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[54] **ELECTRONIC FUEL INJECTION SYSTEM HAVING SPEED ENRICHMENT**

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[52] **U.S. Cl.** .....**123/32 EA,** 123/119, 123/140 MC

[51] **Int. Cl.**.....**F02b 3/00**

[58] **Field of Search** .....123/32 EA, 32 AE, 123/119

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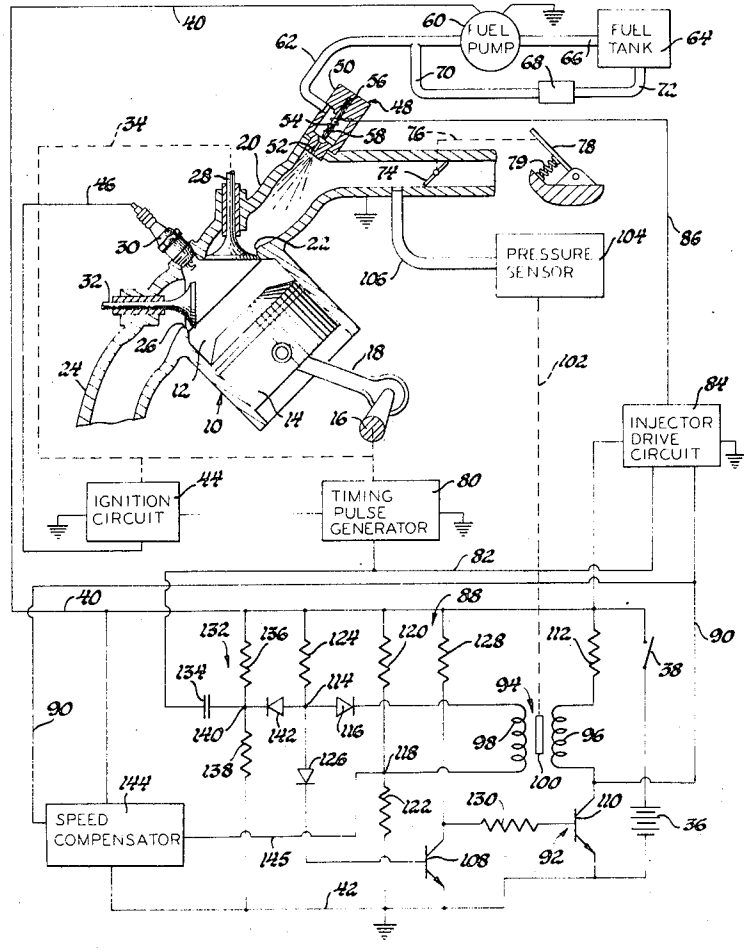
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[57] **ABSTRACT**

Fuel is applied to an internal combustion engine for the duration of control pulses produced at a frequency proportional to the speed of the engine. The duration of the control pulses is determined as a function of the amplitude of a bias voltage. A speed voltage unidirectionally varies from a base level at the termination of each preceding control pulse to a peak amplitude at the initiation of each succeeding control pulse. A compensation voltage is substantially constant over the duration of each succeeding control pulse at an amplitude proportional to the peak amplitude of the speed voltage during each preceding cycle. The amplitude of the bias voltage is determined in response to the amplitude of the compensation voltage thereby to define the duration of the control pulses as a function of engine speed.

