United States Patent

[11] 3,623,459

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[21] Appl. No. 39,720
[22] Filed May 22, 1970
[45] Patented Nov. 30, 1971
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[54] **FUEL SUPPLY CONTROL SYSTEM HAVING ACCELERATION COMPENSATION**
6 Claims, 3 Drawing Figs.

[52] U.S. Cl. .... 123/32 EA, 123/119, 123/139 E
[51] Int. Cl. F02m 51/00
[50] Field of Search .... 123/32 AE, 32 EA, 119, 139.17, 140.3

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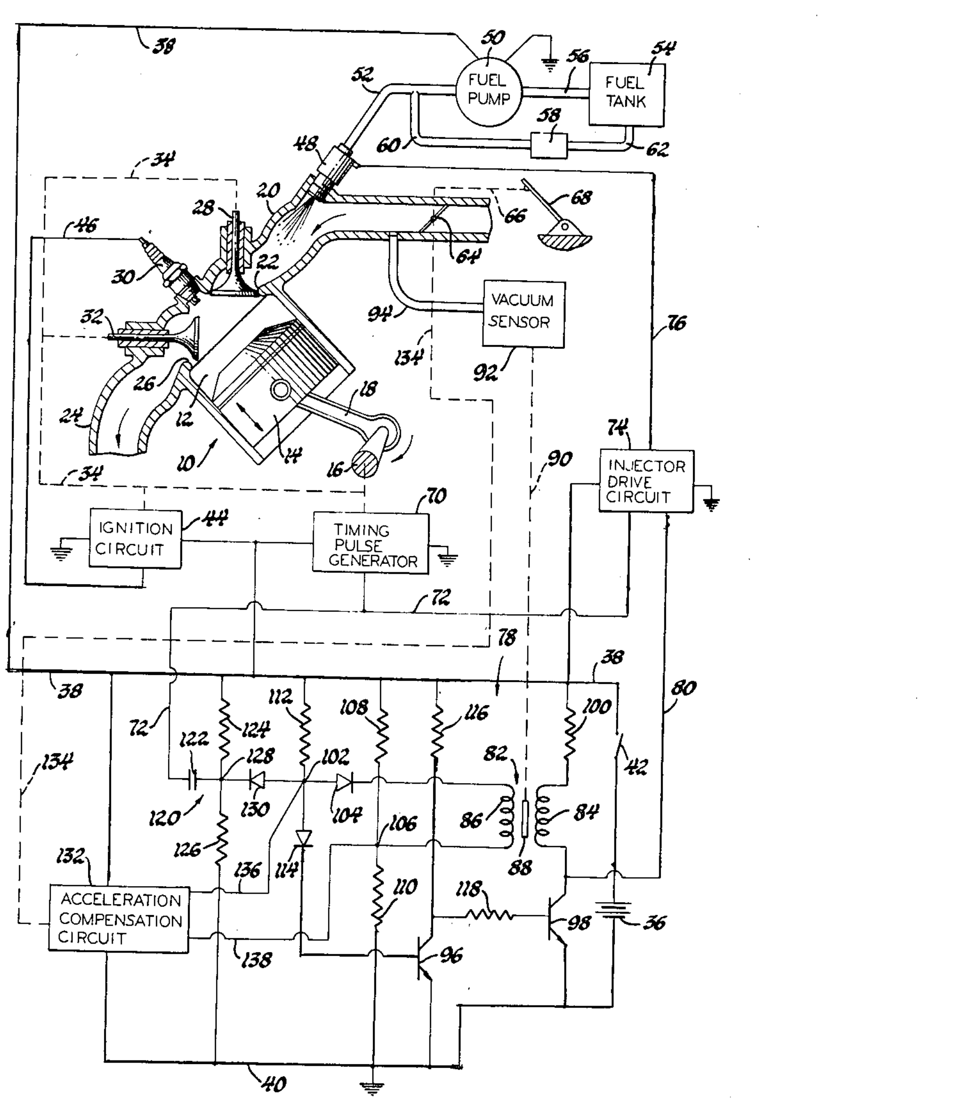
ABSTRACT: An electronic fuel injection control system for an internal combustion engine includes an acceleration compensation circuit for increasing the amount of fuel applied to the engine during acceleration. In the control system, control pulses are produced in response to the occurrence of trigger pulses. The trigger pulses are developed in synchronization with the operation of the engine. Fuel is applied to the engine at a constant rate for the duration of each of the control pulses. The duration of the control pulses is determined as a function of a bias voltage. During acceleration of the engine, the acceleration compensation circuit varies the bias voltage so as to increase the duration of the control pulses by a substantially constant amount during an initial time period and by a linearly decreasing amount during a subsequent time period. In addition, the acceleration compensation circuit develops an extra trigger pulse in response to the onset of acceleration. Further, the acceleration compensation circuit is completely insensitive to the contact bounce of a sensing switch which detects acceleration of the engine.



