

[54] **ELECTRONIC FUEL INJECTION SYSTEM INCLUDING TRANSIENT POWER COMPENSATION**

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

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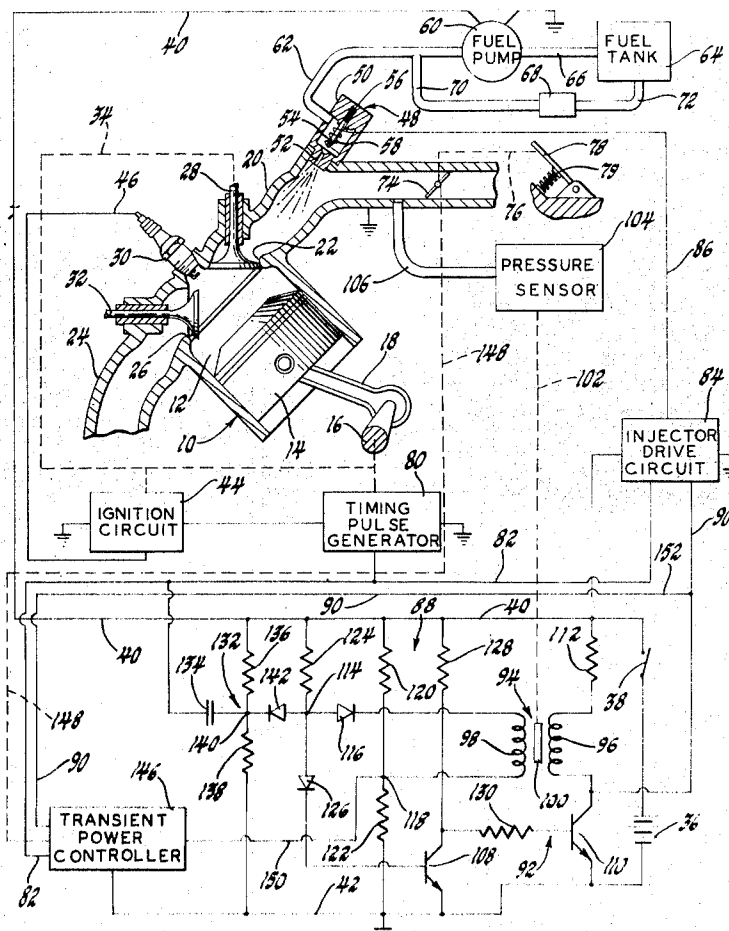
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[57] **ABSTRACT**

In an internal combustion engine system, the inductance of an inductor is determined in response to the rate of change in the position of a throttle member. At the same time, the inductor is energized with a control current having a magnitude which varies at a constant rate of change. As a result, a throttle voltage is developed across the inductor having an amplitude which is directly proportional to the rate of change in the position of the throttle member. The amount of fuel applied to the engine is regulated as a function of the amplitude of the throttle voltage. Optionally, the amount of fuel delivered to the engine is also controlled as a function of the amplitude of a speed voltage which is proportional to the speed of the engine.

