control line 90 is effectively disconnected from the ground line 42. Accordingly, a control pulse C is initiated on the control line 90. The voltage level of the control pulse C is primarily determined by the supply potential on the power line 40.

Further, with the timing switch transistor 116 turned off at time t_1 , the control junction 118 in the control circuit 92 is also effectively disconnected from the ground line 42. Consequently, a bias voltage B is instantaneously established at the junction 118 by the first control resistor 102 and a speed compensator 166 as will be more fully described later. For the present time, the operation of the speed compensator 166 will be ignored. Hence, it is assumed that the speed compensator 166 has no effect on the control circuit 92 so that the bias voltage B is substantially constant at a bias level which is approximately equal to the supply potential on the power line 40.

In addition, at time t_1 , the control voltage A at the junction 118 instantaneously increases to a maximum peak level above the reference level of the reference voltage R. The maximum peak level of the control voltage A is approximately equal to the bias level of the bias voltage B. Immediately, the control winding 106 of the control transducer 100 begins charging through the first and second control resistors 102 and 104. As a result, the amplitude of the control voltage A gradually decreases in accordance with a L/R time constant provided by the inductance of the winding 106 and the combined resistances of the first and second resistors 102 and 104. At time t_2 , the control voltage A decreases to a minimum peak level which is equal to the reference level of the reference voltage R.

At time t_1 , the differential amplifier 126 switches from the first state to the second state as the amplitude of the control voltage A rises above the amplitude of the reference voltage R. In the second state, the transistor 130 is turned on and the transistor 132 is turned off to render the buffer switch 128 fully nonconductive. With the buffer switch transistors 150 and 152 turned off, the control switch transistor 116 and the output switch transistor 158 remain turned off. At time t_2 , the differential amplifier 126 switches from the second state to the first state as the amplitude of the control voltage A falls below the amplitude of the reference voltage R. With the differential amplifier 126 in the first state, the transistor 130 is turned off and the transistor 132 is turned on to render the buffer switch 128 fully conductive. With the buffer switch transistors 150 and 152 turned on, the control switch transistor 116 and the output switch transistor 158 are turned on. With the control switch transistor 116 turned on, the junction 118 is effectively connected to the ground line 42. Thus, the amplitude of the control voltage A is again clamped to the ground potential on the ground line 42. Further, with the output switch transistor 158 turned on, the control line 90 is effectively connected to the ground line 42. Hence, the control pulse C is terminated on the control line 90.

It will now be appreciated that the duration of the control pulses C is equal to the duration of the control voltage A as determined in direct relation to the L/R time constant provided by the inductance of the control winding 106 and the total resistance of the first and second control resistors 102 and 104. Further, since the inductance of the control winding 106 is directly related to the negative pressure within the intake mani-

fold 20 of the engine 10, the duration of the control pulses C is also directly related to the intake pressure of the engine 10. Thus, as the intake pressure of the engine 10 increases, the duration of the control pulses C also increases. Of course, the duration of the control pulses C may be additionally determined as a function of several other engine operating parameters, such as engine temperature or battery voltage. Since the fuel injector 46 is energized for the duration of the control pulses C, the amount of fuel applied to the engine 10 is determined in direct proportion to the duration of the control pulses C.

The frequency of the control pulses C is defined by the frequency of the trigger pulses applied at the junction 124 of the control pulse generator 88. Hence, the frequency of the control pulses C is directly related to the output speed of the engine 10. As a result, the amount of fuel applied to the engine 10 is inherently a function of engine output speed. However, due to certain speed related fuel delivery phenomena, such as volumetric efficiency it is necessary that the normal fuel quantity be changed in response to variations in the output speed of the engine 10. The effects of these fuel delivery phenomena may be best understood by reference to FIG. 3, which illustrates a set of typical fuel demand curves D_1 - D_4 , assuming the engine 10 includes eight cylinders. The fuel demand curves D_1 - D_4 each represent a graph of engine fuel quantity versus engine output speed at different constant intake pressures. More specifically, the intake pressure of the engine 10 increases in progressing from the fuel demand curve D_1 to the fuel demand curve D_4 . Since the quantity of fuel delivered to the engine 10 is directly related to the duration of the control pulses C, the ordinate of the graph also represents the duration of the control pulses C.

In general, the fuel demand curves D_1 - D_4 each exhibit one transition point at approximately the same lower speed limit N_o and another transition point at approximately the same upper speed limit N_u . Below the lower speed limit N_o , the fuel demand curves D_1 - D_4 are each relatively constant at different minimum levels. Between the lower speed limit N_o and the upper speed limit N_u , the fuel demand curves D_1 - D_4 each gradually increase from the different minimum levels to different maximum levels. Above the upper speed limit N_u , the fuel demand curves D_1 - D_4 are relatively constant at the different maximum levels at very high engine speeds and very high engine loads, the fuel demand curves D_1 - D_4 exhibit some roll-off. However, for purposes of the present invention, this minor roll-off may be neglected.