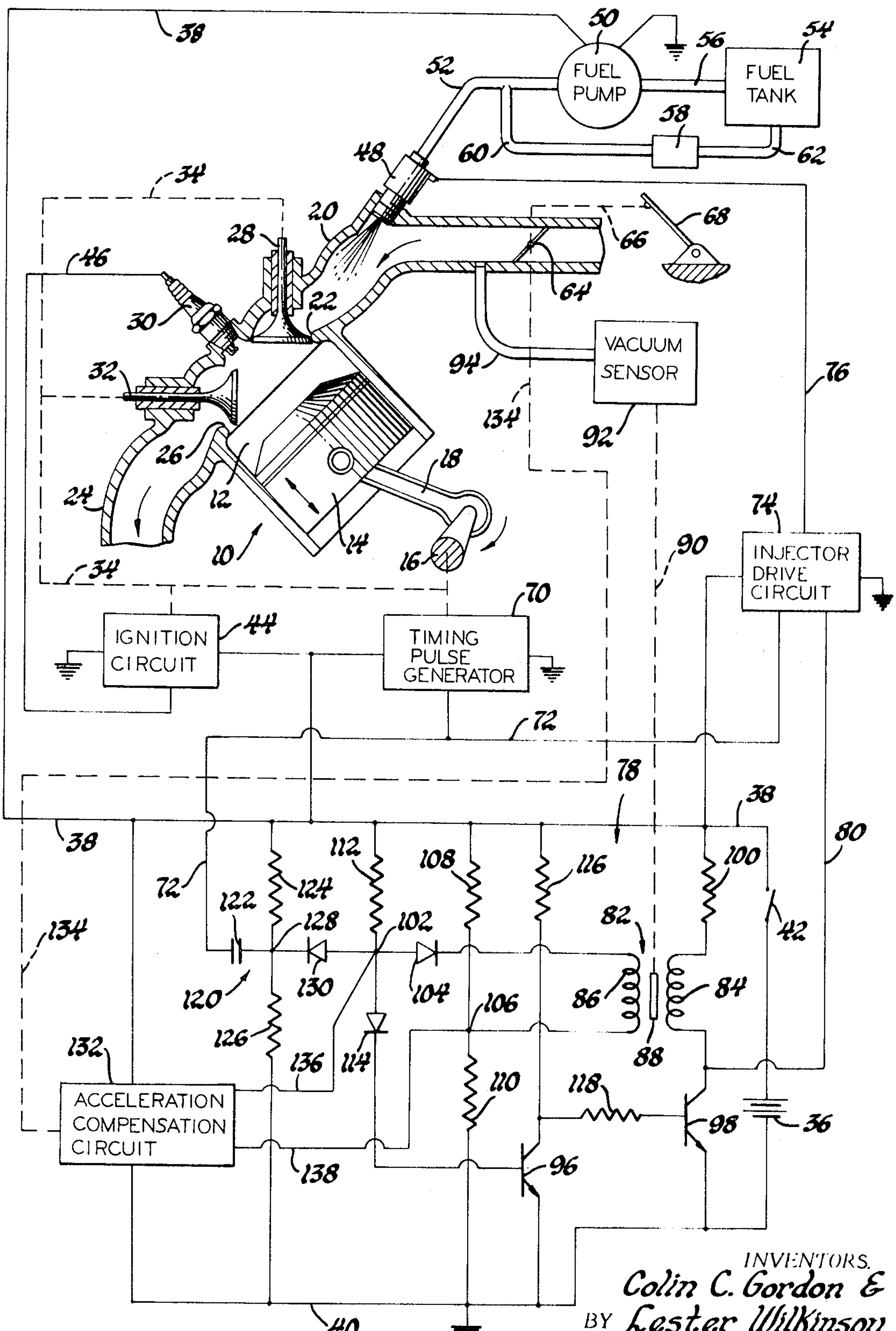


Fig.1

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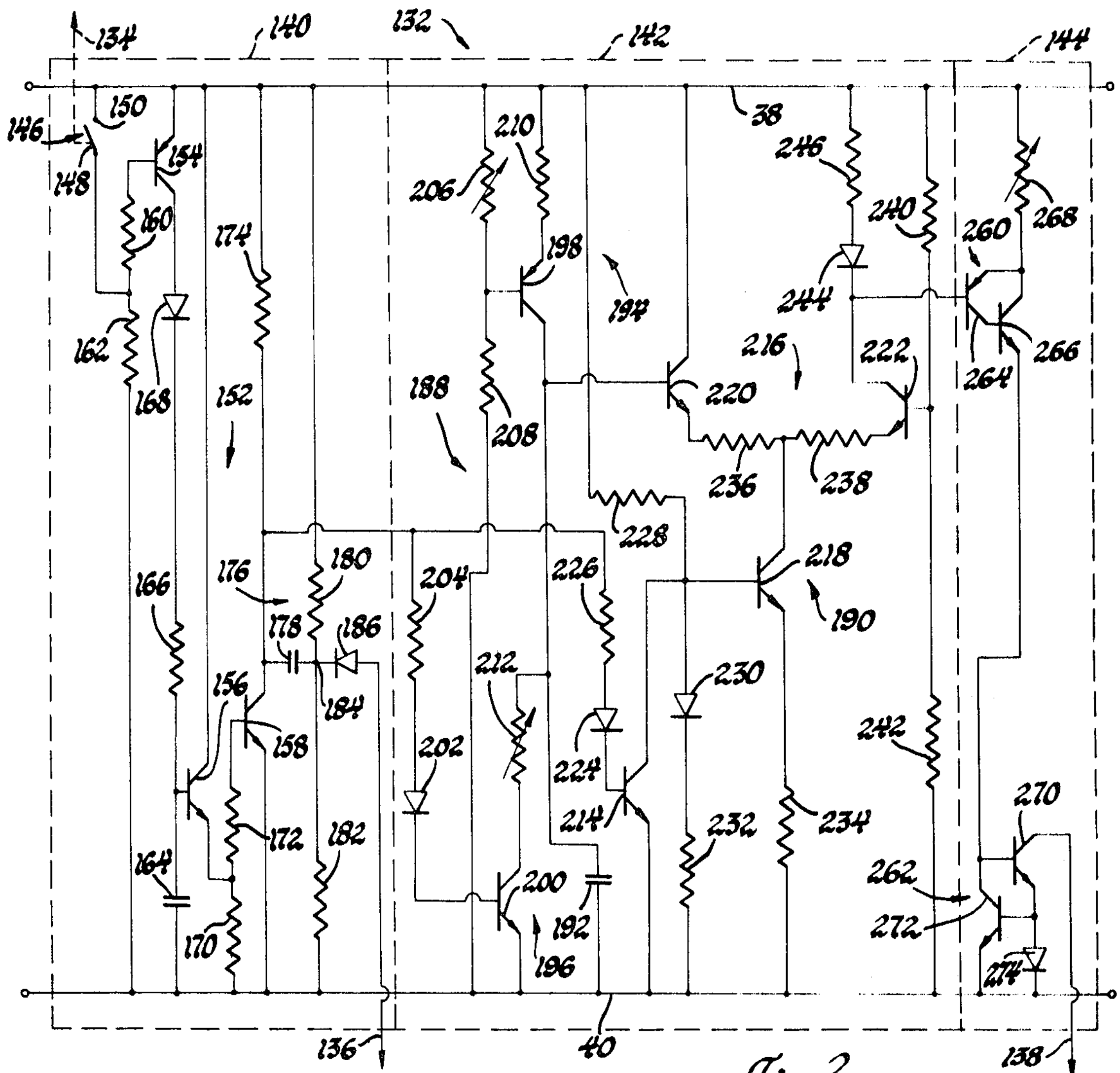

Fig.2

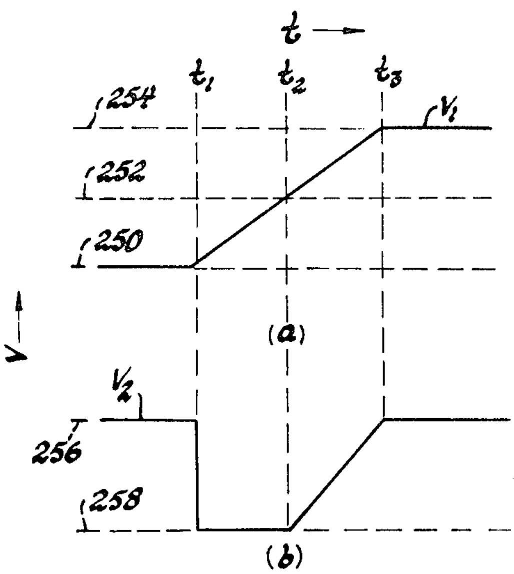

Fig.3

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FUEL SUPPLY CONTROL SYSTEM HAVING ACCELERATION COMPENSATION

The present invention relates to a fuel supply control system for an internal combustion engine. More particularly, the invention relates to an electronic fuel injection control system for increasing the amount of fuel applied to an internal combustion engine in response to an increase in the demand for power from the engine. Of course, assuming the engine load remains relatively constant, an increase in the demand for power from the engine will result in acceleration of the engine. Hence as referred to hereinafter, the phenomena of engine acceleration is subject to the condition that the engine load remain relatively constant.

In one well-known type of electronic fuel injection control system, control pulses are produced in response to the occurrence of trigger pulses. The trigger pulses are developed in synchronization with the operation of the engine. Fuel is applied to the engine at a constant rate for the duration of each of the control pulses. The duration of the control pulses is at least partially determined as a function of a bias voltage. The present invention provides an acceleration compensation circuit for application to such an electronic fuel injection control system.