5 Claims, 6 Drawing Figures



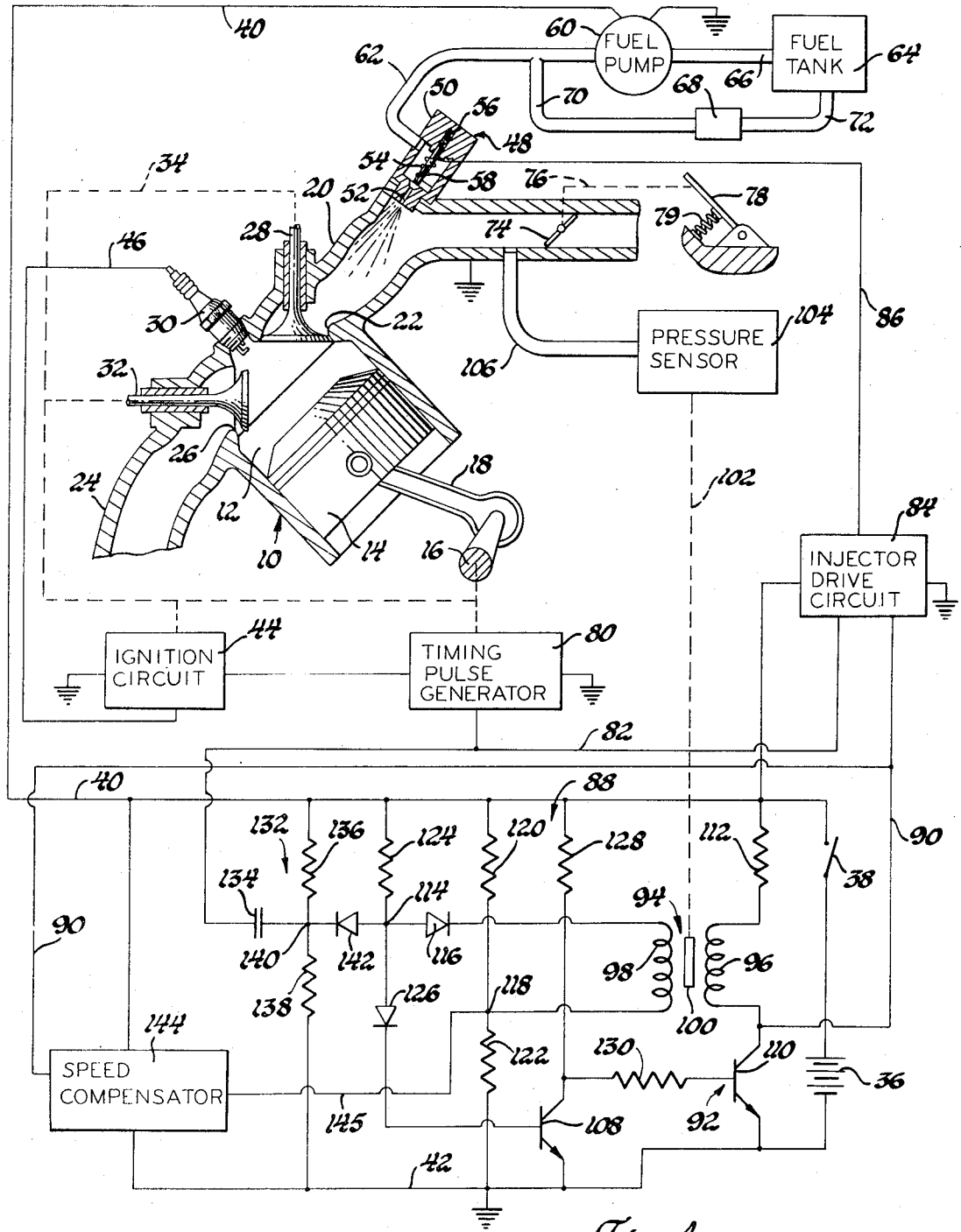


Fig. 1

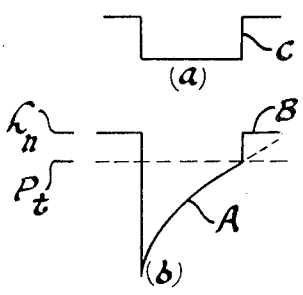


Fig. 2

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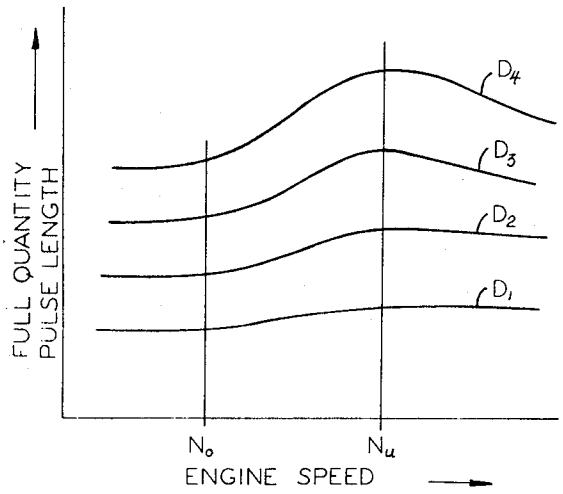


