

- [54] **FUEL INJECTION SYSTEM**
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[22] Filed: **Dec. 27, 1972**
[21] Appl. No.: **318,999**

Related U.S. Application Data

- [63] Continuation-in-part of Ser. No. 99,335, Dec. 18,
1970, abandoned.
[52] U.S. Cl. 123/32 EA, 123/140 MC, 123/139 AN,
123/119 R
[51] Int. Cl. **F02m 51/00**
[58] Field of Search 123/32 EA, 32 AE, 119 R,
123/140 MC, 139 AN

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[57] **ABSTRACT**

A fuel injection system for a multi-cylinder internal combustion engine, including a fuel pump adapted to be driven by the engine so as to increase the pressure of fuel to be injected for each cycle of the engine operation in substantially proportion to an increase in the engine speed, and an electronic control circuit adapted to produce a fuel injection pulse signal having a pulse width decreasing in proportion to an increase in the engine speed, by which the quantity of fuel to be injected for each cycle of the engine operation remains substantially unchanged irrespective of the variations in the engine speed.

4 Claims, 9 Drawing Figures

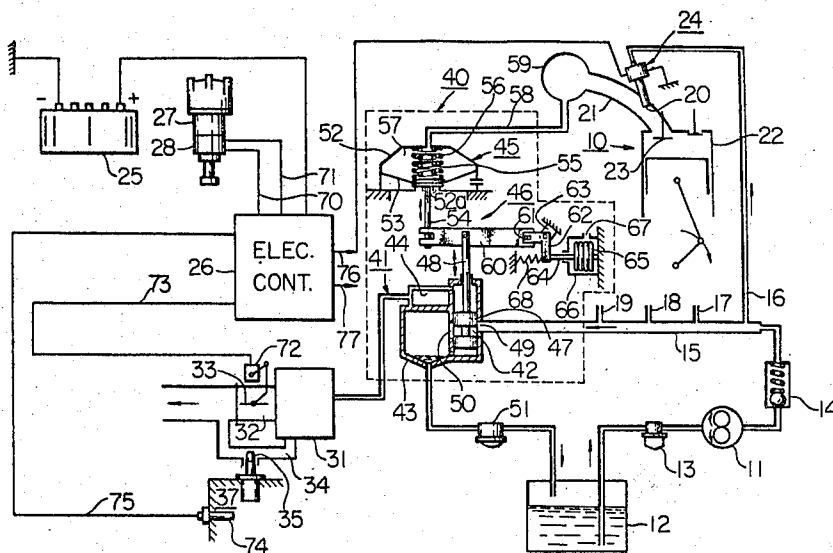


Fig. 2

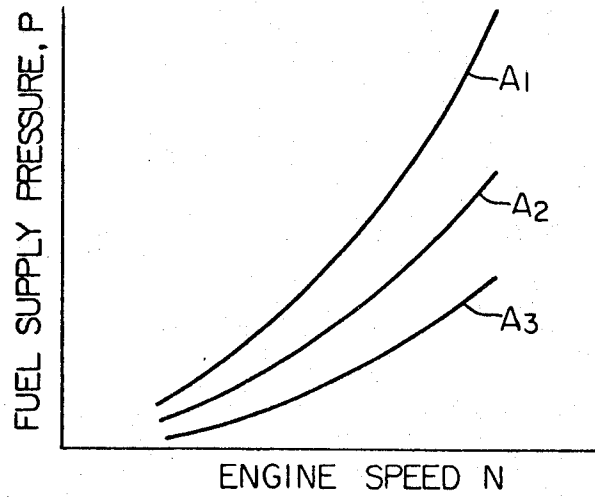


Fig. 3

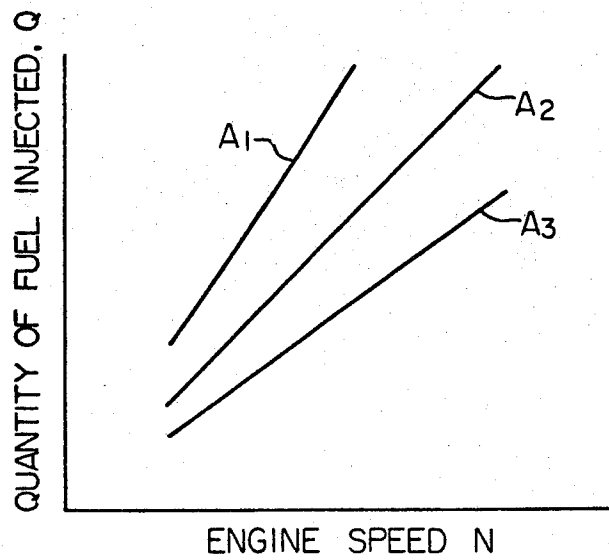


Fig. 4

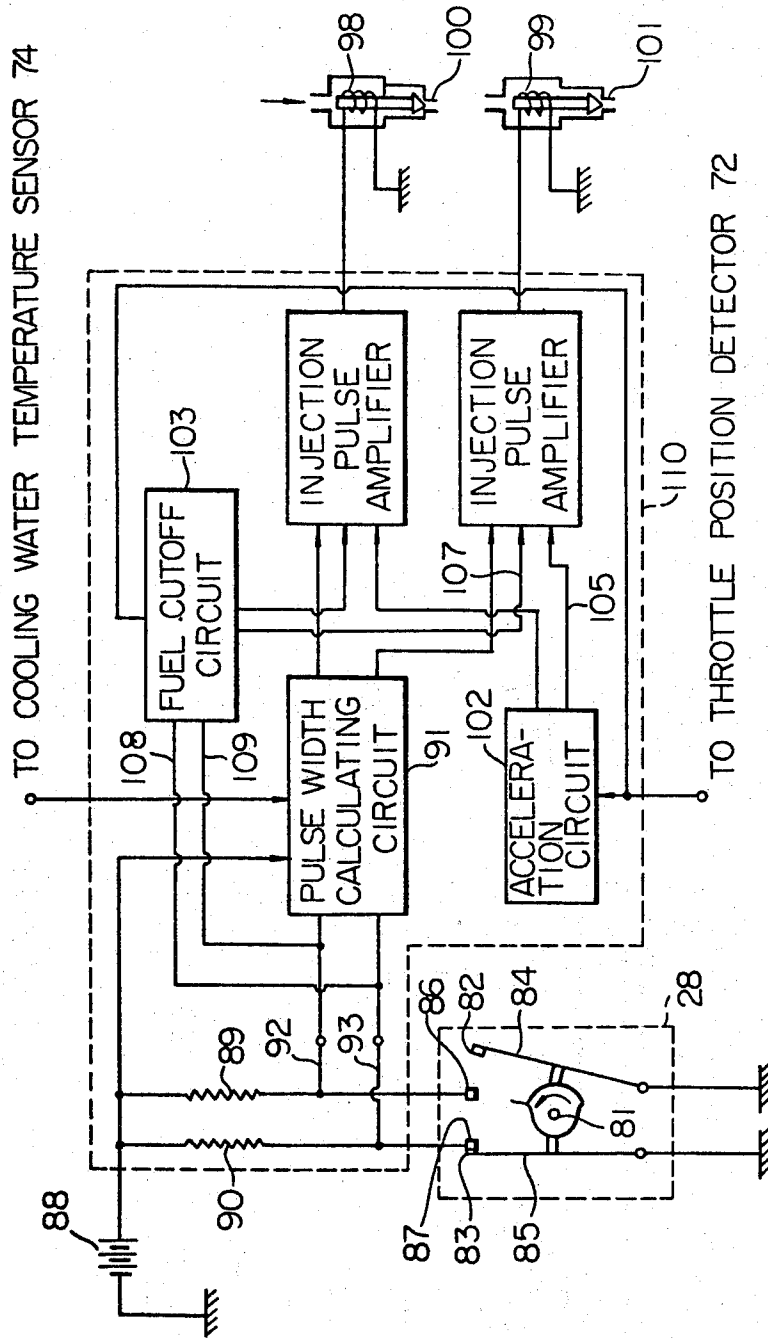


Fig. 5

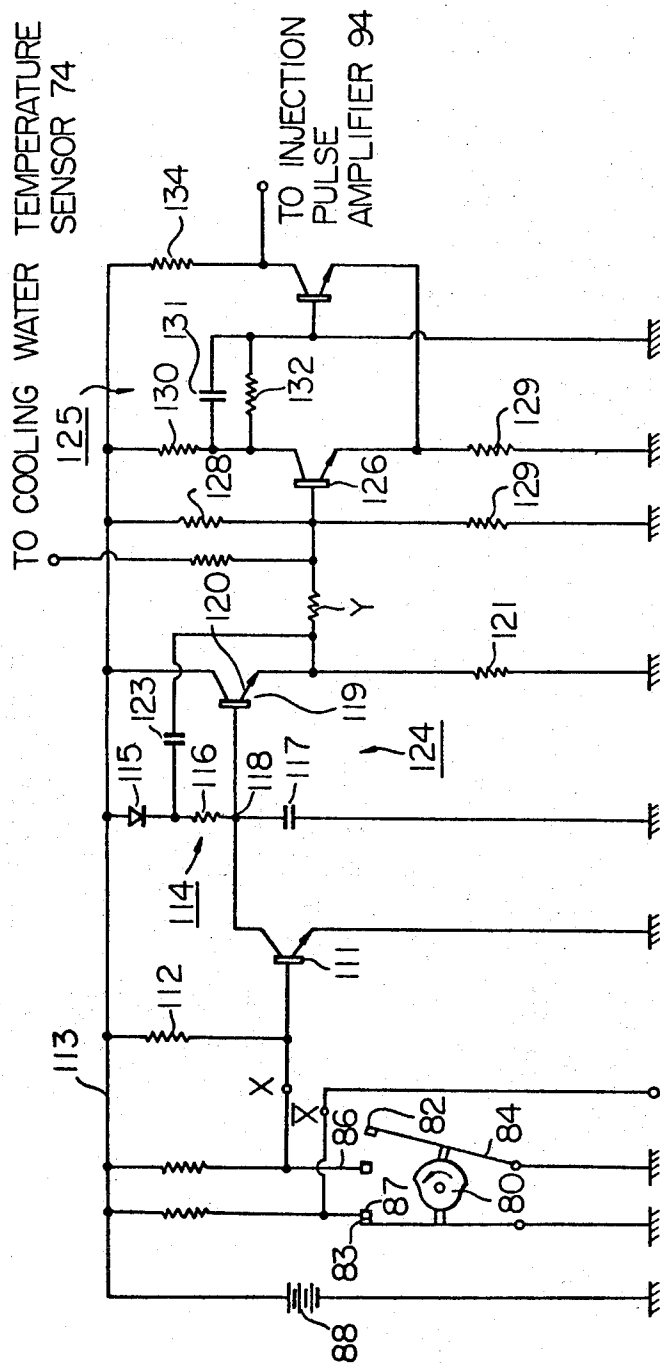


Fig. 6

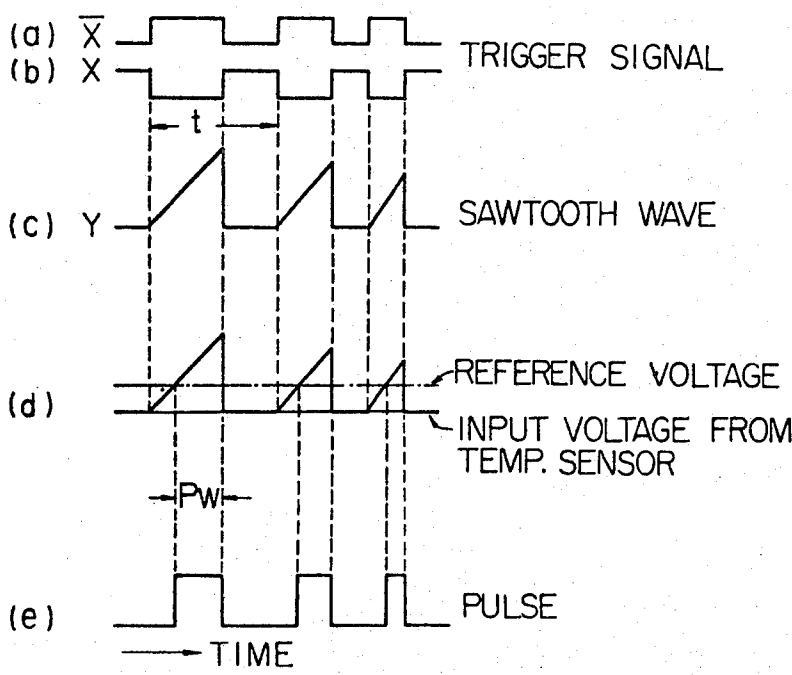


Fig. 7

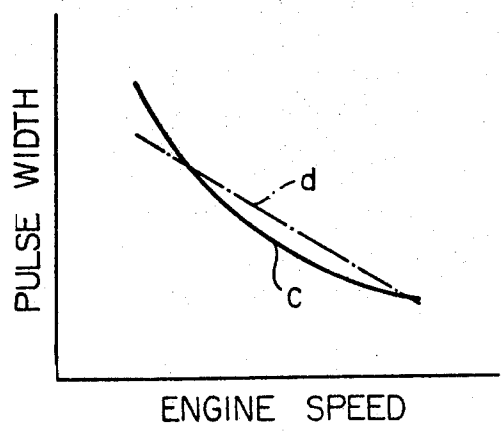