According to one aspect of the invention, an acceleration-detecting device is activated in response to acceleration of the engine. The acceleration-detecting device includes a trigger circuit for providing an extra trigger pulse when the detecting device is activated. The extra trigger pulse substantially instantaneously increases the amount of fuel applied to the engine at the onset of acceleration. Consequently, there is no discernible stumble or hesitation in the engine output response when acceleration is initiated.

As contemplated by another aspect of the invention, the acceleration-detecting device includes a sensing switch having mechanical contacts which are actuated in response to acceleration of the engine. In addition, the acceleration-detecting device includes a sensing circuit which is responsive to an actuation of the sensing switch contacts for enabling an increase in the amount of fuel applied to the engine. Further, the sensing circuit includes a timing network for rendering the sensing circuit substantially unresponsive to a subsequent actuation of the sensing switch until after expiration of a predetermined time delay period following a preceding actuation of the sensing switch. Accordingly, the sensing circuit is completely insensitive to jittering or bouncing of the sensing switch contacts as a result of actuation.

In a further aspect of the invention, a voltage generating circuit is responsive to activation of the acceleration-detecting device to produce a compensation voltage having an initial step portion and a subsequent ramp portion. More specifically, when the acceleration-detecting device is activated, the compensation voltage initially instantaneously shifts from a first compensation level to a second compensation level where it remains substantially constant over a first time period, and the compensation voltage subsequently linearly returns to the first compensation level over a second time period.

As contemplated by yet another aspect of the invention, the voltage-generating circuit includes a control voltage-generating circuit and a compensation voltage-generating circuit. The control voltage-generating circuit includes a constant current integrator for producing a control voltage which linearly varies from a first control level through a second control level to a third control level. The compensation voltage-generating circuit includes a differential amplifier for defining the compensation voltage in such a manner that the first time period extends from the time the control voltage departs from the first control voltage until it arrives at the second control level and the second time period extends from the time the control voltage departs from the second control level until it arrives at the third control level.

In a still further aspect of the invention, a bias voltage-changing circuit varies the bias voltage of the electronic fuel injection control system in response to the compensation voltage to increase the duration of the control pulses by a substantially constant amount during the first time period and by a linearly decreasing amount during the second time period. In other words, the duration of the control pulses is instantaneously increased from a nominal uncompensated value to a maximum compensated value in response to the step portion of the compensation voltage and is gradually decreased from the maximum compensated value to the nominal uncompensated value in response to the ramp portion of the compensation voltage.

As determined by the duration of the control pulses, the amount of fuel applied to the engine is correspondingly increased during acceleration. In particular, the applied fuel is increased by a substantially constant amount during the first time period so as to match the increased fuel demand of the engine as it accelerates from a lower speed to a higher speed. Further, the applied fuel is increased by a linearly decreasing amount during the second time period so as to match the decreased fuel demand of the engine as it arrives at the higher speed. Accordingly, the engine output response exhibits a desirable steady surge at the initiation of acceleration and does not exhibit an objectionable sudden dip at the termination of acceleration.

These and other aspects and advantages of the invention will become more apparent by reference to the following detailed description of a preferred embodiment when considered in conjunction with the accompanying drawing, in which:

FIG. 1 is a schematic diagram of a fuel supply control system for an internal combustion engine incorporating the principles of the invention.

FIG. 2 is a schematic diagram of an acceleration compensation circuit incorporating the principles of the invention.

FIG. 3 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 a 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** to 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 cam shaft. An electrical power supply is provided by the vehicle battery **36** which is connected between a power line **38** and a ground line **40** through the vehicle ignition switch **42**. A conventional ignition circuit **44** is electrically connected to the power line **38** and is mechanically coupled with the crankshaft **16**. 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 operation of the engine **10**. Hence, the ignition circuit **44** combines with the ignition switch **42** and the spark plug **30** to form an ignition system.

A fuel injector **48** is mounted on the intake manifold **20** for injecting fuel into the intake manifold **20** at a constant flow rate when the injector **48** is energized. Conventionally, the fuel injector **48** may include a valve having a plunger which is driven to a fully open position against a bias spring in response to energization of a solenoid and which is driven to a fully closed position by the bias spring when the solenoid is deenergized. However, it is to be understood that the fuel injector 48 may be virtually any suitable constant flow rate valve.

A fuel pump 50 is connected to the vehicle fuel tank 54 by a conduit 56 for pumping fuel from the fuel tank 54 to the fuel injector 48. Preferably, the fuel pump 50 is connected to the power line 38 to be electrically driven from the vehicle battery 36. Alternately, the fuel pump 50 could be connected to the crankshaft 16 to be mechanically driven from the engine 10. A pressure regulator 58 is connected to the conduit 52 by a conduit 60 and is connected to the fuel tank 54 by a conduit 62 for regulating the pressure of the fuel applied to the fuel injector 48. Thus, the fuel injector 48 combines with the fuel tank 54, the fuel pump 50, and the pressure regulator 58 to form a fuel supply system.

A throttle 64 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 64. The throttle 64 is connected through a suitable linkage 66 with the vehicle accelerator pedal 68. As the accelerator pedal 68 is depressed, the throttle 64 is opened to increase the flow of air into the intake manifold 20. Conversely, as the accelerator pedal 68 is released, the throttle 64 is closed 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 an 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 64. As previously described, the position of the accelerator pedal 68 controls the position of the throttle 64.

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 downward within the combustion chamber 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. 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 combustion chamber 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 an 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 fuel supply control system.

A timing pulse generator 70 is coupled with the crankshaft 16 for developing timing pulses having a frequency which is proportional to and synchronized with the rotating speed of the crankshaft 16. The timing pulses are applied to a timing line 72. Preferably, the timing pulse generator 70 is some type of inductive speed transducer followed by a bistable circuit. However, the timing generator 70 may be virtually any suitable pulse producing device such as a multiple contact rotary switch.

An injector drive circuit 74 is connected to the power line 38 and to the timing line 72. Further, the injector drive circuit 74 is connected through an injection line 76 to the fuel injector 48. The injector drive circuit 74 is responsive to the timing pulses produced by the timing pulse generator 70 to energize the fuel injector valve 48 in synchronization with the speed of the crankshaft 16 in much the same manner as the ignition circuit 44 energizes the spark plug 30. The length of time for which the fuel injector 48 is energized by the drive circuit 74 is determined by the width or duration of control pulses produced by a modulator or control pulse-generating circuit 78 which will be more fully described later. The control pulses are applied by the control pulse-generating circuit 78 to the injector drive circuit 74 over a control line 80 in synchronization with the timing pulses produced by the timing pulse generator 70. In other words, the injector drive circuit 74 is responsive to the coincidence of a timing pulse and a control pulse to energize the fuel injector 48 for the duration or width of the control pulse.

The injector drive circuit 74 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 74 also select which one or ones of the fuel injectors 48 are to be energized on each respective timing pulse. As an example, where the fuel injectors 48 are mounted on the intake manifold 20, they may be divided into two separate groups which are alternately energized on successive ones of the timing pulses. Conversely, where the fuel injectors 48 are mounted directly on additional cylinders 12, the timing pulses may be applied to operate a counter which individually selects the fuel injectors 48 for energization.