Fig.3

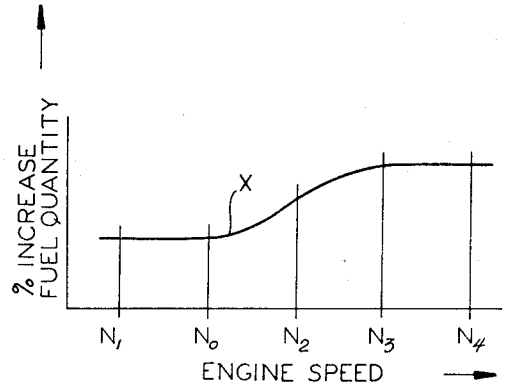


Fig.4

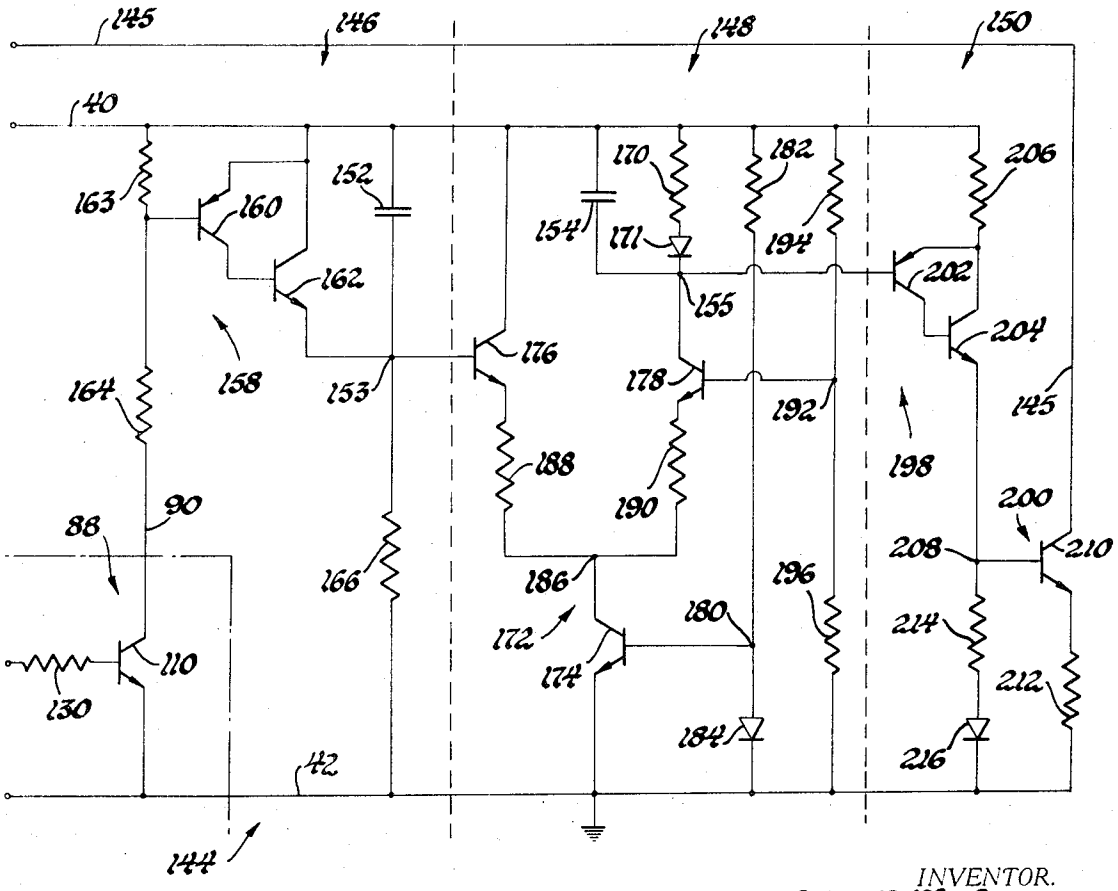


Fig.5

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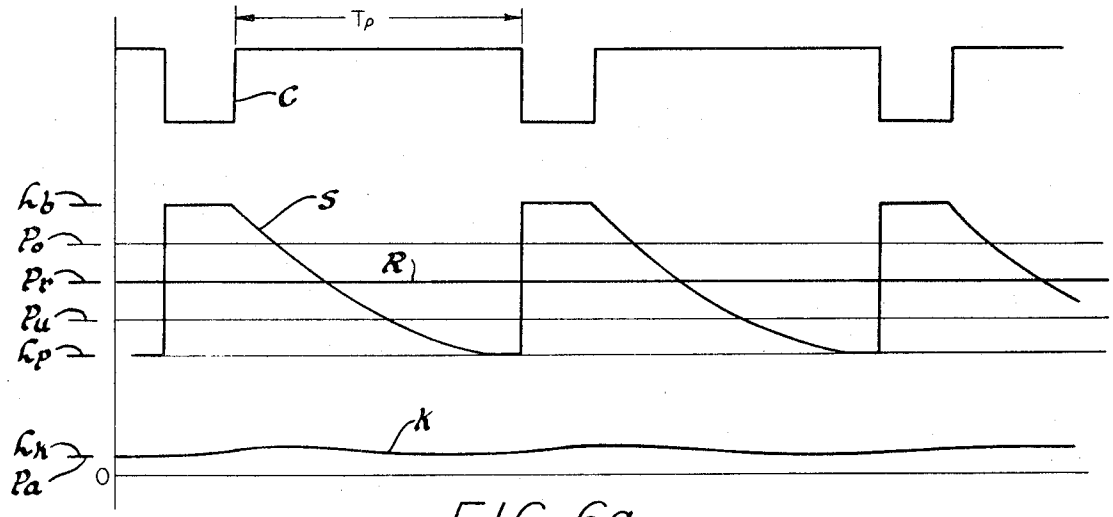


FIG. 6a

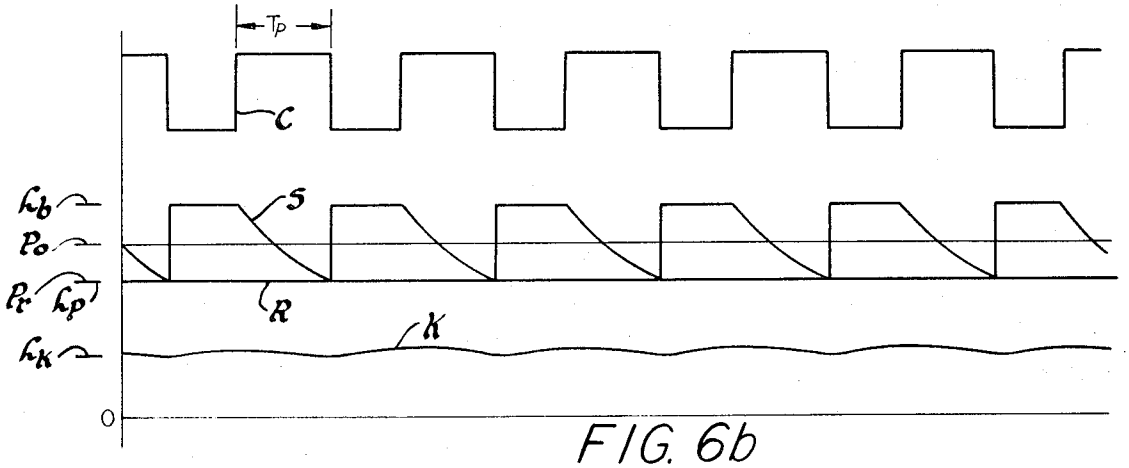


FIG. 6b

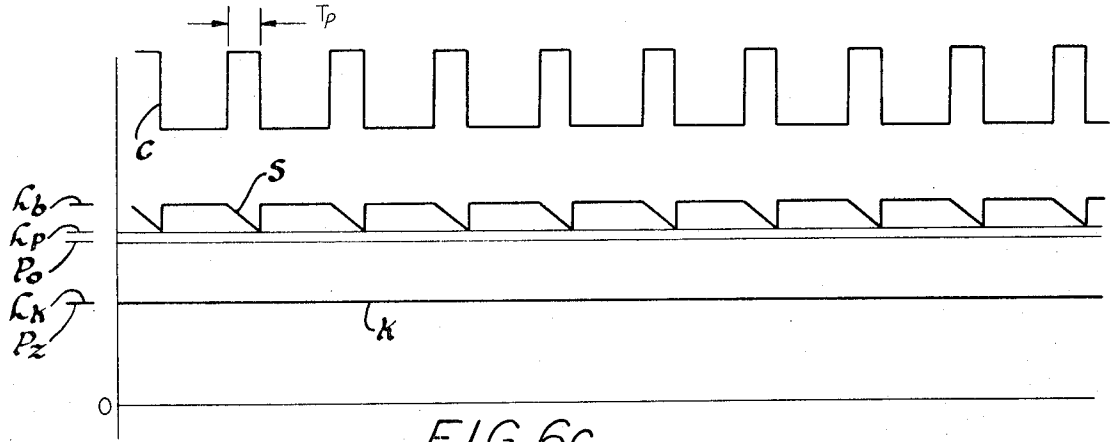


FIG. 6c

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ELECTRONIC FUEL INJECTION SYSTEM HAVING SPEED ENRICHMENT

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 altering the amount of fuel applied to the engine in response to variations in engine speed.

In one well known type of electronic fuel injection system, control pulses are produced in synchronization with the rotating speed of the engine. The duration of the control pulses is determined as a function of at least one engine operating parameter. Further, the duration of the control pulses is at least partially determined as a function of the amplitude of a bias voltage. Fuel is applied to the engine at a constant rate for 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 related to engine speed. However, due to certain fuel delivery phenomena related to the speed of the engine, such as volumetric efficiency, it is necessary that more or less fuel be applied to the engine in response to variations in engine speed. The present invention proposes an electronic fuel injection system which provides the desired speed compensation.

According to one aspect of the invention, a speed voltage comprises successive cycles in which the amplitude of the speed voltage increases from a base level at the termination of each preceding control pulse to a peak level at the initiation of each succeeding control pulse. As a result, the peak level of the speed voltage is inversely related to the speed of the engine. The amplitude of the bias voltage is held substantially constant over the duration of each succeeding control pulse at a bias level determined as a function of the peak level of the speed voltage during each preceding cycle. Consequently, the duration of each of the control pulses is defined in response to engine speed.