Fig. 8

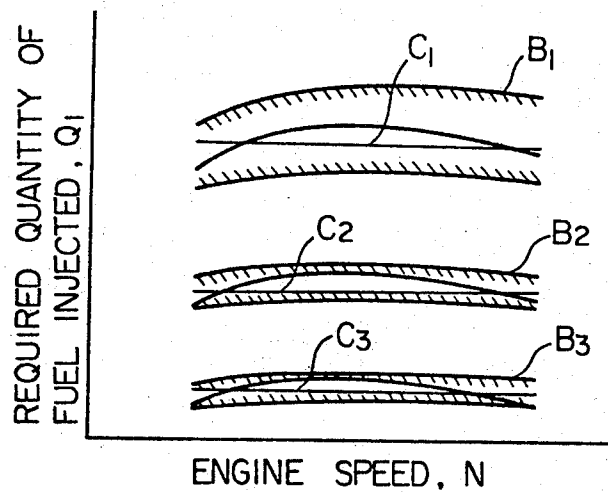
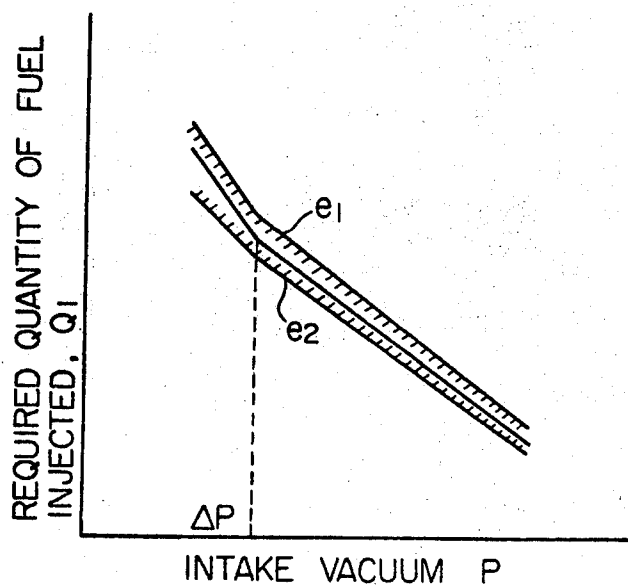


Fig. 9



FUEL INJECTION SYSTEM

This invention is a continuation-in-part of application of Ser. No. 99,335 filed on Dec. 18, 1970 and now abandoned.

This invention relates generally to a fuel injection system for a multi-cylinder internal combustion engine and, more particularly, to a fuel injection system for supplying the fuel in controlled rates to the individual engine cylinders.