The control pulse generating circuit 78 is provided by a monostable multivibrator or blocking oscillator. The blocking oscillator 78 includes a control transducer 82 having a primary winding 84 and a secondary winding 86 which are variably inductively coupled through a movable magnetizable core 88. The deeper the core 88 is inserted into the primary and secondary windings 84 and 86, the greater the inductive coupling between the primary winding 84 and the secondary winding 86. The movable core 88 is mechanically connected through a suitable linkage 90 with a vacuum sensor 92. The vacuum sensor 92 communicates with the intake manifold 20 of the engine 10 downstream from the throttle 64 through a conduit 94 thereby to monitor the negative pressure within the intake manifold 20. The vacuum sensor 92 moves the core 88 within the control transducer 82 to regulate the inductive coupling between the primary and secondary windings 84 and 86 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 64, the core 88 is inserted deeper within the control transducer 82 to proportionately increase the inductive coupling between the primary winding 84 and the secondary winding 86.

The blocking oscillator 78 further includes a pair of NPN-junction transistors 96 and 98. The primary winding 84 is connected from the collector electrode of the transistor 98 through a limiting resistor 100 to the power line 38. The secondary winding 86 is connected from an input junction 102 through a steering diode 104 to a bias junction 106 between a pair of biasing resistors 108 and 110 which are connected in series between the power line 38 and the ground line 40. A biasing resistor 112 is connected between the junction 102 and the power line 38. The base electrode of the transistor 96 is connected through a steering diode 114 to the junction 102. The emitter electrodes of the transistors 96 and 98 are connected directly to the ground line 40. The collector electrode of the transistor 96 is connected through a biasing resistor 116 to the power line 38 and is connected through a biasing resistor 118 to the base electrode of the transistor 98.

A differentiator 120 is provided by a capacitor 122 and a pair of resistors 124 and 126. The resistors 124 and 126 are connected in series between the power line 38 and the ground line 40. The capacitor 122 is connected from the timing line 72 to a junction 128 between the resistors 124 and 126. A steering diode 130 is connected from the junction 128 between the biasing resistors 124 and 126 to the input junction 102. In operation, the timing pulses are applied through the timing line 72 to the differentiator 120. The differentiator 120 develops negative trigger pulses at the junction 128 in response to the timing pulses. The trigger pulses are applied to the input junction 102 through the diode 130. Thus, it will be apparent that the differentiator 120 combines with the timing generator 70 to form a trigger pulse-generating circuit.

The modulator or control pulse-generating circuit 78 is generally well known in the fuel injection art. Accordingly, since it is only incidental to the present invention, the operation of the control pulse-generating circuit 78 will not be described in great detail. It will be readily appreciated that various other types of pulse-generating circuits could be employed in place of the monostable blocking oscillator 78.

In operation, the monostable multivibrator or blocking oscillator 78 switches from a stable state to an unstable state in response to a decrease in the voltage at the input junction 102 below a predetermined threshold level. The voltage appearing at the junction 102 comprises a feedback voltage provided by the control transducer 82 and a bias voltage provided by the biasing resistors 108, 110 and 112. Specifically, when the voltage at the junction 102 rises above the threshold level, the transistor 96 is rendered fully conductive through the coupling action of the diode 114 and the transistor 98 is rendered fully nonconductive through the biasing action of the resistor 118.

With the feedback voltage absent, the bias voltage provided by the resistors 108, 110 and 112 normally maintains the voltage at the junction 102 above the threshold level so that the transistor 96 is normally turned on and the transistor 98 is normally turned off. However, when a negative trigger pulse arrives at the junction 102, the voltage at the junction 102 immediately drops below the threshold level. Consequently, the transistor 96 is turned off through the coupling action of the diode 114 and the transistor 98 is turned on through the biasing action of the resistors 116 and 118. With the transistor 98 turned on, a control pulse is initiated on the control line 80. The level of the control pulse is defined by the saturation voltage drop of the transistor 98.

With the transistor 98 turned on, a current is established in the primary winding 84 of the control transducer 82 to develop the feedback voltage across the secondary winding 86 of the control transducer 82. The feedback voltage initially instantaneously decreases from the level of the bias voltage to a lower level and subsequently gradually increases back to the level of the bias voltage. The feedback voltage is coupled through the diode 104 to the junction 102 to hold the voltage at the junction 102 below the threshold level so that the transistor 96 remains turned off and the transistor 98 remains turned on.

The lower level of the feedback voltage is determined by the inductive coupling between the primary and secondary windings 84 and 86 of the control transducer 82. In turn, the inductive coupling between the primary and secondary windings 84 and 86 is defined by the position of the movable core 88. The rate at which the feedback voltage increases from the lower level back to the level of the bias voltage is fixed by the L/R time constant of the primary winding 84 and the limiting resistor 100. As the feedback voltage increases, the voltage at the junction 102 eventually rises above the threshold level. Accordingly, the transistor 96 is turned on and the transistor 98 is turned off. With the transistor 98 turned off, the control pulse on the control line 80 is terminated. Thus, the duration of the control pulse appearing on the control line 80 is determined by the vacuum sensor 92 and the control transducer 82 as an inverse function of the vacuum within the intake manifold 20 of the engine 10.

An acceleration compensation circuit 132 is connected between the power line 38 and the ground line 40. The acceleration compensation circuit 132 includes an input connected with the throttle 64 through a suitable linkage 134. Correspondingly, the acceleration compensation circuit 132 includes one output connected with the input junction 102 in the control pulse-generating circuit 78 through an output line 136 and includes another output connected with the bias junction 106 in the control pulse-generating circuit 78 through an output line 138. In a manner to be more fully described later, the acceleration compensation circuit 132 is responsive to acceleration of the engine 10 for regulating the operation of the control pulse-generating circuit 78 to develop a single additional control pulse and to increase the duration of the control pulses thereby to increase the amount of fuel applied to the engine 10.

Referring to FIG. 2, the acceleration compensation circuit 132 includes a power-detecting section or acceleration-detecting section 140, a voltage-generating section 142, and a bias voltage-changing section 144. The acceleration-detecting section 140 includes a sensing switch 146 having a pair of mechanical switch contacts 148 and 150 which are operable from a normally closed or unactuated position to an opened or actuated position in response to an increase in the demand for power from the engine 10. As previously described, the sensing switch 146 may be a position switch connected with the throttle 64 through the linkage 134 for actuation as the throttle 64 is opened to initiate acceleration of the engine 10. Alternately, the sensing switch 146 may be a pressure switch connected with the intake manifold 20 for actuation when the vacuum within the intake manifold 20 rapidly decreases as the throttle 64 is opened to initiate acceleration of the engine 10. In either event, the contacts 148 and 150 of the sensing switch 144 are driven from the closed position to the opened position in response to the onset of engine acceleration.

In addition, the acceleration-detecting section 140 includes a sensing circuit 152 comprising a PNP-junction transistor 154 and a pair of NPN-junction transistors 156 and 158. The base electrode of the transistor 154 is connected through a pair of biasing resistors 160 and 162 to the ground line 40. The contacts 148 and 150 of the sensing switch 146 are connected between the power line 38 and the junction between the biasing resistors 160 and 162. The emitter electrode of the transistor 154 is connected directly to the power line 38. A timing capacitor 164 is connected between the base electrode of the transistor 156 and the ground line 40. A charging or limiting resistor 166 is connected in series with a turnoff diode 168 between the base electrode of the transistor 156 and the collector electrode of the transistor 154. The collector electrode of the transistor 156 is connected directly to the power line 38. The emitter electrode of the transistor 156 is connected through a discharging resistor 170 to the ground line 40 and is connected through a biasing resistor 172 to the base electrode of the transistor 158. The collector electrode of the transistor 158 is connected through a limiting resistor 174 to the power line 38. The emitter electrode of the transistor 158 is connected directly to the ground line 40.