5 Claims, 5 Drawing Figures



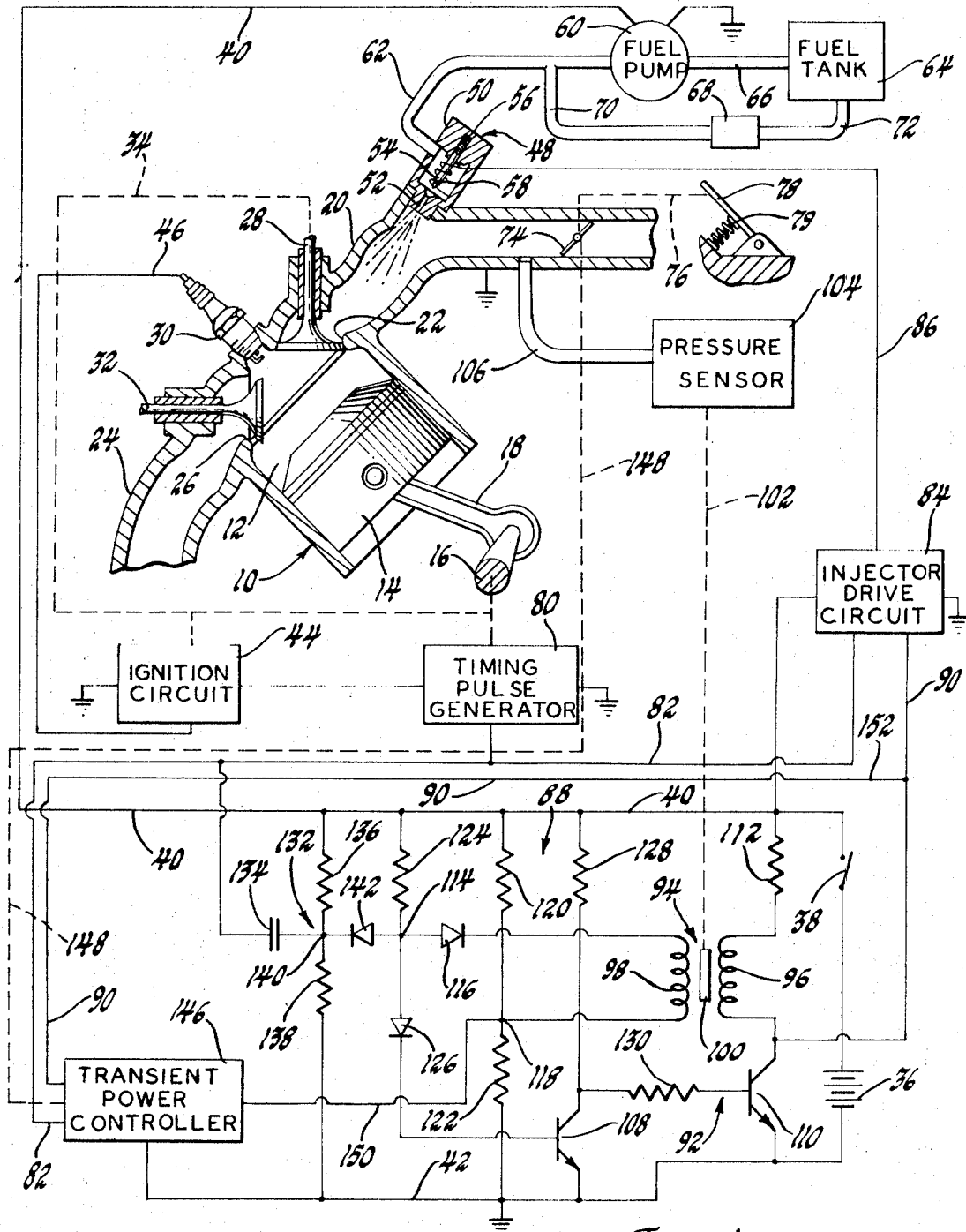


Fig. 1

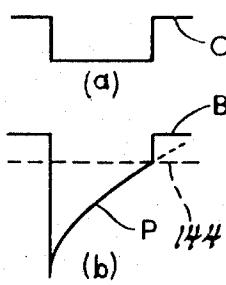


Fig. 2

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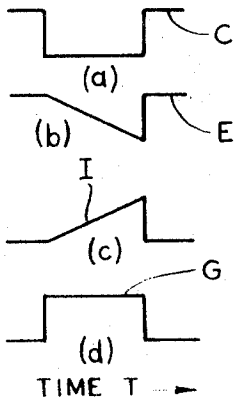
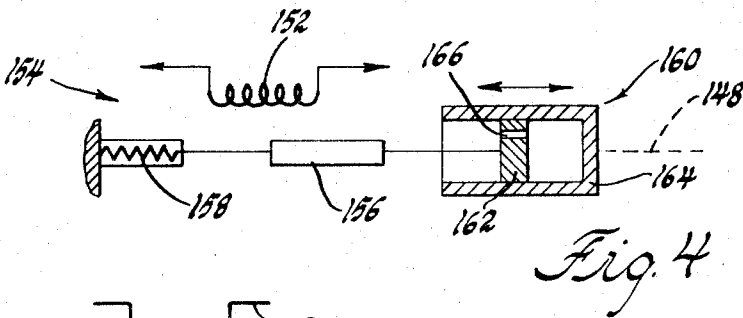
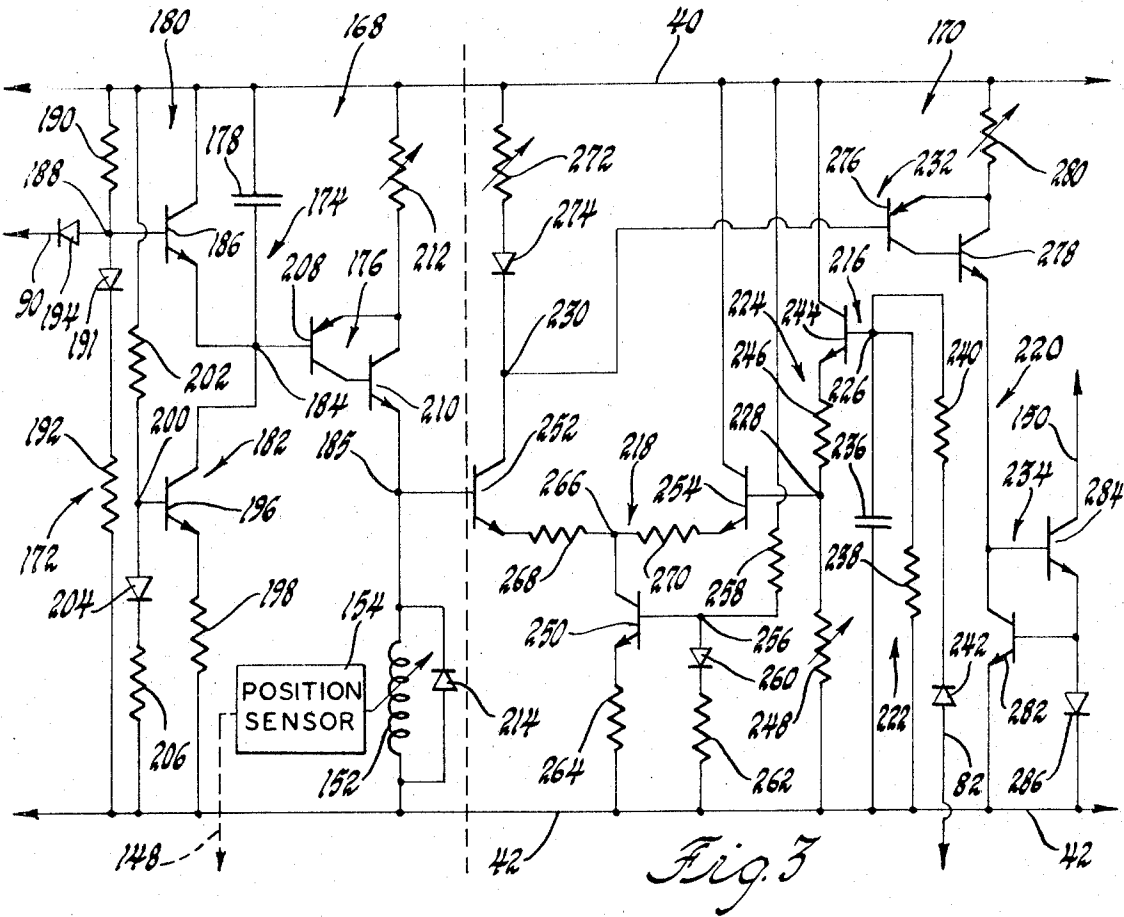


Fig. 5

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ELECTRONIC FUEL INJECTION SYSTEM INCLUDING TRANSIENT POWER COMPENSATION

This invention relates to an electronic fuel injection system for an internal combustion engine. More particularly, the invention relates to an apparatus for regulating the amount of fuel applied to an engine during transient excursions in the engine power output.