In order to achieve optimum operation of the engine 10, the fuel demand curves D_1 - D_4 indicate that the amount of fuel normally applied to the engine 10 must be compensated for variations in engine speed. More specifically, extra fuel should be added to the normal fuel quantity in accordance with an optimum speed compensation curve X, which is illustrated in FIG. 4. The speed compensation curve X represents a graph of the desired percentage increase in the normal fuel quantity versus engine speed. As might be expected, the optimum fuel compensation curve X is an average approximation of the respective fuel demand curves D_1 - D_4 .

According to the fuel compensation curve X, a linearly increasing amount of extra fuel should be added

to the normal fuel quantity in response to increasing engine speed between the lower speed limit N_o and the upper speed limit N_u . That is, the normal duration of the control pulses C as determined by the pressure within the intake manifold 20 should be extended by a compensation percentage which linearly increases from a minimum compensation percentage K_z to a maximum compensation percentage K_a as the engine speed linearly increases between the lower speed limit N_o and the upper speed limit N_u . However, when the speed of the engine 10 is below the lower speed limit N_o , the constant minimum compensation percentage K_z should be added to the normal fuel quantity. Similarly, when the speed of the engine 10 is above the upper speed limit N_u , the constant maximum compensation percentage K_a should be added to the normal fuel quantity. In other words, the normal duration of the control pulses C as determined by the pressure within the intake manifold 20 should be increased by the constant minimum compensation percentage K_z when the engine speed is below the lower speed limit N_o and by the constant maximum compensation percentage K_a when the engine speed is above the upper speed limit N_u . The present invention comprises an electronic fuel injection system including a speed compensator 166 for providing the desired speed compensation.

FIG. 7 illustrates a preferred embodiment of the speed compensator 166 including a speed pulse generator 168, a speed voltage generator 170, and a bias voltage modifier or pulse length controller 172. The speed pulse generator 168 includes an NPN junction transistor 174. The emitter electrode of the transistor 174 is connected directly to the ground line 42. The base electrode of the transistor 174 is connected through a temperature compensating diode 176 to a junction 178. The collector electrode of the transistor 174 is connected directly to a junction 180. A timing capacitor 182 is connected between the junction 178 and the junction 159 which is connected to the collector electrode of the transistor 158 in the control pulse generator 88. A timing resistor 184 is connected between the junction 178 and the power line 40. A biasing resistor 186 is connected between the junction 180 and the power line 40.

Referring to FIGS. 5 and 7, the transistor 174 is normally rendered fully conductive through the biasing action of the resistor 184. That is, the bias voltage applied to the junction 178 is above the threshold potential of the transistor 174 so that the transistor 174 is fully turned on. With the transistor 174 turned on, the junction 180 is effectively connected to the ground line 42 through the transistor 174. When the transistor 158 is turned off to initiate a control pulse C on the control line 90, the junction 159 is effectively disconnected from the ground line 42. As a result, the capacitor 182 charges through the resistor 160 so that the potential at the junction 159 is greater than the potential at the junction 178. Nevertheless, the potential at the junction 178 remains above the threshold potential of the transistor 174 so that the transistor 174 remains turned on.

When the transistor 158 is subsequently turned on to terminate the control pulse C on the control line 90, the junction 159 is effectively connected to the ground line 42. Due to the charge on the capacitor 182, the potential at the junction 178 instantaneously drops below the threshold potential of the transistor 174 thereby to

render the transistor 174 fully nonconductive. With the transistor 174 turned off, the junction 180 is effectively disconnected from the ground line 42. Accordingly, a speed pulse P is initiated at the junction 180. The voltage level of the speed pulse P is defined by the supply potential on the power line 40.

After the initiation of the speed pulse P, the potential at the junction 178 gradually rises as the capacitor 182 discharges through the resistor 184. Eventually, the potential at the junction 178 rises above the threshold potential of the transistor 174 thereby to render the transistor 174 fully conductive. With the transistor 174 turned on, the speed pulse P at the junction 180 is terminated as the junction 180 is effectively connected to the ground line 42. Thus, the speed pulses P have a fixed duration determined by the RC time constant provided by the capacitor 182 and the resistor 184. Of course, the frequency of the speed pulses P is directly proportional to the speed of the engine 10.

Referring to FIG. 7, speed voltage generator 170 includes a capacitor 188, a discharging circuit 190 and a charging circuit 192. The capacitor 188 is connected between a junction 194 and the ground line 42. The discharging circuit 190 includes an NPN junction transistor 196. The base electrode of the transistor 196 is connected directly to the junction 180 in the speed pulse generator 168. The emitter electrode of the transistor 196 is connected directly to the ground line 42. The collector electrode of the transistor 196 is connected through a biasing resistor 198 and a temperature compensating diode 200 to a junction 202. A blocking diode 204 is connected between the junction 194 and the junction 202. A biasing resistor 206 is connected between the junction 202 and the power line 40.

The charging circuit 192 includes a constant current source 208 and a speed switch 210. The constant current source 208 includes a PNP junction transistor 212 and an NPN junction transistor 214. The emitter electrode of the transistor 212 and the collector electrode of the transistor 214 are connected together through a limiting resistor 216 to the power line 40. The collector electrode of the transistor 212 is connected directly to the base electrode of the transistor 214. The emitter electrode of the transistor 214 is connected directly to the junction 194. The base electrode of the transistor 212 is connected directly to a junction 218. A biasing resistor 220 is connected in series with a temperature compensating diode 222 between the junction 218 and the power line 40. A string of four biasing resistors 224, 226, 228 and 230 are connected in series between the junction 218 and the ground line 42 so as to form junctions 232, 234 and 236 between the resistors 224, 226, 228 and 230, respectively.