In another aspect of the invention, the amplitude of a compensation voltage increases from a compensation level at the initiation of each succeeding control pulse. The compensation level is determined in proportion to the peak level of the speed voltage during each preceding cycle. The increase in the amplitude of the compensation voltage is defined by a time constant which is relatively long compared to the longest duration of the control pulses. Hence, the amplitude of the compensation voltage remains substantially constant at the compensation level over the duration of each of the control pulses. The amplitude of the bias voltage is determined in response to the amplitude of the compensation voltage thereby to define the duration of the control pulses as a function of engine speed.

As contemplated by another aspect of the invention, the increase in the amplitude of the speed voltage is defined by a time constant such that the peak level of the speed voltage is at an upper potential when the engine speed is at a low speed limit and is at a lower potential when the engine speed is at a high speed limit. The amplitude of the compensation voltage is established at a minimum potential when the peak level of the speed voltage is at or below the lower potential and is established at a maximum potential when the peak level of the speed voltage is at and above the upper potential. Further, the amplitude of the compensation voltage between the maximum potential and the minimum potential is proportional to the peak level of the speed voltage between the upper potential and the lower potential.

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 drawing.

In the drawing:

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 fuel injection system illustrated in FIG. 1.

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

FIG. 5 is a schematic diagram of a speed compensation circuit incorporating the principles of the invention.

FIG. 6 is a graphic diagram of several waveforms useful in explaining the operation of the speed compensation circuit illustrated in FIG. 3.

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 synchronization 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 system.

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 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 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. 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. 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 bistable 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 monostable multivibrator or blocking oscillator 92. The blocking oscillator 92 includes a control transducer 94 having a primary winding 96 and a secondary winding 98 which are variably inductively coupled through a movable magnetizable core 100. The deeper the core 100 is inserted into the primary and secondary windings 96 and 98, the greater the inductive coupling between the primary winding 96 and the secondary winding 98. The movable core 100 is mechanically connected through a suitable linkage 102 with a pressure sensor 104. The pressure sensor 104 communicates with the intake manifold 20 of the engine 10 downstream from the throttle 74 through a conduit 106 for monitoring the negative pressure or vacuum within the intake manifold 20. The pressure sensor 104 moves the core 100 within the control transducer 94 to regulate the inductive coupling between the primary and secondary windings 96 and 98 as an inverse function of the vacuum within the intake manifold 20. Therefore, as the vacuum within the intake manifold 20 decreases in response to the opening of the throttle 74, the core 100 is inserted deeper within the control transducer 94 to proportionately increase the inductive coupling between the primary winding 96 and the secondary winding 98.

The monostable multivibrator or blocking oscillator 92 further includes a pair of NPN Junction transistors 108 and 110. The primary winding 96 is connected from the collector electrode of the transistor 110 through a limiting resistor 112 to the power line 40. The secondary winding 98 is connected from an input junction 114 through a steering diode 116 to a bias junction 118 between a pair of biasing resistors 120 and 122 which are connected in series between the power line 40 and the ground line 42. A biasing resistor 124 is connected between the junction 114 and the power line 40. The base electrode of the transistor 108 is connected through a steering diode 126 to the junction 114. The emitter electrodes of the transistors 108 and 110 are connected directly to the ground line 42. The collector electrode of the transistor 108 is connected through a biasing resistor 128 to the power line 40 and is connected through a biasing resistor 130 to the base electrode of the transistor 110.

Further, the control pulse generator 88 includes a differentiator 132 provided by a capacitor 134 and a pair of resistors 136 and 138. The resistors 136 and 138 are connected in series between the power line 40 and the ground line 42. The capacitor 134 is connected from the timing line 82 to a junction 140 between the resistors 136 and 138. A steering diode 142 is connected from the junction 140 between the resistors 136 and 138 to the input junction 114. In operation, timing pulses are applied through the timing line 82 to the differentiator 132. The differentiator 132 develops negative trigger pulses at the junction 140 in response to the timing pulses. The diode 142 applies the trigger pulses from the junction 140 to the junction 114.

Referring to FIGS. 1 and 2, the monostable multivibrator or blocking oscillator 92 switches from a stable state to an unstable state in response to a decrease in the voltage at the input junction 114 below a predetermined threshold potential P_t. The voltage appearing at the junction 114 comprises the combination of a pressure voltage A and a bias voltage B as shown in FIG. 2*b*. The pressure voltage A is provided by the control transducer 94 and the bias voltage B is provided by a bias voltage network including the resistors 120, 122 and 124. When the voltage at the junction 114 is above the threshold potential P_t, the transistor 108 is rendered fully conductive through the coupling action of the diode 126 and the transistor 110 is rendered fully nonconductive through the biasing action of the resistor 130.

With the pressure voltage A absent, the bias voltage B provided by the resistors 120, 122 and 124 is at a normal level L_n which maintains the voltage at the junction 114 above the threshold potential P_t so that the transistor 108 is normally turned on and the transistor 110 is normally turned off. However, when a negative trigger pulse arrives at the junction 114, the voltage at the junction 114 immediately drops below the threshold potential P_t. Consequently, the transistor 108 is turned off through the coupling action of the diode 126, and the transistor 110 is turned on through the biasing action of the resistors 128 and 130. With the transistor 110 turned on, a control pulse C, as shown in FIG. 2*a*, is initiated on the control line 90. The level of the control pulse C is defined by the saturation voltage drop of the transistor 110.

With the transistor 110 turned on, a current is established in the primary winding 96 of the control transducer 94 to develop a pressure voltage A across the secondary winding 98 of the control transducer 94. The pressure voltage A initially instantaneously decreases from the level of the bias voltage B to a peak lower level and subsequently gradually decreases back to the level of the bias voltage B. The pressure voltage A is coupled through the diode 116 to the junction 114 to hold the voltage at the junction 114 below the threshold potential P_t. Consequently, the transistor 108 remains turned off and the transistor 110 remains turned on.