Typically, in an internal combustion engine, the power output of the engine is defined by the position of an adjustable throttle member. Thus, when the throttle member is moved from one position to another position, the engine power output correspondingly moves from one level to another level. During acceleration of the engine, the position of the throttle member is shifted to increase the engine power output. During deceleration of the engine, the position of the throttle member is shifted to decrease the engine power output. In either event, it is desirable that the rate of change in the power output of the engine closely parallel the rate of change in the position of the throttle member.

In order to achieve high engine performance, the amount of fuel delivered to the engine must be regulated to provide the change in engine power output called for by the change in throttle member position. Further, for optimum operation of the engine, the amount of fuel applied to the engine must be controlled to produce the rate of change in engine power output called for by the rate of change in throttle member position. Moreover, it is desirable that the amount of fuel applied to the engine in response to movement of the throttle member be modified in accordance with engine speed. The present invention achieves the desired results by providing an electronic fuel injection system which is highly responsive to movement of the throttle, and optionally, which is also responsive to engine speed.

According to one aspect of the invention, the inductance of an inductor is altered in response to changes in the position of the throttle member. At the same time, the inductor is energized with a control current having a linearly varying magnitude. As a result, a throttle voltage is developed across the inductor having an amplitude which is directly proportional to the inductance of the inductor. The application of fuel to the engine is regulated in dependence upon the amplitude of the throttle voltage. Thus, the amount of fuel delivered to the engine is exactly that required to provide the change in engine power output called for by the change in throttle member position.

In a further aspect of the invention, the inductance of the inductor is varied as a function of the rate of change in the position of the throttle member utilizing a dashpot position sensor. Since the magnitude of the control current through the inductor varies at a constant rate of change, the amplitude of the throttle voltage developed across the inductor is directly proportional to the rate of change in the position of the throttle member. Hence, the amount of fuel applied to the engine is precisely that necessary to produce the rate of change in engine power output called for by the rate of change in throttle member position.

As contemplated by another aspect of the invention, a speed voltage is developed having an amplitude proportional to the speed of the engine. The amplitude of the speed voltage combines with the amplitude of the

throttle voltage to determine the amount of fuel metered to the engine. Accordingly, the delivery of fuel to the engine during transient excursions in the engine power output is responsive to 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 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 invention.

FIG. 3 is a schematic diagram of a transient power controller incorporating the principles of the invention.

FIG. 4 is a schematic diagram of a position sensor incorporated within the invention.

FIG. 5 is a graphic diagram of several waveforms useful in explaining 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 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 gasses 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 144. The voltage appearing at the junction 114 comprises the combination of a signal voltage or pressure voltage P and a bias voltage B as shown in FIG. 2b. The pressure voltage P 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 144, 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 P absent, the bias voltage B provided by the resistors 120, 122 and 124 normally maintains the voltage at the junction 114 above the threshold potential 144 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 144. 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. 2a, 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 P across the secondary winding 98 of the control transducer 94. The pressure voltage P 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 P is coupled through the diode 116 to the junction 114 to hold the voltage at the junction 114 below the threshold potential 144. Consequently, the transistor 108 remains turned off and the transistor 110 remains turned on.

The peak lower level of the pressure voltage P 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 P increases from the peak lower level back to the level 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 P increases, the voltage at the junction 114 eventually rises above the threshold potential 144. Accordingly, the transistor 108 is turned on and the tran-

sistor 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 P and the bias voltage B. More particularly, the length of the control pulses C is inversely related to the level of the bias voltage B. Hence, if the level of the bias voltage B is decreased, the length of the control pulses C is increased. Alternately, if the level 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.

It will now be appreciated that the amount of fuel applied to the engine 10 is directly related to the pressure in the intake manifold 20 as determined by the position of the throttle valve 74. Thus, the position of the throttle valve 74 defines the power output of the engine 10. As the throttle valve 74 moves from one position to another position, the power output of the engine 10 moves from one level to another level. Assuming the load on the engine 10 is constant, the engine speed accelerates in response to opening of the throttle valve 74 and decelerates in response to closing of the throttle valve 74. In either event, it is desirable that the rate of change in the power output of the engine 10 closely parallel the rate of change in the position of the throttle valve 74.

Hence, in order to achieve high engine performance, the amount of fuel delivered to the engine 10 must be controlled to provide the change in the power output of the engine 10 called for by the change in the position of the throttle valve 74. Further, for optimum operation of the engine 10, the amount of fuel applied to the engine 10 must be regulated to produce the rate of change in the power output of the engine 10 called for by the rate of change in the position of the throttle valve 74. It is also desirable that the amount of fuel applied to the engine 10 in response to movement of the throttle valve 74 be modified in accordance with the speed of the engine 10. The present invention achieves these desired results by providing an electronic fuel injection system including a transient power controller 146 which is highly responsive to movement of the throttle valve 74, and optionally, which is also responsive to the speed of the engine 10.