Referring to FIGS. 5 and 7, the capacitor 188 develops a speed voltage S at the junction 194. The amplitude of the speed voltage S is controlled by the discharging circuit 190 and the charging circuit 192. The transistors 212 and 214 of the current source 208 are continually rendered conductive in a constant current mode. As a result, a constant charging current is applied through the resistor 216 and the transistor 214 to the junction 194. The magnitude of the charging current determines the value of the charge rate on the capacitor 188. In turn, the magnitude of the charging current is defined by the amplitude of a bias voltage established at the junction 218 through the voltage divider action of the resistors 220, 224, 226, 228 and 230 in

conjunction with the operation of the speed switch or charge rate controller 210.

When a speed pulse P is initiated at the junction 180, the transistor 196 is rendered fully conductive. With the transistor 196 turned on, the capacitor 188 discharges at a rapid discharge rate through the diode 204, the diode 200, the resistor 198 and the transistor 196 to the ground line 42. This occurs even through the current source 208 continually applies a charging current to the junction 194. The amplitude of the speed voltage S at the junction 194 rapidly decreases to a base level L_b primarily defined by the voltage divider action of the resistors 200 and 206. Specifically, the amplitude of the speed voltage S decreases in accordance with the RC time constant provided by the resistor 198 and the capacitor 188. The capacitor 188 discharges until the termination of the speed pulse P. Hence, a fixed discharge period T_d is defined between the termination of each preceding control pulse C and the termination of each succeeding speed pulse P. The duration of each of the speed pulses P is sufficient to insure that the amplitude of the speed voltage S always reaches the base level L_b before the termination of the speed pulse P.

When a speed pulse P is terminated at the junction 180, the transistor 196 is rendered fully nonconductive. With the transistor 196 turned off, the capacitor 188 charges at a constant charge rate through the current source 208. Accordingly, the amplitude of the speed voltage S linearly increases from the base level L_b toward a maximum level L_m defined by the supply potential on the power line 40. In particular, the rate of change in the amplitude of the speed voltage S is defined by the magnitude of the charging current applied to the junction 194 by the current source 208. As will be described in detail later, the linear slope of the speed voltage S is varied by the charge rate controller 210. The capacitor 188 charges until the initiation of the succeeding speed pulse P. Thus, a variable charge period T_c is defined between the termination of each preceding speed pulse P and the initiation of each succeeding control pulse C.

Referring to FIG. 7, bias voltage modifier or pulse length controller 172 includes a differential amplifier 238 and a constant current generator 240. The differential amplifier 238 includes NPN junction transistors 242, 244 and 246. The emitter electrode of the transistor 242 is connected through a biasing resistor 248 to the ground line 42. The base electrode of the transistor 242 is connected directly to a junction 250. A biasing resistor 252 is connected between the junction 250 and the power line 40. A temperature compensating diode 254 is connected in series with a biasing resistor 256 between the junction 250 and the ground line 42. The collector electrode of the transistor 242 is connected directly to a junction 258. The emitter electrode of the transistor 244 is connected through a biasing resistor 260 to the junction 258. Similarly, the emitter electrode of the transistor 246 is connected through a biasing resistor 262 to the junction 258. The base electrode of the transistor 244 is connected to a junction 264. A biasing resistor 266 is connected between the junction 264 and the power line 40. A biasing resistor 268 is connected between the junction 264 and the ground line 42. The collector electrode of the transistor 244 is connected directly to the power line 40. The base electrode of the transistor 246 is connected directly to the

junction 194 in the speed voltage generator 178. The collector electrode of the transistor 246 is connected to a junction 269 in the constant current generator 240.

The transistor 242 combines with the biasing resistors 248, 252 and 256 to form a constant current sink for the transistors 244 and 246 at the junction 258. The transistors 244 and 246 form a balanced differential pair for gradually switching between first and second states in response to the amplitude of the speed voltage S at the junction 194. As the amplitude of the speed voltage S increases from the base level L_b toward a lower level L_o , the transistor 244 is rendered fully conductive and the transistor 246 is rendered fully nonconductive. This is the first state of the differential amplifier 238. When the amplitude of the speed voltage S increases through the lower level L_o , the transistor 244 begins to turn off and the transistor 246 begins to turn on. As the amplitude of the speed voltage S proportionately increases between the lower level L_o and an upper level L_u , the transistor 244 is correspondingly rendered less conductive while the transistor 246 is correspondingly rendered more conductive. When the amplitude of the speed voltage S increases through the upper level L_u , the transistor 244 is rendered fully nonconductive and the transistor 246 is rendered fully conductive. This is the second state of the differential amplifier 238. As the amplitude of the speed voltage S increases above the upper level L_u toward the maximum level L_m , the differential amplifier 238 remains in the second state.