Further, the acceleration-detecting section 140 includes a trigger circuit or differentiator 176 comprising a capacitor 178 and a pair of resistors 180 and 182. The resistors 180 and

182 are connected in series between the power line 38 and the ground line 40. The capacitor 178 is connected between the collector electrode of the transistor 158 and a junction 184 between the resistors 180 and 182. A steering diode 186 is connected between the junction 184 in the differentiator 176 and the output line 136 which is connected to the input junction 102 in the control pulse-generating circuit 78.

In operation, when the contacts 148 and 150 of the sensing switch 146 are closed to the unactuated position, the sensing circuit 152 is driven to a first or stable state and the acceleration-detecting section 140 assumes a deactivated condition. Since the sensing switch contacts 148 and 150 are closed in the unactuated position, the biasing resistors 160 and 162 render the transistor 154 fully nonconductive. With the transistor 154 turned off, the transistor 156 is turned off through the biasing action of the resistor 166 and the diode 168. Likewise, with the transistor 156 turned off, the transistor 158 is turned off through the biasing action of the resistors 170 and 172.

When the contacts 148 and 150 of the sensing switch 146 are opened to the activated position in response to acceleration of the engine 10, the sensing circuit 152 is driven to a second or unstable state and the acceleration detecting section 140 assumes an activated condition. Since the sensing switch contacts 148 and 150 are opened in the actuated position, the biasing resistors 160 and 162 render the transistor 154 fully conductive. With the transistor 154 turned on, the timing capacitor 164 charges rapidly through the charging resistor 166 and the diode 168 above the threshold voltage of the transistor 156. As the voltage on the capacitor crosses the threshold voltage of the transistor 156, the transistor 156 is rendered fully conductive. With the transistor 156 turned on, the transistor 158 is rendered fully conductive through the biasing action of the resistor 172. With the transistor 158 turned on, a detecting pulse is produced at the collector electrode of the transistor 158. The level of the detecting pulse is defined by the saturation voltage drop of the transistor 158.

In a conventional manner, the trigger circuit or differentiator 176 develops a negative trigger pulse at the junction 184 in response to the detecting pulse produced at the collector electrode of the transistor 158. The diode 186 applies the extra trigger pulse over the output line 136 to the input junction 102 in the control pulse-generating circuit 78. Assuming the extra trigger pulse does not arrive at the input junction 102 in coincidence with a normal trigger pulse, the control pulse-generating circuit 78 produces an extra control pulse corresponding to the extra trigger pulse. Accordingly, the amount of fuel applied to the engine 10 is substantially instantaneously increased in response to an increase in the demand for power from the engine 10. The extra control pulse serves to eliminate any stumble or hesitation in the engine output response caused by a time lag between the opening of the throttle 64 and an increase in the amount of fuel applied to the engine 10.

As long as the contacts 148 and 150 of the sensing switch 146 are opened in the actuated position in response to continued acceleration, the sensing circuit 152 is kept in the second state and the acceleration-detecting section 140 remains in the activated condition. When the sensing switch contacts 148 and 150 are subsequently closed to the unactuated position at the termination of acceleration, the sensing circuit 152 is driven to the first or stable state and the detecting section 140 again assumes the deactivated condition, but not immediately. Since the transistor 154 is turned off as the sensing switch 146 is returned to the unactuated position, the timing capacitor 164 discharges through the base-emitter junction of the transistor 156 and the discharging resistor 168 to the ground line 40. Further, the capacitor 164 also discharges somewhat through the biasing resistor 172 and the base-emitter junction of the transistor 158. The discharge of the capacitor 164 keeps the transistors 156 and 158 turned on until after the expiration of a predetermined time delay period following the closure of the sensing switch contacts 148 and 150 to the unactuated position. The time delay period extends from the time the sensing switch contacts 148 and 150 are closed until the time the voltage in the capacitor 164 falls below the threshold level of the transistor 156. Thus, the timing capacitor 164 combines primarily with the resistance of the base-emitter junction of the transistor 156 and the discharging resistor 170 to provide a timing network for determining the time delay period.

During the time delay period, the sensing circuit 152 is effectively insensitive to a subsequent actuation of the sensing switch 146. If the sensing switch contacts 148 and 150 are opened to the actuated position during the time delay period, the sensing circuit 152 merely remains in the second or unstable state. However, in this event, the capacitor 164 is again fully charged so that the expiration of the time delay period is started anew. Hence, the sensing circuit 152 is unresponsive to a subsequent actuation of the sensing switch 146 until after the expiration of the time delay period following a preceding actuation of the sensing switch 146. Consequently, any bouncing or jittering of the contacts 148 and 150 as the sensing switch 146 is returned to the unactuated position does not affect the sensing circuit 152.

The voltage-generating section 142 of the acceleration compensation circuit 132 includes a control voltage-generating circuit 188 and a compensation voltage-generating circuit 190. The control voltage-generating circuit 188 includes a control capacitor 192 which is connected with a current regulating or charging circuit 194 and with a voltage regulating or discharging circuit 196. The charging circuit 194 includes a PNP-junction transistor 198 and the discharging circuit 196 includes an NPN-junction transistor 200. The base electrode of the transistor 200 is connected through a turnoff diode 202 and a biasing resistor 204 to the collector electrode of the transistor 158 in the sensing circuit 152. The emitter electrode of the transistor 200 is connected directly to the ground line 40. The base electrode of the transistor 198 is connected to a junction between a variable biasing resistor 206 and a fixed biasing resistor 208. The resistors 206 and 208 are connected in series between the power line 38 and the ground line 40. The emitter electrode of the transistor 198 is connected through a limiting resistor 210 to the power line 38. The control capacitor 192 is connected from the ground line 40 directly to the collector electrode of the transistor 198 and indirectly to the collector electrode of the transistor 200 through a variable limiting resistor 212.

The compensation voltage-generating circuit 190 includes an NPN-junction transistor 214 and a balanced differential amplifier 216. The differential amplifier 216 includes NPN-junction transistors 218, 220 and 222. The base electrode of the transistor 214 is connected through a turnoff diode 224 and a biasing resistor 226 to the collector electrode of the transistor 158 in the sensing circuit 152. The emitter electrode of the transistor 214 is connected directly to the ground line 40. The collector electrode of the transistor 214 is connected directly to the base electrode of the transistor 218 in the differential amplifier 216.

In the differential amplifier 216, the base electrode of the transistor 218 is connected through a biasing resistor 228 to the power line 38 and through a temperature-compensating diode 230 and a biasing resistor 232 to the ground line 40. The emitter electrode of the transistor 218 is connected through a biasing resistor 234 to the ground line 40. The collector electrode of the transistor 218 is connected to a junction between a pair of like biasing resistors 236 and 238 which are connected in series between the emitter electrodes of the transistor 220 and 222. The base electrode of the transistor 220 is connected to the control capacitor 192. The collector electrode of the transistor 220 is connected directly to the power line 38. The base electrode of the transistor 222 is connected to a junction between a pair of biasing resistors 240 and 242 which are connected in series between the power line 38 and the ground line 40. The collector electrode of the transistor 222 is connected through a temperature-compensating diode 244 and a limiting resistor 246 to the power line 38.