The transient power controller 146 is connected between the throttle valve 74 and the control pulse generator 88 for regulating the amount of fuel delivered to the engine 10 in response to movement of the throttle valve 74. In particular, the transient power controller 146 includes a mechanical input connected with the throttle valve 74 through a suitable linkage 148 and an electrical input connected to the control pulse generator 88 via the control line 90. Further, the transient power controller 146 includes an output connected to the junction 118 in the control pulse generator 88 via an output line 150. In operation, the transient power controller 146 shifts the level of the bias voltage B appearing at the junction 118 to change the length of the control pulses C produced by the monostable multivibrator 88. More specifically, the transient power controller 146 is responsive to the rate of change in the po-

sition of the throttle valve 74 to vary the length of the control pulses C to produce a like rate of change in the power output of the engine 10. In addition, the transient power controller 146 includes an input connected to the timing pulse generator 80 via the timing line 82 for modifying the overall shift in the level of the bias voltage B in response to the speed of the engine 10.

Referring to FIG. 3, the transient power regulator 146 includes a variable inductor or winding 152. A transient power actuator or position sensor 154 including the linkage 148 varies the inductance of the winding 152 in response to movement of the throttle valve 74. Thus, as the position of the throttle valve 74 is changed, the transient power actuator 154 changes the inductance of the winding 152. More precisely, the transient power actuator 154 provides a dashpot action for defining the change in the inductance of the winding 152 as a function of the rate of change in the position of the throttle valve 74. The transient power actuator 154 may be made responsive to opening of the throttle valve 74, closing of the throttle valve 74, or both. When the throttle valve 74 is moved from a less opened to a more opened position, the power output of the engine 10 increases. When the throttle valve 74 is moved from a more opened position to a less opened position, the power output of the engine 10 decreases. FIG. 4 illustrates an embodiment of the transient power actuator or position sensor 154 which is responsive to the rate of change in the position of the throttle valve 74 during both opening and closing of the throttle valve 74.

Referring to FIG. 4, the transient power actuator 154 includes a movable magnetizable core 156 which is electromagnetically coupled with the winding 152 to define the inductance of the winding 152. Preferably, the core 156 is axially translational into and out of the winding 152. As the core 156 is axially displaced with respect to the winding 152, the electromagnetic coupling between the core 156 and the winding 152 is altered so as to change the inductance of the winding 152. A spring 158 is connected between a reference surface and one end of the core 156. The spring 158 is capable of being loaded in tension or in compression. A dashpot device 160 is connected between the linkage 148 and the other end of the core 156. Specifically, the dashpot device 160 includes a piston 162 which is mounted for reciprocation within a cylinder 164. The piston 162 is surrounded by a fluid medium, such as air, within the cylinder 164. The piston 162 is connected to the core 156 while the cylinder 164 is connected to the linkage 146. A bleed passage 166 extends through the piston 162 to permit the flow of fluid between the inner and outer sides of the piston 162 during movement within the cylinder 164. Hence, the bleed passage 166 defines the time constant or response characteristic of the dashpot device 160.

Normally, the spring 158 maintains the core 156 in a rest position, as shown in FIG. 3, in which the spring 158 is completely unloaded. In the rest position, the inductance L of the winding 152 is established at a nominal inductance L_n . Assuming the accelerator pedal 78 is depressed to open the throttle valve 74, the cylinder 164 is pushed sharply to the left by the linkage 146. Initially, the piston 162 moves to the left with the cylinder 164 as fluid flows through the bleed passage 166 from the inner side to the outer side of the piston 162. As a result, the core 156 is forced into the winding 152

thereby to increase the inductance of the winding 152. As the core 156 moves into the winding 152, the spring 158 is loaded in compression. Hence, the spring 158 acts to push the core 162 to the right. As fluid flows through the bleed passage 166 from the inner side to the outer side of the piston 162, the piston 162 moves to the right. Eventually, the core 156 is restored to the rest position by the action of the spring 158.

Initially, the inductance L of the winding 152 rapidly increases from the nominal inductance L_n to a peak maximum or upper inductance L_u as the piston 162 moves leftward with the cylinder 164 in response to opening of the throttle valve 74. The peak maximum inductance L_u is directly related to the total inward displacement of the core 156 with respect to the winding 152. In turn, the inward displacement of the core 156 is a direct function of the rate of change in the position of the throttle valve 74 as it opens in response to depression of the accelerator pedal 78. Accordingly, the initial increase in the inductance of the winding 152, or the peak upper inductance L_u , is directly proportional to the rate of change in the opening of the throttle valve 74. Subsequently, as the core 156 returns to the rest position, the inductance of the winding decreases from the maximum inductance L_u to the nominal inductance L_n . The rate of decrease in the inductance L of the winding 152 is governed by the time constant or response characteristic of the dashpot device 160.

Alternately, assuming the accelerator pedal 78 is released to close the throttle valve 74, the cylinder 164 is pulled sharply to the right by the linkage 148. Initially, the piston 162 likewise moves to the left with the cylinder 164 as fluid flows through the bleed passage 166 from the outer side to the inner side of the piston 162. As a result, the core 156 is forced out of the winding 152 thereby to decrease the inductance of the winding 152. As the core moves out of the winding 152, the spring 158 is loaded in tension. Thus, the spring 158 acts to pull the core 156 to the left. As fluid flows through the bleed passage 166 from the outer side to the inner side of piston 162, the piston 162 moves to the left. Eventually, the core 156 is restored to the rest position by the action of the spring 158.

Initially, the inductance L of the winding 152 rapidly decreases from the nominal inductance L_n to a peak minimum or lower inductance L_o as the piston 162 moves rightward with the cylinder 164. The peak minimum inductance L_o is directly related to the magnitude of the total outward displacement of the core 156 with respect to the winding 152. In turn, the outward displacement of the core 156 is a direct function of the rate of change in the position of the throttle valve 74 as it closes in response to release of the accelerator pedal 78. Consequently, the initial decrease in the inductance of the winding 152, or the peak lower inductance L_o , is directly proportional to the rate of change in the closing of the throttle valve 74. Thereafter, as the coil 156 returns to the rest position, the inductance of the winding 152 increases from the peak minimum inductance L_o to the nominal inductance L_n . The rate of increase in the inductance L of the winding 152 is governed by the time constant or response characteristic of the dashpot device 160.