One recent trend in the automotive technology is to have various mechanical and pneumatic units of a motor vehicle supplanted by electronic devices. An example of such electronic devices is an electronically controlled fuel injection system which controls the rate of fuel injection by varying the widths of electric pulses applied to a solenoid-actuated injection valve in accordance with the engine load to change the time duration in which the injection valve is kept open while maintaining the pressure of the fuel at a constant level. Under heavy engine load conditions, the pulse width is made larger so as to supply fuel at a higher rate to the cylinders, while under light engine load conditions the pulse width is narrowed to reduce the quantity of fuel supplied.

This type of fuel injection system, however, involves serious difficulties in generating a pulse having pulse-width optimum for high engine speed and/or heavy engine load conditions in each of the engine operating cycles, because of the limited time duration of each of the engine cycles under these conditions, the duration being of the order of 10ms for 6,000 rpm, for instance. Under light engine load and/or low speed conditions, on the other hand, it is rather easy to produce a pulse having a reasonable width because of the relatively prolonged cyclic period of engine operation at low speeds. When the engine is operating at a high speed under heavy engine load conditions, the pulsewidth of the pulse signal applied to the injection valve tends to decrease below a required value, resulting in a decrease in the engine output or in a shutdown of the engine.

It is therefore an object of this invention to provide a fuel injection system which is capable of supplying a proper quantity of fuel to the individual cylinders at all speed and load conditions of the engine.

It is another object of this invention to provide a fuel injection system in which the quantity of the fuel injected by nozzles for a certain period of time remains substantially unchanged irrespective of the engine speed.

It is a further object of this invention to provide a fuel injection system which is adapted to supply enriched fuel during starting, warm-up and acceleration and to cutoff fuel during coasting.

In order to achieve these objects, the present invention provides a fuel injection system for an internal combustion engine which system is adapted to vary the pulse width of a fuel injection pulse in proportion to the engine speed while simultaneously varying the pressure of fuel to be supplied to the engine cylinders so that a proper quantity of fuel is supplied to the individual engine cylinders throughout all speed and load conditions of the engine. The fuel injection system comprises a fuel pump which is adapted to be driven by the internal combustion engine so that the pressure of fuel to be delivered to a fuel distributing pipe increases as the engine speed increases. The pressure of fuel in the fuel

distributing pipe is controlled by a fuel pressure regulating system which is constituted by a pressure regulating unit and a diaphragm unit associated therewith. The pressure regulating unit includes first and second chambers, the first chamber having an inlet port communicating with the fuel distributing pipe and an outlet port communicating with the second chamber while the second chamber connected to a fuel tank to pass the fuel in said second chamber back to said fuel tank.

A spool valve is slidably disposed in the first chamber for controlling the degree of communication between the inlet and outlet ports to regulate the pressure of fuel in said fuel distributing pipe. This spool valve is controlled by the diaphragm unit in dependence on an intake manifold vacuum. To this end, the diaphragm unit has a diaphragm disposed in a vacuum chamber connected to an intake manifold of the engine, the diaphragm being interconnected to the spool valve of the pressure regulating unit. With this construction, the diaphragm is responsive to the intake manifold vacuum so that, when the engine is operating under light engine load conditions at part throttle, that is, when only a limited quantity of air is drawn into the engine cylinders, a greater vacuum develops in the intake manifold to move the diaphragm to a position in which the spool valve increases the degree of communication between the inlet and outlet ports thereby decreasing the pressure of fuel in said fuel distributing pipe. When, however, the engine is operating under heavy load conditions at full throttle, the intake manifold vacuum decreases with a result that the diaphragm is moved by the action of a spring means to a position in which the spool valve decreases the degree of communication between the inlet and outlet ports for thereby increasing the pressure of fuel in the fuel distributing pipe. Thus, the pressure of fuel to be delivered to the individual engine cylinders increases as the intake manifold vacuum increases and also increases as the engine speed increases.