The peak lower level of the pressure voltage A is determined by the inductive coupling between the primary and secondary windings 96 and 98 of the control transducer 94. In turn, the inductive coupling between the primary and secondary windings 96 and 98 is defined by the position of the movable core 100. The rate at which the pressure voltage A increases from the peak lower level back to the normal level L_n of the bias voltage B is determined by the L/R time constant of the primary winding 96 and the limiting resistor 112. As

the pressure voltage A increases, the voltage at the junction 114 eventually rises above the threshold potential P_t. Accordingly, the transistor 108 is turned on and the transistor 110 is turned off. With the transistor 108 turned off, the control pulse C on the control line 90 is terminated.

Thus, the duration of the control pulses occurring on the control line 90 is determined by the combination of the pressure voltage A and the bias voltage B. More particularly, the length of the control pulses C is inversely related to the amplitude of the bias voltage B. Hence, if the amplitude of the bias voltage B is decreased, the length of the control pulses C is increased. Alternately, if the amplitude of the bias voltage is increased, the length of the control pulses C is decreased. However, assuming for the moment that the bias voltage B is constant, the duration of the control pulses C is defined by the pressure sensor 104 and the control transducer 94 as an inverse function of the vacuum within the intake manifold 20 of the engine 10.

As previously described, the frequency of the control pulses C produced by the control pulse generator 88 is proportional to the speed of the engine 10. As a result, the amount of fuel applied to the engine 10 is inherently a function of engine 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 engine speed. 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 comprises eight cylinders. The fuel demand curves D_1–D_4 each represent a graph of fuel quantity versus engine speed at different constant manifold pressures. Since the quantity of fuel delivered to the engine 10 is directly related to the length of the control pulses C, the ordinate of the graph also represents control pulse length.

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 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 a 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 fuel compensation curve X is a general approximation of each of the respective fuel demand curves D_1–D_4.

According to the fuel compensation curve X, an 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 in the intake manifold 20 should be extended by a percentage which increases with increasing engine speed 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, a constant minimum amount of fuel should be added to the normal fuel quantity. Similarly, when the speed of the engine 10 is above the upper speed limit N_u, a constant maximum amount of fuel should be added to the normal fuel quantity. In other words, the normal duration of the control pulses C as determined by the pressure in the intake manifold 20 should be increased by a constant minimum percentage when the engine speed is below the lower speed limit N_o and by a constant maximum percentage when the engine speed is above the upper speed limit N_u.

The present invention provides an electronic fuel injection system including a speed compensator 144 for varying the amount of fuel delivered to the engine in accordance with the speed compensation curve X. The speed compensator 144 includes an input connected over the control line 90 to the output transistor 110 of the control pulse generator 88 and an output connected over an output line 145 to the junction 118 in the control pulse generator 88. However, it will be appreciated that an engine different from the engine 10, and having fuel demand curves different from the fuel demand curves D_1–D_4, would necessarily have a speed compensation curve different from the speed compensation curve X. Hence, some engines may require a speed compensation curve exactly opposite to the speed compensation curve X. That is, a speed compensation curve which decreases from a maximum level at the lower speed limit N_o to a minimum level at the upper speed limit N_u. As will become more apparent later, the speed compensator 144 is capable of providing either type of speed compensation curve.

FIG. 5 illustrates a preferred embodiment of the speed compensator 144 including a speed voltage generator 146, a compensation voltage generator 148 and a bias voltage modifier 150. FIG. 6 illustrates the operation of the speed compensation 144 at three different engine speeds N_1, N_2 and n_3. In FIG. 6*a*, the engine speed N_1 is below the lower speed limit N_o. In FIG. 6*b*, the engine speed N_2 is midway between the lower speed limit N_o and the upper speed limit N_u. In FIG. 6*c*, the engine speed N_3 is above the upper speed limit N_u. Referring to FIGS. 5 and 6, a speed voltage S is developed across a capacitor 152 at a junction 153. Further, a compensation voltage K is developed across a capacitor 154 at a junction 155. As shown in FIG. 5, the speed voltage S is measured between the junction 153 and the ground line 42 while the compensation voltage is measured between the junction 155 and the ground line 42. Hence, as the speed voltage S and the compensation voltage K increases in magnitude across the respective capacitors 152 and 154, the absolute amplitude of the voltages S and K declines from the potential of the power line 40 toward the potential of the ground line 42.

The speed voltage generator 146 produces the speed voltage S at the junction 153. The amplitude of the speed voltage S unidirectionally varies from a base

level L_b at the termination of each preceding control pulse C to a peak level L_p at the initiation of each of each succeeding control pulse C. As a result, the peak amplitude of the speed voltage S is inversely proportional to the speed of the engine **10**. The compensation voltage generator **148** produces the compensation voltage K at the junction **155**. The amplitude of the compensation voltage K is substantially constant at a compensation level L_k which is proportional to the peak level L_p of the speed voltage S. The bias voltage modifier **150** shifts the amplitude of the bias voltage B from the normal level L_n in response to the amplitude of the compensation voltage K to define the duration of the control pulses C as a function of the speed of the engine **10**.

The speed voltage generator **146** includes the capacitor **152** connected between the power line **40** and the junction **153**. A switching device **158** is provided by a PNP junction transistor **160** and an NPN junction transistor **162**. The emitter electrode of the transistor **160** and the collector electrode of the transistor **162** are connected together to the power line **40**. The collector electrode of the transistor **160** is connected directly to the base electrode of the transistor **162**. The emitter electrode of the transistor **162** is connected directly to the junction **152**. The base electrode of the transistor **160** is connected through a biasing resistor **163** to the power line **40** and through a biasing resistor **164** over the control line **90** to the control pulse generator **88**. In addition, a variable limiting resistor **166** is connected between the junction **153** and the ground line **42**.

As previously described, the speed voltage S is developed across the capacitor **152** at the junction **153**. In response to the initiation or leading edge of each control pulse C, the transistors **160** and **162** of the switching device **158** are rendered fully conductive. With the switching device **158** turned on, the capacitor **152** is discharged through the transistors **160** and **162** to effectively clamp the amplitude of the speed voltage S at the base level L_b which is approximately equal to the supply potential on the power line **40**. In response to the termination or trailing edge of each control pulse C, the transistors **160** and **162** of the switching device **158** are rendered fully nonconductive. With the switching device **158** turned off, the capacitor **152** charges through the resistor **166**. As a result, the amplitude of the speed voltage S increases from the base level L_b in accordance with the RC time constant provided by the capacitor **152** and the resistor **166**. In response to the initiation or leading edge of the next control pulse C, the switching device **158** is again turned on to clamp the amplitude of the speed voltage S at the base level L_b.