The upper and the lower levels L_u and L_o of the speed voltage S are determined by the biasing resistors 260, 262, 266 and 268. Preferably, the resistors 260 and 262 have a like resistance while the resistors 266 and 268 have a like resistance. However, this constraint is not critical. The biasing resistors 266 and 268 form a voltage divider network for developing a reference voltage at the junction 264. The amplitude of the reference voltage is substantially constant at a reference level L_r , defined by the ratio of the resistances of the resistors 266 and 268. Similarly, the ratio of the resistances of the resistors 260 and 262 defines the upper and lower levels L_u and L_o with respect to the reference level L_r . Thus, the upper and lower levels L_u and L_o of the speed voltage S are defined by relative resistance ratios rather than absolute resistance values.

The constant current generator 240 includes first and second constant current sources 270 and 272 and a constant current sink 274. The first constant current source 270 includes a PNP junction transistor 276 and an NPN junction transistor 278. The emitter electrode of the transistor 276 and the collector electrode of the transistor 278 are connected through a limiting resistor 280 to the power line 40. The collector electrode of the transistor 276 is connected directly to the base electrode of the transistor 278. The emitter electrode of the transistor 278 is connected directly to the junction 269 which is connected to the collector electrode of the transistor 246 in the differential amplifier 238. The base electrode of the transistor 276 is connected directly to a junction 282. A proportioning diode 284 is connected between the junctions 282 and 269.

The second constant current source 272 includes an NPN junction transistor 286 and a PNP junction transistor 288. The emitter electrode of the transistor 286 and the collector electrode of the transistor 288 are connected together through a limiting resistor 290 to

the power line 40. The collector electrode of the transistor 286 is connected directly to the base electrode of the transistor 288. The base electrode of the transistor 286 is connected directly to the junction 282. The emitter electrode of the transistor 288 is connected directly to a junction 292 in the constant current sink 274.

The constant current sink 274 includes a pair of NPN junction transistors 294 and 296. The base electrode of the transistor 294 and the collector electrode of the transistor 296 are connected together directly to the junction 292. The base electrode of the transistor 296 and the emitter electrode of the transistor 294 are connected together directly to a junction 298. A temperature compensating diode 300 is connected between the junction 298 and the ground line 42. The emitter electrode of the transistor 296 is connected directly to the ground line 42. The collector electrode of the transistor 294 is connected directly to the control junction 118 in the control network 92 of the control pulse generator 88.

As previously described, the conductivity of the transistor 246 varies between a fully turned off condition when the differential amplifier 238 is in a first state and a fully turned on condition when the differential amplifier 238 is in the second state. When the transistor 246 is conductive, a compensation current is drawn out of the junction 269 by the transistor 246. The magnitude of the compensation current is proportional to the conductivity of the transistor 246 as determined by the amplitude of the speed voltage S. Further, when a compensation current is drawn out of the junction 269, a pilot current is drawn out of the junction 282 through the diode 284. The magnitude of the pilot current is proportional to the magnitude of the compensation current. The transistors 276 and 278 of the constant current source 270 are rendered conductive in a constant current mode in response to the pilot current. As a result, the constant current source 270 is turned on to develop a first drive current through the resistor 280 and the transistor 278. The magnitude of the first drive current is proportional to the magnitude of the pilot current. More specifically, the pilot current and the first drive current combine to form the compensation current at the junction 269.

Moreover, the transistors 286 and 288 of the constant current source 272, are rendered conductive in a constant current mode in response to the pilot current drawn out of the junction 282. Consequently, the constant current source 272 is turned on to define a second drive current through the resistor 290 and the transistor 288. The magnitude of the second drive current is proportional to the magnitude of the pilot current. More properly, the magnitude of the second drive current is defined relative to the magnitude of the first drive current by the ratio of the resistances of the resistors 280 and 290. Hence, the magnitude of the second drive current injected into the junction 292 is directly related to the magnitude of the compensation current drawn out of the junction 269. The transistors 294 and 296 of the constant current sink 274, are rendered conductive in a constant current mode in response to the second drive current. Specifically, the transistor 296 draws a bias current out of the junction 292 while the transistor 294 draws a like bias current out of the junction 118 in the control network 92 of the control pulse generator 88. The bias current is equal to the second

drive current less the base current of the transistor 294. Thus, the magnitude of the bias current drawn out of the junction 118 is directly proportional to the magnitude of the compensation current drawn out of the junction 269.

Referring to FIGS. 1, 2, 5 and 7, the magnitude of the bias current drawn out of the junction 118 is directly proportional to the amplitude of the speed voltage S between the upper and lower voltage levels L_u and L_o . Thus, as the amplitude of the speed voltage S increases, the magnitude of the bias current drawn out of the junction 118 correspondingly increases. However, the amplitude of the bias voltage B at the junction 118 is inversely proportional to the magnitude of the bias current drawn out of the junction 118. Therefore, as the amplitude of the speed voltage S increases, between the upper and lower levels L_u and L_o , the amplitude of the bias voltage B proportionately decreases from the maximum level. The lower the amplitude of the bias voltage B, the shorter the length of the control pulses C developed by the control pulse generator 88. It is assumed that the bias voltage B is a constant over the length of any given control pulse C.