Referring again to FIG. 3, the transient power controller 146 includes a throttle voltage generator 168 and a bias voltage modifier 170. The throttle voltage generator 168 develops a throttle voltage having an

amplitude responsive to the rate of change in the position of the throttle valve 74. More particularly, the throttle voltage generator 168 includes the winding 152 and a control current regulator 172 for energizing the winding 152 with a control current. The control current regulator 172 includes a control voltage generator 174 for producing a varying control voltage and a control current source 176 for developing a varying control current in response to the control voltage. As a result of the varying control current through the inductor 152, a throttle voltage is developed across the inductor 152 having an amplitude determined by the inductance of the winding 152.

The control voltage generator 174 includes a capacitor 178 which cooperates with a discharging circuit 180 and a charging circuit 182 to develop a control voltage at a junction 184. The discharging circuit 180 is connected with the control pulse generator 88 and in parallel with the capacitor 178 for discharging the capacitor 178 to clamp the control voltage at a fixed level in response to the absence of a control pulse from the control pulse generator 88. The charging circuit 182 is connected in series with the capacitor 178 for charging the capacitor 178 with a constant charging current to linearly increase the amplitude of the control voltage in response to the presence of a control pulse from the control pulse generator 88. The current source 176 is connected to the winding 152 for energizing the winding 152 with a control current having a linearly increasing magnitude in response to the linearly increasing amplitude of the control voltage at the junction 184. Since the magnitude of the energizing current varies at a constant rate of change, a throttle voltage is developed across the winding 152 at a junction 185 having an amplitude which is directly proportional to the inductance of the winding 152.

Specifically, the capacitor 178 is connected between the power line 40 and the junction 184. The clamping circuit or discharging circuit 180 includes an NPN junction transistor 186. The collector electrode of the transistor 186 is connected directly to the power line 40. The emitter electrode of the transistor 186 is connected directly to the junction 184. The base electrode of the transistor 186 is connected to a junction 188. A biasing resistor 190 is connected between the power line 40 and the junction 188. A temperature compensating diode 191 and a biasing resistor 192 are connected in series between the junction 188 and the ground line 42. Further, a turnoff diode 194 is connected between the junction 188 and the control line 90 which is connected to the control pulse generator 88.

The charging circuit 182 includes an NPN junction transistor 196. The collector electrode of the transistor 196 is directly connected to the junction 184. The emitter electrode of the transistor 196 is connected through a biasing resistor 198 to the ground line 42. The base electrode of the transistor 196 is connected to a junction 200. A biasing resistor 202 is connected between the power line 40 and the junction 200. A temperature compensating diode 204 and a biasing resistor 206 are connected in series between the junction 200 and the ground line 42.

The control current source 180 includes the combination of a PNP junction transistor 208 and an NPN junction transistor 210. The base electrode of the transistor 208 is connected to the junction 184. The collec-

tor electrode of the transistor 208 and the base electrode of the transistor 210 are connected together. The emitter electrode of the transistor 208 and the collector electrode of the transistor 210 are connected together through a variable limiting resistor 212 to the power line 40. The emitter electrode of the transistor 210 is connected to the junction 185. The variable inductor or winding 152 is connected between the junction 185 and the ground line 42. In addition, a spike suppression diode 214 is connected across the winding 152.

The operation of the throttle voltage generator 168 may be best understood by reference to FIGS. 3 and 5. When a control pulse C, as shown in FIG. 5a, is terminated by the control pulse generator 88 and is absent from the control line 90, the transistor 186 is rendered conductive in an emitter-follower mode through the biasing action of the resistors 190 and 192. With the transistor 186 in a conductive condition, the capacitor 178 is relatively discharged through the transistor 186. Hence, the control voltage E at the junction 184, as shown in FIG. 5b, is clamped at a base level determined by the conduction of the transistor 186. The transistor 196 is rendered conductive in a constant current mode through the biasing action of the resistors 198, 202 and 206. That is, the operating point of the transistor 196 is set in the active region between saturation and cutoff to draw a constant charging current out of the junction 184. However, the capacitor 178 remains relatively discharged through the transistor 186. With the control voltage E clamped at the base level, the transistors 208 and 210 in the current source 180 are rendered less conductive in a constant current mode. With the transistors 208 and 210 in a low conductive condition, the control current I through the resistor 212 is at a base value as shown in FIG. 5c. Since the control current I is substantially constant at the base value, the throttle voltage G developed across the winding 152 is substantially zero as shown in FIG. 5d. The diode 214 dissipates the flyback voltage developed across the winding 152 as the transistors 208 and 210 are turned off at the termination of each control pulse C.

When a control pulse C is initiated by the control pulse generator 88 and is present on the control line 90, the transistor 186 is rendered fully nonconductive through the turnoff action of the diode 194. With the transistor 186 turned off, the control voltage E at the junction 184 is unclamped. Accordingly, in response to the constant charging current defined by the transistor 196, the amplitude of the control voltage E linearly decreases from the base level. In other words, the control voltage E exhibits an amplitude which decreases at a constant rate of change. As the control voltage E decreases, the transistors 208 and 210 of the current source 180 are rendered more conductive in a constant current mode to develop a control current I through the limiting resistor 212. The magnitude of the control current I is inversely related to the amplitude of the control voltage E. Hence, the magnitude of the control current I linearly increases as the amplitude of the control voltage E linearly decreases. As a result, the control current I exhibits a magnitude which increases at a constant rate of change. The variable resistor 212 may be adjusted to set the relative magnitude of the control current I.