In operation, a control voltage V_1, as shown in FIG. 3*a*, is established across the control capacitor **192**. Acceleration of the engine **10** is initiated at time t_1. Before time t_1, the transistor **198** is normally rendered conductive in a constant current mode at an operating point somewhere between saturation and cutoff through the biasing action of the resistors **206** and **208**. With the transistor **198** operating in a constant current mode, a constant charging current is applied to the control capacitor **192** through the limiting resistor **210** and the transistor **198**. The precise magnitude of the constant charging current may be regulated by adjusting the resistance of the variable biasing resistor **206**.

Further, before time t_1, the sensing circuit **150** is driven to the first state in response to the absence of engine acceleration. Hence, with the transistor **156** turned off, the transistor **200** is rendered fully conductive through the biasing action of the resistors **174** and **204** and the diode **202**. With the transistor **200** turned on, the control voltage V_1 across the control capacitor **192** is clamped at a first or lower control level **250** through the limiting resistor **212** and the transistor **200**. The exact magnitude of the lower control level **250** may be regulated by adjusting the resistance of the variable resistor **212**.

At time t_1, the sensing circuit **152** is driven to the second state in response to the occurrence of engine acceleration. Thus, with the transistor **158** turned on, the transistor **200** is rendered fully nonconductive through the biasing action of the resistor **204** and the diode **202**. With the transistor **200** turned off, the control voltage V_1 across the control capacitor **192** is unclamped. Accordingly, the capacitor **192** charges from the constant charging current provided by the transistor **198** through the resistor **210**. As a result, the control voltage V_1 increases linearly from the first or lower control level **250** at time t_1, through a second or intermediate control level **252** at time t_2, to a third or upper control level **254** at time t_3. Hence, the control capacitor **192** combines primarily with the transistor **198** to form a constant current integrator for producing the linear control voltage V_1 when enabled in response to the switching of the transistor **200** at the onset of acceleration of the engine **10**.

As previously described, the first or lower control level **250** is defined as that voltage level at which the control capacitor **192** is clamped by the transistor **200** and the resistor **212**. The second or intermediate control level **252** is defined as that voltage level at which the transistor **220** begins to turn on and the transistor **222** begins to turn off in the differential amplifier **216**. This voltage level is determined by the voltage divider action of the biasing resistors **240** and **242** in conjunction with the gain of the differential amplifier **216**. The third or upper control level **254** is defined as that voltage level at which the transistor **220** is rendered fully conductive and the transistor **222** is rendered fully nonconductive. Since no limiting resistor is connected to the collector electrode of the transistor **220** in the differential amplifier **216**, the upper control level **254** is approximately equal to the voltage level on the power line **38**. However, it will be readily appreciated that the upper control level **254** could be less than the voltage level on the power line **38** depending upon the biasing of the transistor **220**.

The control voltage V_1 established across the control capacitor **192** is applied to the base electrode of the transistor **220** in the differential amplifier **216**. A compensation voltage V_2, as shown in FIG. 3*b*, is developed at the collector electrode of the transistor **222**. More specifically, with the transistor **158** turned off in the sensing circuit **152** before time t_1, the transistor **214** is rendered fully conductive through the biasing action of the resistors **174** and **226** and the diode **224**. With the transistor **214** turned on, the transistor **218** in the differential amplifier **216** is rendered fully nonconductive. With the transistor **218** turned off, no current sink is provided for the transistors **220** and **222** so that the differential amplifier **216** is effectively disabled. Consequently, the transistors **220** and **222** are rendered fully nonconductive. With the transistor **222** turned off, the compensation voltage V_2 is at a first or upper compensation level **256**. The upper compensation level **256** is approximately equal to the voltage level on the power line **38**.

At time t_1, with the transistor **158** turned on in the sensing circuit **152**, the transistor **214** is rendered fully nonconductive through the biasing action of the resistor **226** and the diode **224**. With the transistor **214** turned off, the transistor **218** in the differential amplifier **216** is rendered fully conductive. With the transistor **218** turned on, a current sink is provided for the transistors **220** and **222** so that the differential amplifier **216** is effectively enabled. At time t_1, the control voltage V_1 is at the lower control level **250**. Accordingly, since the control voltage V_1 is below the intermediate control level **252**, the transistor **222** is rendered fully conductive and the transistor **220** is rendered fully nonconductive. With the transistor **222** turned on, the compensation voltage V_2 substantially instantaneously shifts from the first or upper compensation level **256** to a second or lower compensation level **258**. The lower compensation level **258** is primarily defined by the voltage divider action of the resistors **244**, **238** and **234**.

During a first or initial time period t_1–t_2, the control voltage V_1 linearly increases from the lower control level **252** to the intermediate control level **254**. Thus, the initial time period t_1–t_2 may be defined as extending from the time the control voltage V_1 departs from the lower control level **250** until it arrives at the intermediate control level **252**. Since the control voltage V_1 is below the intermediate control level **252**, the transistor **222** remains turned on and the transistor **220** remains turned off throughout the first time period t_1–t_2. Hence, the compensation voltage V_2 exhibits a step portion which remains substantially constant at the lower compensation level **258** over the first time period t_1–t_2.

During a second or subsequent time period t_2–t_3, the control voltage V_1 linearly increases from the intermediate control level **252** to the upper control level **254**. Thus, the subsequent time period t_2–t_3 may be defined as extending from the time the control voltage V_1 departs from the intermediate control level **252** until it arrives at the upper control level **254**. Since the control voltage V_1 is above the intermediate control level **252**, the transistor **222** gradually turns off and the transistor **220** gradually turns on throughout the second time period t_2–t_3. As a result, the compensation voltage V_2 exhibits a ramp portion which linearly varies from the lower compensation level **258** to the upper compensation level **256**.

After time t_3, the transistor **222** remains turned off so that the compensation voltage V_2 remains at the upper compensation level **256**. As previously described, the sensing circuit **152** eventually returns to the first state following the termination of engine acceleration. Accordingly, the transistor **200** is turned on to again clamp the control voltage V_1 at the first or lower control level **250**. Further, the transistor **214** is turned on to again disable the differential amplifier **216**. In this condition, the voltage-generating section **142** of the acceleration compensation circuit **132** is ready to repeat the previously set forth operation in response to the next acceleration of the engine **10**.

The bias voltage changing section **144** of the acceleration compensation circuit **132** includes a high-gain amplifier arrangement **260** and a constant current sink configuration **262**. The amplifier **260** includes a PNP-junction transistor **264** and an NPN-junction transistor **266**. The base electrode of the transistor **264** is connected directly to the collector electrode of the transistor **222** in the differential amplifier **216**. The base electrode of the transistor **266** is connected directly to the collector electrode of the transistor **264**. The emitter electrode of the transistor **264** and the collector electrode of the transistor **266** are connected through a variable limiting resistor **268** to the power line **38**.