As previously described, the increase in the amplitude of the speed voltage S at the junction 194 is inversely related to the speed of the engine 10. Hence, as the speed of the engine 10 increases, the amplitude of the speed voltage S decreases. Conversely, the amplitude of the bias voltage B at the junction 118 is directly related to the speed of the engine 10. Thus, as the speed of the engine 10 increases, the amplitude of the bias voltage B also increases. Since the amplitude of the bias voltage B defines the peak level of the control voltage A, the length of the control pulses C is directly related to the speed of the engine 10. Consequently, as the speed of the engine 10 increases, the length of the control pulses C also increases. This provides a coarse or first order speed compensation for increasing the amount of fuel delivered to the engine 10 with increasing engine speed.

More specifically, the peak amplitude of the speed voltage S linearly increases over the duration of the charge period T_c . The duration of the charge period T_c is inversely related to the frequency of the speed pulses P as determined by the speed of the engine 10. In this way, the amplitude of the speed voltage S is inversely related to the speed of the engine 10, but in a nonlinear manner. That is, assuming the speed of the engine 10 varies linearly with time, the peak amplitude of the speed voltage S varies nonlinearly with time. Hence, as the speed of the engine 10 increases at a fixed rate, the duration of the charge period T_c and the peak amplitude of the speed voltage S decrease at an ever decreasing rate. Alternately, as the speed of the engine 10 decreases at a fixed rate, the duration of the charge period T_c and the amplitude of the speed voltage S increase at an ever increasing rate.

Referring to FIG. 4, the optimum speed compensation curve X for the engine 10 indicates that the amount of extra fuel applied to the engine 10 to compensate for variations in engine speed should be linearly related to the speed of the engine 10 between the upper speed limit N_u and the lower speed limit N_o . In other words, for each change in the speed of the engine 10 between the upper and lower speed limits N_u and N_o , the length of the control pulses C should experience a linearly proportional change. However, due to the

nonlinear relationship between the amplitude of the speed voltage S and the speed of the engine 10, the desired speed compensation curve X cannot be duplicated with the circuitry so far described.

In order to demonstrate this nonlinear effect, it is assumed that the speed compensator 166 is calibrated so that the amplitude of the speed voltage S reaches the upper level L_u as the speed of the engine 10 reaches the lower speed limit N_o and so that the amplitude of the speed voltage S reaches the lower level L_o as the speed of the engine 10 reaches the upper speed limit N_u . Under these circumstances, the speed compensator 166 yields the nonlinear speed compensation curve Y rather than the linear speed compensation curve X. While the compensation curve X is linear between the upper and lower speed limit N_u and N_o , the compensation curve Y is nonlinear between the upper and lower speed limits N_u and N_o . Thus, for each change in the speed of the engine 10 between the upper and lower speed limits N_u and N_o , the length of the control pulses C experiences a nonlinear change.

According to the present invention, the inherent nonlinearity between the amplitude of the speed voltage S and the speed of the engine 10 is corrected by additionally varying the slope of the speed voltage S as a function of the speed of the engine 10. This provides a fine or second order speed compensation. In particular, the rate of change in the amplitude of the speed voltage S is shifted in response to changes in the speed of the engine 10 between the upper and lower speed limits N_u and N_o in such a manner that the speed compensator 166 approximates the optimum speed compensation curve X. The required changes in the slope of the speed compensation curve S are provided by the charge rate controller 210 of the speed voltage generator 170.

Referring to FIG. 7, the charge rate controller 210 includes a pair of NPN junction transistors 302 and 304. The collector electrode of the transistor 302 is connected directly to the junction 236. The emitter electrode of the transistor 302 is connected directly to the ground line 42. The collector electrode of the transistor 304 is connected directly to the junction 232. The emitter electrode of the transistor 304 is connected directly to the junction 234. The base electrode of the transistor 302 is connected through a biasing resistor 306 to a junction 308. The base electrode of the transistor 304 is connected through a biasing resistor 310 to the junction 308. An integrating capacitor 312 is connected between the junction 308 and the ground line 42. An integrating resistor 314 is also connected between the junction 308 and the ground line 42 across the capacitor 312. A coupling diode 316 is connected between the junction 308 and the junction 180 in the speed pulse generator 168.

In operation, the speed pulses P are applied through the diode 316 to the junction 308. The capacitor 312 and the resistor 314 integrate the speed pulses P at the junction 308 to develop a sensor voltage having an amplitude which is directly proportional to the speed of the engine 10. Hence, as the speed of the engine 10 increases, the amplitude of the sensor voltage at the junction 308 proportionately increases. As previously described, the slope of the speed voltage S is directly related to the charge rate on the capacitor 188 as defined by the bias voltage at the junction 218. In turn this bias voltage is determined by the conductive condition of the transistors 302 and 304.