The current source 180 applies the control current I to energize the winding 152. As a result, the throttle voltage G developed across the winding 152 at the

junction 185 is given by the following conventional relationship:

$$G = L(di/dt)$$

where L is the inductance of the winding 152 and di/dt is the first derivative with respect to time T of the control current I. However, since the magnitude of the control current I varies at a constant rate of change, the first derivative di/dt of the control current I is a constant. The value of this constant is dependent upon the relative magnitude of the control current I as defined by the limiting resistor 212. Since the first derivative di/dt of the control current I is a constant, the amplitude of the throttle voltage G is directly proportional to the inductance L of the winding 152.

As previously described, the inductance L of the inductor 152 is a direct function of the rate of change in the position of the throttle valve 74 as measured by the transient power actuator 154 including the dashpot device 60. In response to opening of the throttle valve 74 during acceleration of the engine 10, the inductance L of the winding 152 rapidly increases to a peak maximum inductance L_m and thereafter gradually decreases back to a nominal inductance L_n . Similarly, in response to closing of the throttle valve 74 during deceleration of the engine 10, the inductance L of the winding 152 rapidly decreases to a peak minimum inductance L_o and thereafter gradually returns to the nominal inductance L_n . The return rate of the inductance L from the peak maximum inductance L_m and the peak minimum inductance L_o is determined by the time constant or response characteristic of the dashpot device 160. Preferably, this time constant is selected so that the inductance L of the winding 152 is essentially a constant over the length of any given control pulse C. As a result, the amplitude of the throttle voltage G is also essentially a constant for the duration of any given control pulse C. Of course, the presence of some series resistance in the winding 152 produces a slight rise in the amplitude of the throttle voltage G during each control pulse C. However, neglecting this minor aberration, the amplitude of the throttle voltage G is directly related to the rate of change in the position of the throttle valve 74 as represented by the inductance L of the winding 152.

The bias voltage modifier 170 shifts the level of the bias voltage B in the control pulse generator 88 to change the length of the control pulses in response to the amplitude of the throttle voltage G. The bias voltage modifier or compensation current regulator 170 includes a reference voltage generator 216, a compensation voltage generator 218 and a compensation current generator 220. The reference voltage generator 216 produces a reference voltage. The compensation voltage generator 218 develops a compensation voltage having an amplitude dependent upon the amplitude of the reference voltage and the amplitude of the throttle voltage. The compensation current generator 220 defines a compensation current having a magnitude which is a function of the amplitude of the compensation voltage. The compensation current is applied to the control pulse generator 88 to shift the level of the bias voltage B thereby to define the duration of the control pulses C as an inverse function of the magnitude of the compensation current.

Preferably, the reference voltage generator 216 is provided by a speed sensor including an integrating network 222 and a voltage divider network 224. The

integrating network 222 is connected to the timing pulse generator 80 via the timing line 82 to define an integrator voltage at a junction 226 having an amplitude directly related to the frequency of the timing pulses as determined by the speed of the engine 10. The voltage divider network 224 is responsive to the amplitude of the integrator voltage to define a speed voltage at a junction 228 having an amplitude directly proportional to the speed of the engine 10.

The compensation voltage generator 218 is provided by a differential amplifier connected between the junctions 185 and 228 for defining a compensation voltage at a junction 230 having an amplitude determined by the difference between the amplitude of the throttle voltage and the amplitude of the speed voltage. The compensation current generator 220 includes a constant current source 232 and a constant current sink 234. The current source 232 is connected to the junction 230 to develop a compensation current having a magnitude inversely related to the amplitude of the compensation voltage. The current sink 234 is connected to the junction 118 in the control pulse generator 88 via the output line 150 to draw a bias current out of the control pulse generator 88 having a magnitude equal to the magnitude of the compensation current. As a result, the level of the bias voltage in the control pulse generator 88 is varied in direct proportion to the rate of change in the position of the throttle valve 74 as indicated by the amplitude of the throttle voltage.

Specifically, the integrating network 222 includes a capacitor 236 connected between the junction 226 and the ground line 42. An integrating resistor 238 is connected across the capacitor 236 between the junction 226 and the ground line 42. An input resistor 240 and a turnoff diode 242 are connected in series between the junction 226 and the timing line 82. The voltage divider network 224 includes an NPN junction transistor 244. The base electrode of the transistor 244 is connected directly to the junction 226. The collector electrode of the transistor 244 is connected directly to the power line 40. A biasing resistor 246 is connected between the emitter electrode of the transistor 244 and the junction 228. A biasing resistor 248 is connected between the junction 228 and the ground line 42.

The differential amplifier 218 includes NPN junction transistors 250, 252 and 254. The base electrode of the transistor 250 is connected to a junction 256. A biasing resistor 258 is connected between the power line 40 and the junction 256. A temperature compensating diode 260 and a biasing resistor 262 are connected in series between the junction 256 and the ground line 42. The emitter electrode of the transistor 250 is connected through a biasing resistor 264 to the ground line 42. The collector electrode of the transistor 250 is connected to a junction 266 between a pair of like biasing resistors 268 and 270. The biasing resistor 268 is connected between the emitter electrode of the transistor 252 and the junction 266. The biasing resistor 270 is connected between the emitter electrode of the transistor 254 and the junction 266. The base electrode of the transistor 252 is connected directly to the junction 185 and the throttle voltage generator 168. The base electrode of the transistor 254 is connected to the junction 228 in the reference voltage generator or speed sensor 216. The collector electrode of the transistor 252 is connected to the junction 230. The collector electrode of the transistor 254 is connected directly to the power

line 40. A variable limiting resistor 272 and a temperature compensating diode 274 are connected in series between the power line 40 and the junction 230.