Accordingly, the speed voltage S comprises successive cycles during which the amplitude of the speed voltage S reaches a peak level L_p at the initiation of each succeeding control pulse C. Due to the time constant provided by the capacitor **152** and the resistor **166**, the amplitude of the speed voltage S increases in a fairly linear manner. Hence, the peak amplitude or peak level L_p of the speed voltage S is directly related to a time period T_p extending from the termination of each preceding control pulse C to the initiation of each succeeding control pulse C. In turn, the time period T_p is inversely related to the frequency of the control pulses C in a nonlinear manner. That is, if the frequency of the control pulses C increases at a fixed rate, the duration of the time period T_p decreases at an ever increasing rate. As a result, the peak amplitude of the speed voltage C is inversely related to the speed of the engine **10** in the same nonlinear manner.

The time constant provided by the capacitor **152** and the resistor **166** is adjusted by varying the resistance of the resistor **166**. In particular, this time constant is set so that the peak amplitude of the speed voltage S across the capacitor **152** is at an upper potential P_u when the engine speed is at the lower speed limit N_o and the peak amplitude of the speed voltage S is at a lower potential P_o when the engine speed is at the upper speed limit N_u. In other words, the peak level L_p of the speed voltage S equals the upper potential P_u when the engine speed is at the lower limit N_o and the peak level L_p of the speed voltage S equals the lower potential P_o when the engine speed is at the upper speed limit N_u. Hence, with the engine **10** at the speed N_1 as shown in FIG. **6***a*, the peak level L_p of the speed voltage S is above the upper potential P_u. With the engine **10** at the speed N_2 as shown in FIG. **6***b*, the peak level L_p of the speed voltage S is midway between the upper potential P_u and the lower potential P_o. Further, with the engine **10** at the speed N_3 as shown in FIG. **6***c*, the peak level L_p of the speed voltage S is below the lower potential P_o. The significance of the relationship between the amplitude of the speed voltage S and the upper and lower potentials P_u and P_o will become more apparent later.

The compensation voltage generator **148** includes the capacitor **154** connected between the power line **40** and the junction **155**. A limiting resistor **170** is connected in series with a temperature compensating diode **171** between the power line **40** and the junction **155**. A differential amplifier **172** includes NPN junction transistors **174, 176** and **178**. The base electrode of the transistor **174** is connected to a junction **180**. A biasing resistor **182** is connected between the power line **40** and the junction **180**. A temperature compensating diode **184** is connected between the junction **180** and the ground line **42**. The emitter electrode of the transistor **174** is connected directly to the ground line **42**. The collector electrode of the transistor **174** is connected to a junction **186**. A pair of biasing resistors **188** and **190** are connected between the junction **186** and the emitter electrodes of the transistors **176** and **178**, respectively. The base electrode of the transistor **176** is connected to the junction **152**. The base electrode of the transistor **178** is connected to a junction **192**. A pair of biasing resistors **194** and **196** are connected from the junction **192** to the power line **40** and the ground line **42**, respectively. The collector electrode of the transistor **176** is connected directly to the power line **40**. The collector electrode of the transistor **178** is connected directly to the junction **154**.

In conjunction with the biasing resistor **182** and the temperature compensating diode **184**, the transistor **174** provides a constant current sink for the transistors **176** and **178** of the differential amplifier **172**. The transistors **176** and **178** form a balanced differential pair for gradually switching between first and second conductive conditions in response to the amplitude of the speed voltage S at the junction **152**. As the amplitude of the speed voltage S increases from the base level L_b toward the lower potential P_o, the transistor **176** is rendered fully conductive and the transistor **178** is rendered fully nonconductive. This is the first conductive condition of reference differential amplifier **172**. When

the amplitude of the speed voltage S increases through the lower potential P_o, the transistor **176** begins to turn off and the transistor **178** begins to turn on. As the amplitude of the speed voltage S proportionately increases between the lower level P_o and the upper level P_u, the transistor **176** is correspondingly rendered less conductive while the transistor **178** is correspondingly rendered more conductive. When the amplitude of the speed voltage S increases through the upper potential P_u, the transistor **176** is rendered fully nonconductive and the transistor **178** is rendered fully conductive. This is the second conductive condition of the differential amplifier **172.** As the amplitude of the speed voltage S increases from the upper potential P_u to the peak level L_p, the differential amplifier **172** remains in the second conductive condition.

The upper and lower potentials P_u and P_o of the speed voltage S are determined by the biasing resistors **188, 190, 194** and **196.** Preferably, the resistors **188** and **190** have a like resistance while the resistors **194** and **196** have a like resistance. However, this constraint is not critical. The biasing resistors **194** and **196** form a voltage divider network for developing a reference voltage R at the junction **192.** The amplitude of the reference voltage R is substantially constant at a reference potential P_r defined relative to the supply potential on the power line **40** by the ratio of the resistances of the resistors **194** and **196.** Similarly, ratio of the resistances of the resistors **188** and **190** defines the upper and lower potentials P_u and P_o with respect to the reference potential P_r. Therefore, since the upper and lower potentials P_u and P_o of the speed voltage S are defined by relative resistance ratios rather than absolute resistance values, the biasing resistors **188, 190, 194** and **196** may conveniently be formed within an integrated circuit which requires no external calibration except for an adjustment of the variable resistor **166.**

During each control pulse C, the differential amplifier **172** is reset to the first conductive condition since the amplitude of the speed voltage S at the base level L_b. At the initiation of each succeeding control pulse C, the conductive position of the differential amplifier **172** between the first and second conductive conditions is dependent upon the potential position of the peak amplitude or peak level L_p of the speed voltage S relative to the upper and lower potentials P_u and P_o. When the peak level L_p of the speed voltage S is above the upper potential P_u as shown in FIG. **6***a*, the differential amplifier **172** is fully switched to the second conductive condition during each cycle of the speed voltage S. When the peak level L_p of the speed voltage S is midway between the upper and lower potentials P_u and P_o as shown in FIG. **6***b*, the differential amplifier **172** is half-switched between the first and second conductive conditions during each cycle of the speed voltage S. When the peak level L_p of the speed voltage S is below the lower potential P_o as shown in FIG. **6**c, the differential amplifier **172** remains in the first conductive condition during each cycle of the speed voltage S.