When the speed of the engine 10 is below an engine speed N_3 which is below the lower speed limit N_0 , the amplitude of the sensor voltage is below the threshold potential of the transistor 302 and is below the threshold potential of the transistor 304. As a result, the transistors 302 and 304 are both rendered fully nonconductive. With the transistors 302 and 304 turned off, the bias voltage at the junction 218 is defined by the voltage divider action of the resistors 220, 224, 226, 228 and 230. The resultant rate of increase in the amplitude of the speed voltage S at the junction 194 is such that the speed compensator 166 yields a nonlinear speed compensation curve Y_1 as shown in FIG. 6.

The speed compensation curve Y_1 extends from the minimum compensation percentage K_2 at an engine speed N_1 which is above the lower speed limit N_0 to the maximum compensation percentage K_a at an engine speed N_6 which is below the upper speed limit N_u . As the speed of the engine 10 increases toward the engine speed N_1 , the fuel compensation percentage remains substantially constant at the minimum compensation percentage K_2 along the speed compensation curve Y_1 . Further, as the speed of the engine 10 increases from the engine N_1 toward an engine speed N_3 , the fuel compensation percentage increases from the minimum compensation percentage K_2 toward a compensation percentage K_2 along the speed compensation curve Y_1 .

When the speed of the engine 10 reaches the engine speed N_3 , the amplitude of the sensor voltage at the junction 308 exceeds the threshold potential of the transistor 302 as primarily defined by the biasing action of the resistor 306. Accordingly, the transistor 302 is rendered fully conductive. With the transistor 302 turned on, a short circuit is effectively placed across the biasing resistor 230 so that the bias voltage at the junction 218 is now defined by the voltage divider action of the resistors 220, 224, 226 and 228. With the biasing resistor 230 shunted by the transistor 302, the bias voltage at the junction 218 decreases thereby to increase the rate of increase in the amplitude of the speed voltage S at the junction 194 such that the speed compensator 166 yields a nonlinear speed compensation curve Y_2 as shown in FIG. 6.

The speed compensation curve Y_2 extends from the minimum compensation percentage K_2 at an engine speed N_2 which is above the engine speed N_1 and below the engine speed N_3 to the maximum compensation percentage K_a at an engine speed N_7 which is above the engine speed N_6 and below the upper speed limit N_u . When the speed of the engine 10 reaches the engine speed N_3 , the fuel compensation percentage shifts from the compensation percentage K_2 on the speed compensation curve Y_1 to the compensation percentage K_1 on the speed compensation curve Y_2 . As the speed of the engine 10 increases from the engine speed N_3 toward an engine speed N_5 , the fuel compensation percentage increases from the compensation percentage K_1 toward a compensation percentage K_4 along the speed compensation curve Y_2 .

When the speed of the engine 10 reaches the engine speed N_5 , the amplitude of the sensor voltage at the junction 308 exceeds the threshold potential of the transistor 304 as primarily defined by the biasing action of the resistors 228 and 310. Consequently, the transistor 304 is rendered fully conductive. With the transistor 304 turned on, a short circuit is effectively placed across the biasing resistor 226 so that the bias voltage

at the junction 218 is now defined by the voltage divider action of the resistors 220, 224 and 228. With the biasing resistor 226 shunted by the transistor 304, the bias voltage at the junction 218 decreases thereby to increase the rate of increase in the amplitude of the speed voltage S at the junction 194 such that the speed compensation 166 yields a non-linear speed compensation curve Y_3 as shown in FIG. 6.

The speed compensation curve Y_3 extends from the minimum compensation percentage K_3 at an engine speed N_4 which is above the engine speed N_3 and below the engine speed N_5 to the maximum compensation percentage K_a at an engine speed N_8 which is above the engine speed N_7 and below the upper speed limit N_u . When the speed of the engine 10 reaches the engine speed N_5 , the fuel compensation percentage shifts from the compensation percentage K_4 on the speed compensation curve Y_2 to a compensation percentage K_3 on the speed compensation curve Y_3 . As the speed of the engine 10 increases from the engine speed N_5 toward the engine speed N_6 , the fuel compensation percentage increases from the compensation percentage K_3 to the maximum compensation percentage K_a along the speed compensation curve Y_3 . Further, as the speed of the engine 10 increases above the engine speed N_6 , the fuel compensation percentage remains substantially constant at the maximum compensation percentage K_a along the speed compensation curve Y_3 .

As shown in FIG. 6, the previously described operation of the speed compensator 166 yields a resultant speed compensation curve Z comprising the speed compensation curve Y_1 below the engine speed N_3 , the speed compensation curve Y_2 between the engine speed N_3 and the engine speed N_5 , and the speed compensation curve Y_3 above the engine speed N_5 . This resultant speed compensation curve Z is a stepped approximation to the optimum speed compensation curve X . Preferably, the engine speed N_3 at which the resultant curve Z is shifted from the curve Y_1 to the curve Y_2 and the engine speed N_5 at which the resultant curve Z is shifted from the curve Y_2 to the curve Y_3 are selected to provide a least square-error fit to the optimum curve X . By least square-error fit it is meant that the total area defined between the resultant curve Z and the optimum curve X is equally distributed above and below the optimum curve X . Of course, the resolution of the resultant curve Z to the optimum curve X may be improved by increasing the number of steps in the resultant curve Z thereby decreasing the total area defined between the resultant curve Z and the optimum curve X . This may be accomplished by providing additional transistors like the transistors 302 and 304 and by providing additional resistors like the resistors 224, 226, 228 and 230.