The constant current source 232 includes a PNP junction transistor 276 and an NPN junction transistor 278. The base electrode of the transistor 276 is connected to the junction 230 in the differential amplifier 218. The emitter electrode of the transistor 276 and the collector electrode of the transistor 278 are connected together through a variable limiting resistor 280 to the power line 40. The collector electrode of the transistor 276 and the base electrode of the transistor 278 are connected together. The emitter electrode of the transistor 278 is connected to the current sink 234.

The constant current sink 234 includes a pair of NPN junction transistors 282 and 284. The base electrode of the transistor 282 and the emitter electrode of the transistor 284 are connected together through a temperature compensating diode 286 to the ground line 42. The emitter electrode of the transistor 282 is likewise connected to the ground line 42. The collector electrode of the transistor 282 and the base electrode of the transistor 284 are connected together with the emitter electrode of the transistor 278 and the current source 232. The collector electrode of the transistor 284 is connected to the output line 150.

In conventional fashion, the integrating network 222 averages the rectangular timing pulses appearing on the timing line 82 to develop an integrator voltage at the junction 226. Since the frequency of the timing pulses is directly proportional to the speed of the engine 10, the amplitude of the integrator voltage is also a direct function of engine speed. The transistor 224 operates as an emitter-follower which acts as a variable resistance in the voltage divider network 224. The value of the resistance effectively provided by the transistor 224 is determined by the amplitude of the integrator voltage. As a consequence, the voltage divider network 224 defines a reference voltage or speed voltage at the junction 228 having an amplitude which is directly related to the amplitude of the integrator voltage. Hence, the amplitude of the speed voltage at the junction 228 is likewise directly proportional to the speed of the engine 10.

The differential amplifier 218 provides a compensation voltage at the junction 230 having an amplitude equal to the difference between the amplitude of the throttle voltage appearing at the junction 185 and the amplitude of the reference voltage or speed voltage appearing at the junction 228. More particularly, when a control pulse is terminated by the control pulse generator 88, the throttle voltage is absent from the junction 185. As a result, the transistor 252 is rendered fully nonconductive and the transistor 254 is rendered fully conductive by the reference voltage at the junction 228. With the transistor 252 turned off, the amplitude of the compensation voltage at the junction 230 is at a relatively high level.

In the compensation current generator 220, the transistors 276 and 278 of the constant current source 232 are rendered fully nonconductive by the compensation voltage at the junction 230 when the amplitude of the compensation voltage is at the relatively high level. With the current source 232 turned off, substantially no compensation current is drawn through the resistor 280. Due to the lack of compensation current, the transistors 282 and 284 in the constant current sink 234 are

likewise rendered fully nonconductive. With the current sink 234 turned off, substantially no bias current is drawn out of the output line 150. Consequently, the current sink 234 effectively appears as an extremely high resistance connected between the junction 118 of the control pulse generator 88 and the ground line 42. Of course, the control pulse generator 88 does not produce a control pulse during this time period.

When a control pulse is subsequently initiated by the control pulse generator 88, the throttle voltage is present at the junction 185. As a result, the relative conduction of the transistors 252 and 254 is dependent upon the relative amplitude of the throttle voltage appearing at the junction 185 and the amplitude of the reference voltage or speed voltage appearing at the junction 228. When the amplitude of the throttle voltage is below the amplitude of the reference voltage, the conduction of the transistor 254 is greater than the conduction of the transistor 252. Further, if the amplitude of the throttle voltage is sufficiently below the amplitude of the reference voltage, the transistor 252 is fully turned off and the transistor 254 is fully turned on to define a first fully switched condition. In this condition, the compensation voltage at the junction 230 is at a relatively high level as previously described. Conversely, when the amplitude of the throttle voltage is above the amplitude of the reference voltage, the conduction of the transistor 252 is greater than the conduction of the transistor 254. Moreover, if the amplitude of the throttle voltage is sufficiently above the amplitude of the reference voltage, the transistor 252 is fully turned on while the transistor 254 is fully turned off to define a second fully switched condition. In this condition, the compensation voltage at the junction 230 is at a relatively low level. Thus, the amplitude of the compensation voltage is inversely related to the amplitude of the throttle voltage as determined by the inductance of the winding 152. That is, the amplitude of the compensation voltage ranges from a relatively high level to a relatively low level as the amplitude of the throttle voltage ranges from below to above the amplitude of the reference voltage. The occurrence of the first and second fully switched conditions may be adjusted by varying the resistor 248 to shift the relative amplitude of the reference voltage with respect to the relative amplitude of the throttle voltage.

In the constant current source 232, the transistors 276 and 278 are rendered conductive by the compensation voltage at the junction 230 when the amplitude of the compensation voltage is below the relatively high level. With the current source 232 turned on, a compensation current is developed through the limiting resistor 280 and the transistor 278 having a magnitude inversely related to the amplitude of the compensation voltage. That is, as the amplitude of the compensation voltage decreases, the magnitude of the compensation current increases. The relative magnitude of the compensation current may be adjusted by varying the limiting resistor 280.

Due to the presence of the compensation current, the transistors 282 and 284 are rendered conductive in the constant current sink 234. Specifically, the current sink 234 is responsive to the application of the compensation current through the transistor 282 to draw a like bias current through the transistor 284 and the diode 286. In other words, the magnitude of the bias current equals the magnitude of the compensation current. The

bias current is drawn out of the junction 118 in the control pulse generator 88 through the output line 150. Accordingly, the current sink 234 effectively appears as a variable resistance connected between the junction 118 and the ground line 42.