The compensation voltage k is developed across the capacitor **154** at the junction **155.** During each control pulse C, the transistor **178** in the differential amplifier **172** is rendered fully nonconductive. With the transistor **178** turned off, the capacitor **154** is discharged through the resistor **170.** As a result, the amplitude of the compensation voltage K decreases in accordance with the RC time constant provided by the capacitor **154** and the resistor **170.** However, since this time constant is relatively long compared to the longest duration of the control pulses C, the amplitude of the compensation voltage K remains substantially constant at a compensation level L_k over the duration of each succeeding control pulse C. Therefore, the amplitude of the compensation voltage K is completely independent of variations in the duration of the control pulses C due to pressure changes in the intake manifold **20** of the engine **10.**

Further, the time constant provided by the capacitor **154** and the resistor **170** is relatively short compared to the maximum rate-of-increase in the speed of the engine **10** as the throttle valve **74** is suddenly moved to the fully opened position. Consequently, the compensation level L_k of the compensation voltage K is defined by the conduction of the transistor **178** in the differential amplifier **172** at the initiation of each succeeding control pulse C. Hence, when the differential amplifier **172** is in the second conductive condition at the termination of a control pulse C, the amplitude of the compensation voltage K is at a maximum potential P_a. When the differential amplifier **172** is in the first conductive condition at the termination of the control pulse C, the amplitude of the compensation voltage K is at a minimum potential P_z. In addition, as the differential amplifier **172** is proportionately switched between the first and second conductive conditions at the termination of the control pulse C, the amplitude of the compensation voltage K is correspondingly defined between the maximum and minimum potentials P_a and P_z.

Accordingly, the compensation level L_k of the compensation voltage K is directly related to the peak level L_p of the speed voltage S. When the peak amplitude of the speed voltage S is at or above the upper potential p_u, the amplitude of the compensation voltage K is at the maximum potential P_a. Conversely, when the peak amplitude of the speed voltage S is at or below the lower potential P_o, the amplitude of the compensation voltage K is at the minimum potential P_z. Further the potential position of the amplitude of the compensation voltage K relative to the maximum and minimum potentials p_a and P_z is proportional to the potential position of the peak amplitude of the speed voltage S relative to the upper and lower potentials P_u and P_o. Thus, with the peak level L_p of the speed voltage S below the lower potential P_o as shown in FIG. **6***a*, the compensation level L_k of the compensation voltage K is equal to the maximum potential P_a. With the peak level L_p of the speed voltage S equal to the reference potential P_r as shown in FIG. **6***b* the compensation Level L_k of the compensation voltage K is midway between the maximum and minimum potentials P_a and p_z. Finally, with the peak level L_p of the speed voltage s below the lower potential as shown in FIG. **6***c*, the compensation level L_k of the compensation voltage K is equal to the minimum potential P P_z.

The bias voltage modifier **150** include a constant current source **198** and a constant current sink **200.** The constant current source **198** includes a PNP junction transistor **202** and an NPN junction transistor **204.** The emitter electrode of the transistor **202** and the collector electrode of the transistor **204** are connected through a limiting resistor **206** to the power line **40.** The collector electrode of the transistor **202** is connected directly to the base electrode of the transistor **204.** The base electrode of the transistor **202** is connected directly to

the junction 155. The emitter electrode of the transistor 204 is connected to a junction 208 in the current sink 200.

The constant current sink 200 includes an NPN junction transistor 210. The base electrode of the transistor 210 is connected directly to the junction 208. The emitter electrode of the transistor 210 is connected through a limiting resistor 212 to the ground line 42. A biasing resistor 214 is connected in series with the temperature compensating diode 216 between the junction 208 and the ground line 42. The collector electrode of the transistor 210 is connected directly to the junction 118 in the control pulse generator 88.

In the constant current source 198, the transistors 202 ad 204 are rendered conductive in response to the compensation voltage K to establish a compensation current through the resistor 206. The magnitude of the compensation current is directly related to the amplitude of the compensation voltage K developed across the capacitor 168. That is, as the amplitude of the compensation voltage K increases, the magnitude of the compensation current I increases. In the constant current sink 200, the transistor 210 is rendered conductive in response to the compensation current through the resistor 214 and the diode 216. As a result, the transistor 210 defines a bias current through the resistor 212 having a magnitude directly proportional to the magnitude of the compensation current. The bias current is drawn out of the conjunction 118 in the control pulse generator 88 through the output line 145. Accordingly, the current sink 200 effectively appears as a variable resistance connected between the junction 118 and the ground line 42.

Referring to FIGS. 1, 2 and 6, the length of the control pulses C produced by the control pulse generator 88 is inversely related to the amplitude of the bias voltage B at the junction 114. Further, the amplitude of the bias voltage B is inversely related to the magnitude of the bias current at the junction 118. In turn, the magnitude of the bias current is a direct function of the amplitude of the compensation voltage K at the junction 154. When the speed of the engine 10 is at or below the lower speed limit N_o, the amplitude of the bias voltage B is shifted from the normal level L_n by a minimum amount. Conversely, when the speed of the engine 10 is at or above the upper speed limit N_u, the amplitude of the bias voltage B is shifted from the normal level L_n by a maximum amount. Further, as the speed of the engine 10 is proportionately changed between the upper and lower speed limits N_u and n_o, the amplitude of the bias voltage is proportionately shifted between the maximum and minimum amounts. In this manner, the length of the control pulses C is varied to compensate the amount of fuel applied to the engine 10 for variations in engine speed.

It will now be appreciated that the present invention provides a simple but effective speed compensator for an electronic fuel injection system. In particular, the amount of speed compensation produced by the invention is substantially independent of control pulse length as determined by other factors. However, it is to be understood that the illustrated embodiment of the invention is shown for demonstrative purposes only. Accordingly, various modifications and alterations may be made to the illustrated embodiment without departing from the spirit and scope of the invention.