It will now be understood that the illustrated embodiment of the invention is shown for demonstrative purposes only. Accordingly, various alterations and modifications may be made to the illustrated embodiment without departing from the spirit and scope of the invention. Thus, the optimum speed compensation curve X may take any desired shape, depending entirely upon the fuel delivery requirements of a given engine.

What is claimed is:

1. In an internal combustion engine system including control pulse generator means for producing control pulses collectively having a frequency proportional to the speed of the engine and individually having a length

determined as a function of at least one engine operating parameter, and including fuel supply means connected between the control pulse generator means and the engine for applying fuel to the engine in an amount determined by the length of each of the control pulses; the combination comprising: speed voltage generator means for developing a speed voltage which varies over a time period repetitively defined as a function of the speed of the engine and which varies at a slope which is defined as a function of the speed of the engine and which is constant for any given engine speed; pulse length control means connected between the speed voltage generator means and the control pulse generator means for additionally defining the length of the control pulses as a function of the speed voltage during each of the control pulses thereby to compensate the quantity of fuel applied to the engine in response to the speed of the engine such that the time period of the speed voltage provides a coarse speed compensation and the slope of the speed voltage provides a fine speed compensation.

2. In an internal combustion engine system including control pulse generator means for producing control pulses collectively having a frequency proportional to the speed of the engine and individually having a length determined as a function of at least one engine operating parameter, and including fuel supply means connected between the control pulse generator means and the engine for applying fuel to the engine in an amount determined by the length of each of the control pulses; the combination comprising: speed voltage generator means for developing a speed voltage having an amplitude which varies over a time period defined as a function of the total time interval between the termination of successive control pulses and which varies at a rate of change which is defined as a function of the frequency of the control pulses and which is constant for any given control pulse frequency; pulse length control means connected between the speed voltage generator means and the control pulse generator means for additionally defining the length of the control pulses as a function of the amplitude of the speed voltage during each of the control pulses thereby to compensate the quantity of fuel applied to the engine for variations in the speed of the engine such that the time period over which the amplitude of the speed voltage varies provides a first order speed compensation and the rate of change in the amplitude of the speed voltage provides a second order speed compensation.

3. In an internal combustion engine system including control pulse generator means for producing control pulses collectively having a frequency proportional to the speed of the engine and individually having a length determined as a function of at least one engine operating parameter, and including fuel supply means connected between the control pulse generator means and the engine for applying fuel to the engine in a quantity determined by the length of each of the control pulses; the combination comprising: a capacitor for developing a speed voltage thereacross; pulse length control means connected between the capacitor and the control pulse generator means for defining the length of the control pulses in response to the amplitude of the speed voltage during each of the control pulses; discharging means connected to the capacitor for discharging the capacitor at a rapid discharge rate over a fixed discharge period to clamp the amplitude of the speed voltage at a

base level at the termination of the discharge period which is initiated in response to the termination of each preceding control pulse; charging means connected to the capacitor for charging the capacitor at a constant charge rate to linearly vary the amplitude of the speed voltage from the base level toward a maximum level over a variable charge period initiated in response to the termination of each preceding discharge period and terminated in response to the termination of each succeeding control pulse thereby to provide a coarse speed compensation, the charging means including charge rate control means connected with the engine for shifting the charge rate between at least two different values in response to the speed of the engine thereby to provide a fine speed compensation.

4. In an internal combustion engine system including control pulse generator means for producing control pulses collectively having a frequency proportional to the speed of the engine and individually having a length determined as a function of at least one engine operating parameter, and including fuel supply means connected between the control pulse generator means and the engine for applying fuel to the engine in a quantity determined by the length of the control pulses; the combination comprising: a capacitor for developing a speed voltage thereacross; pulse length control means connected between the capacitor and the control pulse generator means for defining the length of the control pulses as a function of the amplitude of the speed voltage during each of the control pulses; speed pulse generator means for developing speed pulses each initiated in response to the termination of a control pulse thereby to define the termination of a charge period and the initiation of a discharge period and each terminated in response to the expiration of a predetermined time period following the termination of each control pulse thereby to define the termination of a discharge period and the initiation of a charge period; discharging means connected to the capacitor for discharging the capacitor at a rapid discharge rate over the discharge period to clamp the amplitude of the speed voltage at a base level at the termination of each discharge period; charging means connected to the capacitor for charging the capacitor at a constant charge rate over the duration of each charge period to linearly increase the amplitude of the speed voltage from the base level toward a peak level thereby to provide a first order speed compensation, the charging means including charge rate control means connected with the engine for shifting the charge rate from a first value to a second value as the speed of the engine passes through a predetermined engine speed thereby to provide a fine speed compensation.