The fuel injection system also comprises an electronic control circuit which is combined with the fuel pump whereby the pulse width of a fuel injection pulse to be supplied to a fuel injection control valve decreases as the engine speed increases while the pressure of fuel to be supplied to the individual engine cylinders increases as the engine speed increases so that a proper quantity of fuel is supplied to the individual engine cylinders. To achieve this feature, the electronic control system includes an engine driven triggering device adapted for producing a pulse signal dependent upon the engine speed and a pulse width calculating circuit connected thereto. The pulse width calculating circuit has a switching transistor connected to the engine driven triggering device, a saw-tooth wave generator connected to the switching transistor and a Schmidt circuit connected to the saw-tooth wave generator, which are so arranged as to produce a fuel injection pulse with a pulse width proportional to the engine speed.

In the accompanying drawings:

FIG. 1 is a schematic view showing an overall construction of a fuel injection system according to this invention;

FIG. 2 is a plot of the fuel supply pressures in terms of the engine speed as attained in the system of FIG. 1, in which the curves represent different engine intake manifold vacuums;

FIG. 3 is a plot of the quantities of the fuel injected in terms of the engine speed as attained in the system of FIG. 1, wherein the injection nozzle is kept open for a fixed time duration and wherein the curves represent different engine intake manifold vacuums;

FIG. 4 is a block diagram of an electronic control unit incorporated in the fuel injection system of FIG. 1;

FIG. 5 is a circuit diagram of a pulsewidth calculating circuit of the electronic control unit shown in FIG. 4;

FIG. 6 is a view showing voltage waveforms appearing at various points in the pulsewidth calculating circuit of FIG. 5;

FIG. 7 is a plot of the pulsewidth in terms of the engine speed;

FIG. 8 is a plot of the quantity of the fuel required at varying engine speeds; and

FIG. 9 is a plot of the quantity of the fuel required at varying intake manifold vacuums.

Referring now to FIG. 1, there is shown a fuel injection system for use in a multi-cylinder internal combustion engine. In FIG. 1, the fuel injection system proposed by the present invention is shown as being applied to a four-cylinder internal combustion engine, by way of example only, which is generally designated by reference numeral 10. The fuel injection system includes a fuel pump 11 which is connected to and driven by the internal combustion engine 10 so that the pressure of fuel to be injected for each cycle of the engine operation is increased in proportion to the square of the engine speed as seen in FIG. 2. The fuel pump 11 is adapted to deliver fuel under pressure from a fuel tank 12 through a filter 13 and a one-way check valve 14 to a fuel distributing pipe 15. The fuel distributing pipe 15 is shown as having four branch pipes 16 to 19 leading to nozzles of respective engine cylinders. While the fuel injection nozzle, 20, is herein shown as located in an intake manifold branch passage 21, it is to be understood that the fuel injection nozzle could equally as well be located to discharge directly into an intake port of the intake manifold branch passage 21. The intake manifold branch passage 21 opens into the engine cylinder, 22, through an intake valve 23 as customary. The fuel injection nozzle 20 forms part of a fuel injection control valve 24 which is controlled by means comprising an electrical power supply 25, an electronic control unit 26, a distributor 26 and an engine driven triggering device 28. A solenoid is incorporated in the valve 24, which solenoid is connected to the control means by a line 30. The nozzle 20 is adapted to spray fuel into the air entering the engine cylinder 22 when the solenoid remains energized by the control means.

An air cleaner 31 is coupled to a throttle valve chamber 32 having a throttle valve 33 mounted therein. The throttle valve 33 is linked to an accelerator pedal (not shown) to control the rate of air to be admitted to the cylinder 22.

An air bypass passage 34 is provided between the air cleaner 31 and the throttle chamber 32 downstream of the throttle valve 33, supplying additional air to the cylinders 22 during starting and engine warm-up operations. The air bypass passage 34 is provided with a valve 35 which controls the flow of air through the bypass passage 34. The valve 35 is controlled by a thermostat 36 which is so arranged as to sense the temperature of the engine cooling water.