Referring to FIGS. 1-3 and 5, the length of the control pulses C produced by the control pulse generator 88 is inversely related to the level of the bias voltage B at the junction 114. Further, the level of the bias voltage B at the junction 114 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 magnitude of the throttle voltage G at the junction 185 as determined in direct proportion to the inductance L of the winding 152. Accordingly, since the inductance L of the winding 152 is directly related to movement of the throttle valve 74, the length of the control pulses C produced by the control pulse generator 88 is a direct function of the rate of change in the position of the throttle valve 74. In this manner, the amount of fuel applied to the engine 10 is regulated to produce the rate of change in the power output of the engine called for by the rate of change in the position of the throttle valve 74.

More specifically, the length of the control pulses produced by the control pulse generator 88 is directly related to the amplitude of the throttle voltage at the junction 185 and the amplitude of the speed voltage at the junction 228. The amplitude of the speed voltage is directly proportional to the speed of the engine 10. In this manner, the amount of fuel delivered to the engine 10 is controlled in accordance with the rate of change in the position of the throttle valve 74 as modified in response to the speed of the engine 10. Hence, during both opening and closing of the throttle valve 74, the application of fuel to the engine 10 is inversely related to engine speed. This factor provides a much smoother transition in the power output of the engine 10 as the position of the throttle valve 74 is changed.

It will now be readily appreciated that the present invention provides a simple but effective technique for regulating the amount of fuel delivered to an internal combustion engine so as to produce a rate of change in the power output of the engine which parallels the rate of change in the position of the throttle valve. However, it is to be understood that the invention is not limited to the illustrated embodiment which is shown for demonstrative purposes only. Thus, 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 an adjustable throttle member for defining the power output of the engine as a function of the position of the throttle member, the combination comprising: a variable inductor; means connecting the throttle member with the inductor for varying the inductance of the inductor in response to a change in the position of the throttle member; and means connected with the inductor for energizing the inductor with a control current having a linearly varying magnitude to develop a throttle voltage across the inductor having an amplitude directly proportional to the inductance of the inductor; and means including fuel injection means connected between the inductor and the engine for regulating the amount of fuel applied to the engine in response to the

amplitude of the throttle voltage so that the delivery of fuel to the engine is controlled in dependence upon movement of the throttle member.

2. In an internal combustion engine system including an adjustable throttle member for defining the power output of the engine as a function of the position of the throttle member, the combination comprising: a variable inductor for developing a throttle voltage thereacross; means including dashpot means connected between the throttle member and the inductor for varying the inductance of the inductor in direct proportion to the rate of change in the position of the throttle member; means connected with the inductor for energizing the inductor with a control current having a magnitude which varies at a constant rate of change so that the amplitude of the throttle voltage is directly proportional to the rate of change in the position of the throttle member; and means including fuel injection means connected between the inductor and the engine for controlling the amount of fuel delivered to the engine in response to the amplitude of the throttle voltage so that the application of fuel to the engine is regulated in accordance with the rate of change in the position of the throttle member.

3. In an internal combustion engine system including an adjustable throttle member for defining the power output of the engine as a function of the position of the throttle member, the combination comprising: a variable inductor for developing a throttle voltage thereacross; position sensor means including dashpot means connected between the throttle member and the inductor for varying the inductance of the inductor in direct proportion to the rate of change in the position of the throttle member; current regulator means connected to the inductor for energizing the inductor with a control current having a magnitude which varies at a constant rate of change so that the amplitude of the throttle voltage is directly proportional to the rate of change in the position of the throttle member; speed sensor means connected with the engine for developing a speed voltage having an amplitude directly proportional to the speed of the engine; and means including fuel injection means connected with the engine and connected with the speed sensor means and the inductor for controlling the amount of fuel applied to the engine in response to the amplitude of the throttle voltage and in response to the amplitude of the speed voltage so that the delivery of fuel to the engine is regulated in accordance with the rate of change in the position of the throttle member and in accordance with the speed of the engine.

4. In an internal combustion engine system including a throttle member having an adjustable position; control pulse generator means for producing control pulses in synchronization with the operation of the engine, the control pulse generator means cooperating with the throttle member to define the duration of the control pulses as a function of the position of the throttle member, the control pulse generator means including bias voltage generator means for also 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: a variable inductor for developing a throttle voltage thereacross; position sensor means connected between the throttle member and the inductor for varying the inductance of the inductor in direct proportion to the rate of change in the position of the throttle member; current regulator means connected with the inductor for energizing the inductor with a control current having a linearly varying magnitude such that the throttle voltage is directly proportional to the rate of change in the position of the throttle member; and bias voltage modifier means connected between the inductor and the bias voltage generator means for altering the amplitude of the bias voltage as a function of the amplitude of the throttle voltage thereby to tailor the amount of fuel delivered to the engine in response to the rate of change in the position of the throttle member.

5. In an internal combustion engine system including timing pulse generator means for producing timing pulses having a frequency proportional to the speed of the engine; a throttle member having a variable position; control pulse generator means for producing control pulses in response to the occurrence of the timing pulses, the control pulse generator means cooperating with the throttle member for defining the duration of the control pulses as a function of the position of the throttle member, the control pulse generator means including bias voltage generator means for also defining the duration of the control pulses as a function of the level 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: a variable inductor for developing a throttle voltage thereacross; position sensor means including dashpot means connected between the throttle member and the inductor for varying the inductance of the inductor in direct proportion to the rate of change in the position of the throttle member; current regulator means connected to the inductor for energizing the inductor with a control current having a magnitude which varies at a constant rate of change so that the amplitude of the throttle voltage is directly proportional to the rate of change in the position of the throttle member; speed sensor means connected with the timing pulse generator means for developing a speed voltage having an amplitude proportional to the frequency of the timing pulses; and bias voltage modifier means connected between the inductor and the bias voltage generator means for altering the level of the bias voltage in response to the amplitude of the throttle voltage and in response to the amplitude of the speed voltage so that the delivery of fuel to the engine is regulated in accordance with the rate of change in the position of the throttle member and in accordance with the speed of the engine.

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