5. In an internal engine system exhibiting an optimum speed compensation curve representing compensation percentage versus engine speed where the compensation percentage is the desired percentage change in the quantity of fuel normally delivered to the engine at a given engine speed, the combination comprising: control pulse generator means for producing control pulses collectively having a frequency proportional to the speed of the engine and individually having a duration determined as a function of at least one engine operating parameter; fuel supply means connected between the control pulse generator means and the engine for applying fuel to the engine in an amount determined by the duration of each of the control pulses; speed volt-

age generator means for developing a speed voltage which varies at a constant slope over a time period defined as a function of the speed of the engine; pulse duration control means connected between the speed voltage generator means and the control pulse generator means for additionally defining the duration of the control pulses as a function of the speed voltage during each of the control pulses; and the speed voltage generator means including slope control means for varying the slope of the speed voltage as a function of the speed of the engine in such a manner that the actual speed compensation curve approximates the optimum speed compensation curve.

6. In an internal combustion engine system exhibiting an optimum speed compensation curve representing compensation percentage versus engine speed where the compensation percentage is the percentage change in the total quantity of fuel delivered to the engine at a given engine speed, the combination comprising: control pulse generator means for producing control pulses collectively having a frequency proportional to the speed of the engine and individually having a duration determined as a function of at least one engine operating parameter; fuel supply means connected between the control pulse generator means and the engine for applying fuel to the engine in an amount determined by the duration of each of the control pulses; speed voltage generator means for developing a speed voltage having an amplitude which varies at a constant rate of change over a time period defined as a function of the total time interval between the termination of successive control pulses; and pulse duration control means connected between the speed voltage generator means for additionally defining the duration of the control pulses as a function of the amplitude of the speed voltage thereby to define an actual speed compensation curve dependent upon the rate of change in the amplitude of the speed voltage; the speed voltage generator means including amplitude control means for shifting the rate of change in the amplitude of the speed voltage to different predetermined change rates as the speed of the engine reaches different predetermined engine speeds where the predetermined change rates and the predetermined engine speeds are selected so that the actual speed compensation curve is a stepped approximation to the optimum speed compensation curve.

7. In an internal combustion engine system exhibiting an optimum speed compensation curve representing compensation percentage versus engine speed where the compensation percentage is the desired percentage change in the quantity of fuel normally delivered to the engine at a given engine speed, the combination comprising: control pulse generator means for producing control pulses collectively having a frequency proportional to the speed of the engine and individually having a duration determined as a function of at least one engine operating parameter; fuel supply means connected between the control pulse generator means and the engine for applying fuel to the engine in an amount determined by the duration of each of the control pulses; a capacitor for developing a speed voltage thereacross; pulse duration control means connected between the capacitor and the control pulse generator means for defining the duration of the control pulses in response to the amplitude of the speed voltage during each of the control pulses; means connected to the capacitor for discharging the capacitor at a rapid dis-

charge rate over a fixed discharge period to clamp the amplitude of the speed voltage at a base level at the termination of the discharge period which is initiated in response to the termination of each preceding control pulse; means connected to the capacitor for charging the capacitor at a constant charge rate to linearly vary the amplitude of the speed voltage from the base level toward a maximum level over a variable charge period initiated in response to the termination of each preceding discharge period and terminated in response to the termination of each succeeding control pulse thereby to provide an actual speed compensation curve dependent upon the charge rate; and the means further connected to the control pulse generator means for shifting the charge rate to different ones of a plurality of predetermined charge rates as the frequency of the control pulses reaches different ones of a plurality of frequencies corresponding to different ones of a plurality of predetermined engine speeds where the predetermined charge rates and predetermined engine speeds are selected so that the actual speed compensation curve is a least square-error fit to the optimum speed compensation curve.

8. In an internal combustion engine system exhibiting an optimum speed compensation curve representing compensation percentage versus engine speed where the compensation percentage is the desired percentage change in the quantity of fuel normally delivered to the engine at a given engine speed, the combination comprising: control pulse generator means for producing control pulses collectively having a frequency proportional to the speed of the engine and individually having a length determined as a function of at least one engine operating parameter; fuel supply means connected between the control pulse generator means and the engine for applying fuel to the engine in a quantity determined by the length of the control pulses; a capacitor for developing a speed voltage thereacross; pulse duration control means connected between the capacitor and the control pulse generator for defining the duration of the control pulses as a function of the amplitude of the speed voltage during each of the control pulses; speed pulse generator means for developing speed pulses each initiated in response to the termination of a control pulse thereby to define the termination of a charge period and the initiation of a discharge period and each terminated in response to the expiration of a predetermined time period following the termination of each control pulse thereby to define the termination of a discharge period and the initiation of a charge period; discharging means connected to the capacitor for discharging the capacitor at a rapid discharge rate over the discharge period to clamp the amplitude of the speed voltage at a base level at the termination of each discharge period; and charging means connected to the capacitor for charging the capacitor at a constant charge rate over the duration of each charge period to linearly increase the amplitude of the speed voltage from the base level toward a maximum level thereby to provide an actual speed compensation curve which is dependent upon the charge rate; the charging means including charge rate control means connected to the speed pulse generator means for shifting charge rate to different ones of a plurality of predetermined charge rates as the frequency of the speed pulses reaches different ones of a plurality of frequencies corresponding to different ones of a plurality of predetermined engine speeds where the predetermined charge rates and the predetermined engine speeds are selected so that the actual speed compensation curve is a least square-error stepped approximation to the optimum speed compensation curve.

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