What is claimed is:

1. In an internal combustion engine system including control pulse generator means for producing control pulses at a frequency proportional to the speed of the engine, the control pulse generator means including bias voltage generator means for defining the duration of the control pulses as a function of the amplitude of the bias voltage; and fuel injection means connected between the control pulse generator means and the engine for applying fuel to the engine for the duration of each of the control pulses; the combination comprising: speed voltage generator means connected to the control pulse generator means for producing a speed voltage having an amplitude which unidirectionally varies from a base level at the termination of each preceding control pulse to a peak level at the initiation of each succeeding control pulse; and means connected between the speed voltage generator means and the bias voltage generator means for maintaining the amplitude of the bias voltage substantially constant at a level proportional to the peak level of the speed voltage thereby to define the duration of the control pulses in response to the speed of the engine.

2. In an internal combustion engine system including control pulse generator means for producing control pulses at a frequency proportional to the speed of the engine, the control pulse generator means including bias voltage generator means for defining the duration of the control pulses as a function of the amplitude of a bias voltage; and fuel injection means connected between the control pulse generator means and the engine for applying fuel to the engine for the duration of each of the control pulses; the combination comprising: speed voltage generator means connected to the control pulse generator means for producing a speed voltage having successive cycles during which the amplitude of the speed voltage unidirectionally varies from a base level at the termination of each preceding control pulse to a peak level at the initiation of each succeeding control pulse; compensation voltage generator means connected to the speed voltage generator means for producing a compensation voltage having an amplitude which is substantially constant over the duration of each succeeding control pulse at a level proportional to the peak level of the speed voltage during each preceding cycle; and bias voltage modifier means connected between the compensation voltage generator means and the bias voltage generator means for defining the amplitude of the bias voltage as a function of the amplitude of the compensation voltage thereby to determine the duration of the control pulses in response to the speed of the engine.

3. In an internal combustion engine system including control pulse generator means for producing control pulses in synchronization with the speed of the engine, the control pulse generator means including bias voltage generator means for defining the duration of the control pulses as a function of the amplitude of a bias voltage; and fuel injection means connected between the control pulse generator means and the engine for applying fuel to the engine for the duration of each of the control pulses; the combination comprising: speed voltage generator means connected to the control pulse generator means for producing a speed voltage which varies from a base level at the termination of each preceding control pulse, the speed voltage generator means including an RC network having a time constant for defining the amplitude of the speed voltage in ac-

cordance with the time constant which is relatively short compared to the shortest duration between each of the control pulses; compensation voltage generator means connected to the speed voltage generator means for producing a compensation voltage which varies from a base level proportional to the peak level of the speed voltage at the initiation of each succeeding control pulse, the compensation voltage generator means including an RC network having a time constant for defining the amplitude of the compensation voltage in accordance with the time constant which is relatively long compared to the longest duration of each of the control pulses; and bias voltage modifier means connected between the compensation voltage generator means and the bias voltage generator means for controlling the amplitude of the bias voltage in response to the amplitude of the compensation voltage thereby to define the duration of the control pulses as a function of the speed of the engine.

4. In an internal combustion engine system including control pulse generator means for producing control pulses at a frequency proportional to the speed of the engine, the control pulse generator means including bias voltage generator means for defining the duration of each of the control pulses as a function of the level of the bias voltage; and fuel injection means connected between the control pulse generator means and the engine for applying fuel to the engine for the duration of each of the control pulse; the combination comprising: speed voltage generator means connected to the control pulse generator means for producing a speed voltage which varies from a base level at the termination of each preceding control pulse to a peak level at the initiation of each succeeding control pulse so that the peak level of the speed voltage is inversely related to the speed of the engine, the speed voltage generator means including an RC network having a time constant for defining the amplitude of the speed voltage such that the peak level occurs at an upper potential when the engine speed is at a lower limit and occurs at a lower potential when the engine speed is at an upper limit; compensation voltage generator means connected to the speed voltage generator means for producing a compensation voltage which varies from a base level at the initiation of each succeeding control pulse, the compensation voltage generator means including a voltage level converter for defining the base level of the compensation voltage relative to a maximum potential and a minimum potential as the peak level of the speed voltage is defined relative to the upper potential and the lower potential, the compensation voltage generator means further including an RC network having a time constant for defining the amplitude of the compensation voltage substantially constant at the base level over the duration of each succeeding control pulse; and bias voltage modifier means connected between the compensation voltage generator means and the bias voltage generator means for shifting the amplitude of the bias voltage in proportion to the amplitude of the compensation voltage thereby to define the duration of the control pulses as a function of the speed of the engine.

5. In an internal combustion engine system including control pulse generator means for producing control pulses at a frequency proportional to the speed of the engine, the control pulse generator means including bias voltage generator means for defining the duration of the control pulses as a function of the amplitude of a bias voltage; and fuel injection means connected between the control pulse generator means and the engine for applying fuel to the engine for the duration of each of the control pulses; the combination comprising: speed voltage generator means connected to the control pulse generator means and including a capacitor for developing a speed voltage thereacross, discharging means connected to the capacitor for discharging the capacitor from the initiation of each preceding control pulse until the termination of each preceding control pulse to clamp the speed voltage at a base level, and charging means connected to the capacitor for charging the capacitor from the termination of each preceding control pulse to the initiation of each succeeding control pulse according to a relatively short time constant to increase the speed voltage from the base level to a peak level which is at an upper potential when the engine speed is at a low limit and which is at a lower potential when the engine speed is at a high limit; compensation voltage generator means connected to the speed voltage generator means and including a capacitor for developing a compensation voltage thereacross, charging means connected to the capacitor for charging the capacitor from the termination of each preceding control pulse until the initiation of each succeeding control pulse to clamp the compensation voltage at a base level defined relative to a maximum potential and a minimum potential as the peak level of the speed voltage is defined relative to the upper potential and the lower potential, and discharging means connected to the capacitor for continually discharging the capacitor according to a relatively long time constant to maintain the compensation voltage substantially constant at the base level over the duration of each succeeding control pulse; and the bias voltage modifier means connected between the compensation voltage generator means and the bias voltage generator means for defining the amplitude of the bias voltage in response to the amplitude of the compensation voltage thereby to determine the duration of the control pulses as a function of engine speed.

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