The constant current sink **262** includes a pair of NPN-junction transistors **270** and **272** and a temperature-compensating and biasing diode **274**. The base electrode of the transistor **270** and the collector electrode of the transistor **272** are connected directly to the emitter electrode of the transistor **266** in the amplifier **260**. The emitter electrode of the transistor **270** and the base electrode of the transistor **272** are connected through the diode **274** to the ground line **40**. The emitter electrode of the transistor **272** is connected directly to the ground line **40**. The collector electrode of the transistor **242** is connected through the output line **138** to the bias junction **106** in the control pulse-generating circuit **78**.

In operation, the compensation voltage V_2 produced by the differential amplifier **216** drives the high-gain amplifier **260** to establish a corresponding compensation current through the variable resistor **268** and the transistor **266**. The relative magnitude of the compensation current may be regulated by adjusting the resistance of the variable resistor **268**. The constant current sink **262** is responsive to the compensation current produced by the amplifier **260** to define equal constant currents through the transistor **272** and through the transistor **270** and the diode **274**. The constant current through the transistor **270** and the diode **174** effectively provides a compensation resistance across the biasing resistor **110** in the control pulse-generating circuit **78**. Since the constant current through the transistor **270** and the diode **274** is variable in response to variations in the compensation voltage V_2, the bias voltage produced at the bias junction **106** in the control pulse generating circuit **78** is shifted to follow the compensation voltage V_2.

Thus, the bias voltage is decreased by a substantially constant amount during the first or initial time period t_1–t_2 in response to the step portion of the compensation voltage V_2. Similarly, the bias voltage is decreased by a linearly increasing amount during the second or subsequent time period t_2–t_3 in response to the ramp portion of the compensation voltage V_2. Consequently, the duration of the control pulses produced by the control pulse-generating circuit **78** is substantially instantaneously increased from a nominal uncompensated value to a maximum compensated value where it remains substantially constant over the first time period t_1–t_2, and is linearly decreased from the maximum compensated value back to the nominal uncompensated value over the second time period t_2–t_3.

The amount of fuel deposited within the intake manifold **20** of the engine **10** is increased during acceleration as a function of the duration of the control pulses produced by the control pulse-generating circuit **78**. Specifically, the applied fuel is increased by a substantially constant amount during the first time period t_1–t_2 in order to approximately match the increased fuel demand of the engine **10** as it accelerates from a lower speed to a higher speed. Further, the applied fuel is increased by a linearly decreasing amount during the second time period t_2–t_3 in order to approximately match the decreasing fuel demand of the engine **10** as it arrives at the higher speed. As a result, the engine output response initially rapidly rises over the first time period t_1–t_2 and subsequently gradually levels off over the second time period t_2–t_3. Accordingly, there is no objectionable stumble or hesitation at the initiation of acceleration and there is no objectionable jerk or dip at the termination of acceleration.

It will now be apparent that the illustrated invention presents a simple but effective circuit for providing acceleration compensation in an electronic fuel injection control system. In particular, it will be noted that the previously described circuit is readily susceptible to fabrication utilizing integrated circuit processing techniques. However, it is to be clearly understood that the previously described circuit is shown for demonstration purposes only and that various modifications and alterations may be made to it without departing from the spirit and scope of the invention.

What is claimed is:

1. A fuel supply system for an internal combustion engine, comprising: trigger pulse-generating means connected with the engine for developing trigger pulses in synchronization with the operation of the engine; control pulse-generating means connected with the trigger pulse-generating means for producing control pulses in response to the occurrence of the trigger pulses, the duration of the control pulses determined as a function of a bias voltage developed by the control pulse-generating means; fuel supply means connected with the control pulse-generating means and with the engine for applying fuel to the engine during the duration of each of the control pulses; power-detecting means connected with the engine for switching from a deactivated condition to an activated condition in response to an increase in the demand for power from the engine, the power-detecting means including a trigger circuit connected with the control pulse-generating means for applying an extra trigger pulse to the control pulse-generating means when the power-detecting means is switched to the activated condition, whereby the fuel applied to the engine at the onset of acceleration is substantially instantaneously increased; control voltage-generating means for producing a control voltage which linearly varies from a first control level through a second control level to a third control level when the power-detecting means switches to the activated condition; compensation voltage-generating means connected with the control voltage-generating means for producing a compensation voltage, the compensation voltage exhibiting a step portion during an initial time period extending from the time the control voltage departs from the first control level until it arrives at the second control level, and the compensation voltage exhibiting a ramp portion during a subsequent time period extending from the time the control voltage departs from the second control level until it arrives at the third control level; and bias voltage-changing means connected between the compensation voltage-generating means and the control pulse-generating means for varying the bias voltage to increase the duration of the control pulses by a substantially constant amount during the initial time period in response to the step portion of the compensation voltage and by a linearly decreasing amount during the subsequent time period in response to the ramp portion of the compensation voltage, whereby the fuel applied to the engine during acceleration is increased by a substantially constant amount during the initial time period and by a linearly decreasing amount during the subsequent time period.

2. A fuel supply system for an internal combustion engine, comprising: means including control pulse-generating means connected with the engine for producing control pulses having a duration determined as a function of a feedback voltage developed in response to an engine operating parameter and as a function of a bias voltage; fuel supply means connected between the control pulse-generating means and the engine for applying fuel to the engine during the duration of each of the control pulses; power-detecting means connected with the engine for switching from a deactivated condition to an activated condition in response to an increase in the demand for power from the engine; control voltage-generating means including a control capacitor for defining the control voltage thereacross, a voltage-regulating circuit connected with the control capacitor and with the power-detecting means for clamping the capacitor so as to retain the control voltage at a first control level when the power-detecting means is in the deactivated condition and for unclamping the capacitor so as to release the control voltage when the power-detecting means is in the activated condition, and a current regulating circuit connected with the control capacitor for providing a constant current path for the capacitor so that the control voltage linearly varies from the first control level through a second control level to a third control level when the capacitor is unclamped; compensation voltage-generating means including differential amplifier means connected with the acceleration detecting means and with the control capacitor for producing a compensation voltage, the compensation voltage substantially instantaneously shifting from a first compensation level to a second compensation level when the acceleration-detecting means is switched to the activated condition, the compensation voltage then remaining substantially constant at the second compensation level over a first time period extending from the time the control voltage departs from the first control level until it arrives at the second control level, and the compensation voltage thereafter linearly varying from the second compensation level to the first compensation level over a second time period extending from the time the control voltage departs from the second control level until it arrives at the third control level; and bias voltage-changing means connected between the control pulse-generating means for varying the bias voltage in response to the compensation voltage to increase the duration of the control pulses by a substantially constant amount during the first time period and by a linearly decreasing amount during the second time period, whereby the fuel applied to the engine during acceleration is increased by a substantially constant amount over the first time period and by a linearly decreasing amount over the second time period.

3. A fuel supply system for an internal combustion engine, comprising: trigger pulse-generating means connected with the engine for developing trigger pulses in synchronization with the operation of the engine; control pulse-generating means connected with the trigger pulse-generating means for producing control pulses in response to the occurrence of the trigger pulses, the duration of the control pulses determined as a function of a bias voltage developed by the control pulse-generating means; fuel injection means including at least one fuel injector connected between the control pulse-generating means and the engine for applying fuel to the engine during the duration of each of the control pulses; power-detecting means connected with the engine for switching from a deactivated condition to an activated condition in response to an increase in the demand for power from the engine, the power-detecting means including a trigger circuit connected with the control-pulse-generating means for applying an extra trigger pulse to the control pulse-generating means when the power-detecting means is switched to the activated condition; control voltage-generating means including constant current integrator means for producing a control voltage which linearly varies from a first control level through a second control level to a third control level when enabled, and the control voltage-generating means further including switching means connected with the power-detecting means for enabling the constant current integrator means when the power-detecting means is switched to the activated condition; compensation voltage-generating means including differential amplifier means connected with the constant current integrator means for producing a compensation voltage when enabled, the compensation voltage having a first portion which substantially instantaneously shifts from a first compensation level to a second compensation level where it remains substantially constant over a first time period extending from the time the control voltage departs from the first control level until it arrives at the second control level, and the compensation voltage having a second portion which linearly varies from the second compensation level to the first compensation level over a second time period extending from the time the control voltage departs from the second control level until it arrives at the third control level, the compensation voltage-generating means further including switching means connected with the power-detecting means for enabling the differential amplifier means when the power-detecting means is switched to the activated condition; and bias voltage-changing means connected between the differential amplifier means and the control pulse-generating means for varying the bias voltage in response to the first portion of the compensation voltage to instantaneously shift the duration of the control pulses from a nominal uncompensated value to a maximum compensated value where it remains substantially constant during the first time period, and for varying the bias voltage in response to the second portion of the compensation voltage to linearly shift the duration of the control pulses from the maximum compensated value to the nominal uncompensated value during the second time period, whereby the fuel applied to the engine is increased by an amount which is substantially constant during the first time period and which linearly decreases during the second time period.

4. A fuel supply system for an internal combustion engine, comprising: control pulse-generating means for producing a control pulse in response to the application of a trigger pulse, the duration of the control pulse determined as a function of a bias voltage developed by the control pulse-generating means; trigger pulse-generating means connected between the engine and the control pulse-generating means for applying trigger pulses to the control pulse-generating means in synchronization with the operation of the engine thereby to produce corresponding control pulses; fuel injection means connected between the control pulse-generating means and the engine for applying fuel to the engine during the duration of each of the control pulses; power-detecting means connected with the engine for switching from a deactivated condition to an activated condition in response to an increase in the demand for power from the engine, the power-detecting means including a trigger circuit connected with the control pulse-generating means for applying an extra trigger pulse to the control pulse-generating means when the power-detecting means is switched to the activated condition, whereby the fuel applied to the engine at the onset of acceleration is substantially instantaneously increased; control voltage-generating means including a control capacitor for defining a control voltage thereacross, a charging circuit connected with the control capacitor for applying a constant charging current to the capacitor, and a discharging circuit connected with the control capacitor and with the acceleration-detecting means for clamping the control voltage at a first control level when the acceleration-detecting means is in the deactivated condition and for unclamping the control voltage when the acceleration-detecting means is in the activated condition, the control voltage thereby linearly varying from the first control level through a second control level to a third control level under the influence of the constant charging current provided by the charging circuit; compensation voltage-generating means including differential amplifier means connected with the control capacitor for producing a compensation voltage, the compensation voltage having a step portion which substantially instantaneously shifts from a first compensation level to a second compensation level where it remains substantially constant over a first time period extending from the time the control voltage departs from the first control level until it arrives at the second control level, and the compensation voltage having a ramp portion which linearly varies from the second compensation level to the first compensation level over a second time period extending from the time the control voltage departs from the second control level until it arrives at the third control level; and bias voltage-changing means connected between the differential amplifier means and the control pulse-generating means for shifting the bias voltage to substantially instantaneously increase the duration of the control pulses from a nominal uncompensated value to a maximum compensated value where it remains over the first time period in response to the step portion of the compensation voltage, and for shifting the bias voltage to linearly decrease the duration of the control pulses from the maximum compensated value to the nominal uncompensated value over the second time period in response to the ramp portion of the compensation voltage, whereby the fuel applied to the engine during acceleration is increased by a substantially constant amount during the first time period and by a linearly decreasing amount during the second time period.

5. A fuel supply system for an internal combustion engine, comprising: trigger pulse-generating means connected with the engine for developing trigger pulses in synchronization with the operation of the engine, control pulse-generating means connected with the trigger pulse-generating means for producing control pulses in response to the occurrence of the trigger pulses, the duration of the control pulses determined as a function of a bias voltage developed by the control pulse-generating means; fuel supply means connected with the control pulse-generating means and with the engine for applying fuel to the engine during the duration of each of the control

pulses; power-detecting means connected with the engine, the power-detecting means including a sensing switch having mechanical switch contacts which are actuated in response to an increase in the demand for power from the engine, and the power-detecting means further including a sensing circuit connected with the sensing switch for operation from a first state to a second state in response to an actuation of the switch contacts and for operation from the second state to the first state in response to the expiration of a predetermined time delay period after a preceding actuation of the switch contacts, whereby the power-detecting means is substantially insensitive to bouncing of the switch contacts; voltage-generating means connected with the sensing circuit for producing a compensation voltage when the sensing circuit assumes the second state, the compensation voltage exhibiting a step portion during an initial time period and a ramp portion during a subsequent time period; and bias voltage-changing means connected between the voltage-generating means and the control pulse-generating means for varying the bias voltage to increase the duration of the control pulses by a substantially constant amount during the initial time period in response to the step portion of the compensation voltage and by a linearly decreasing amount during the second time period in response to the ramp portion of the compensation voltage, whereby the fuel applied to the engine during acceleration is increased by a substantially constant amount during the initial time period and by a linearly decreasing amount during the subsequent time period.

6. A fuel supply system for an internal combustion engine, comprising: control pulse-generating means for producing a control pulse in response to the application of a trigger pulse, the duration of the control pulse determined as a function of a bias voltage developed by the control pulse-generating means; trigger pulse-generating means connected between the engine and the control pulse-generating means for applying trigger pulses to the control pulse-generating means in synchronization with the operation of the engine thereby to produce corresponding control pulses; fuel injection means connected between the control pulse-generating means and the engine for applying fuel to the engine during the duration of each of the control pulses; power-detecting means connected with the engine, the power-detecting means including a sensing switch having mechanical switch contacts which are actuated in response to an increase in the demand for power from the engine, the power-detecting means further including a sensing circuit connected with the sensing switch for operation from a first state to a second state in response to an actuation of the switch contacts, the sensing circuit including a timing network for rendering the sensing circuit unresponsive to a subsequent actuation of the switch contacts until after the expiration of a predetermined time delay period following a preceding activation of the switch contacts, the power-detecting circuit further including a trigger circuit connected with the sensing circuit for applying an extra trigger pulse to the control pulse-generating means when the sensing circuit assumes the second state; voltage-generating means connected with the sensing circuit for producing a compensation voltage, the compensation voltage substantially instantaneously shifting from a first compensation level to a second compensation level when the sensing circuit assumes the second state, the compensation voltage then remaining substantially constant at the second compensation level during a first time period, and the compensation voltage thereafter linearly varying from the second compensation level to the first compensation level during a second time period; and bias voltage-changing means connected between the voltage-generating means and the control pulse-generating means for shifting the bias voltage in response to the compensation voltage thereby to substantially instantaneously increase the duration of the control pulses from a nominal uncompensated value to a maximum compensated value where it remains during the first time period and to linearly decrease the duration of the control pulses from the maximum compensated duration to the nominal uncompensated value during the second time period; whereby the amount of fuel applied to the engine is increased in response to acceleration.

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