A fuel pressure control device, generally indicated at 40, is provided which comprises a pressure regulating unit 41 having three spaced members 42 and 43, a diaphragm unit 45 and a mechanical linkage 46 operatively interconnecting the units 41 and 45. The pressure regulating unit 41 has slidably mounted in its chamber 42 a piston or spool valve 47. The piston or spool valve 47 is rigidly to a piston rod 48 which, in turn, is operatively connected to the linkage 46. The chamber 42 has formed therein an inlet port 49 communicating with the fuel distributing pipe 15 and an outlet port 50 located opposite to the inlet port 49 and communicating with the chamber 43. The other chamber 42 of the pressure regulating unit 41 communicates with the chamber 43 through a passage 44. This passage 44 is branched to the air cleaner 31 via a conduit 51 so that a substantially atmospheric pressure obtains in these chambers 42 and 43. When the piston or spool valve 47 is in the position shown, i.e., in a position in which the outlet port 49 is permitted to communicate with the inlet port 50, the fuel flows at a certain rate from the distributing pipe 15 into the chamber 43 through the chamber 42. The chamber 43 is adapted to store the fuel flowing therein which is in turn discharged to the fuel tank 12 through a filter 51 as by a mechanical pump (not shown).

The diaphragm unit 45 comprises a housing 52, a diaphragm 53 secured to the housing, an actuating rod 54 and spring means which is herein shown to include two different compression springs 55 and 56 which are accommodated in a chamber 57 which is defined by the housing 52 and the diaphragm 53. The compression springs 55 and 56 bias the diaphragm 53 toward a stop member 52a which may form part of the housing 52. The two springs 55 and 56 have different spring constants for the reason to be discussed later. A vacuum passage 58 provides a communication between the chamber 57 of the diaphragm unit 45 and an air collector 59 of the intake manifold. The actuating rod 54 attached to the diaphragm 53 is operatively connected at its leading end to one end of a lever 60 which forms part of the mechanical linkage 46. A connecting pin 61 is attached to the other end of the lever 60. An angled arm 62 is provided which pivotally engages at one end with the pin 61 and which is rotatable about a stationary pivot 63. The angled arm 62 is operatively connected at the other end to a rod 64 which is connected to a bellows 65. The bellows 65 is accommodated within a housing 66 having a vent 67. The bellows is filled with a gas such as air under pressure and is caused to expand or contract in response to variations in the temperatures and pressure of atmospheric air admitted into the housing through the vent 67. Such expansion or contraction of the bellows 67 causes the rod 64 to protrude or retract, depending upon the atmospheric pressure and temperature. A spring member 68 is provided which urges the angled arm 62 to rotate counter-clockwise as viewed in FIG. 1. The lever 60 is connected at its intermediate portion to the piston rod 48 of the control valve 41, so that movement of the lever plate 60 caused by changes in the intake manifold vacuum, atmospheric pressure and temperature varies the relative position of the piston or spool valve 47, thereby varying the effective area of communication between the inlet port 49 and the outlet port 50 of the chamber 42.

In the operation of the fuel pressure control device 40, when the engine is operating under light engine load conditions at part throttle, that is, when only a limited quantity of air is drawn into the cylinder, a greater vacuum develops in the intake manifold collector 59, moving the diaphragm 53 upward as seen in FIG. 1 and thereby causing the piston rod 48 of the spool valve 47 to protrude. Such movement of the piston rod 48 is reflected by the upward movement of the spool valve 47 so that the effective area of communication between the inlet and outlet ports 49 and 50, respectively, is increased, allowing a greater quantity of fuel to flow into the chamber 43 through the chamber 42. The fuel pressure staying in the fuel distributing pipe 15 is reduced in this manner. During heavy load operation at full throttle, the diaphragm 53 is moved downward into engagement with the stop member 52a, so that the piston rod 48 is moved by the linkage 46 to a position in which the effective area of communication between the ports 49 and 50 is decreased, permitting only a limited quantity of fuel to flow into the chamber 43, whereby a relatively high pressure is established in the fuel distributing pipe 15.

FIG. 2 is a plot of fuel pressure in the fuel distributing pipe P against engine speed N in the fuel pressure control device 40, in which various curves represent different of intake manifold vacuums.

The pump 11 employed to supply fuel under pressure to the check valve 14 is adapted to be driven by the engine 10 at a rate substantially proportional to the engine speed as already mentioned hereinabove. The pump may preferably be a displacement pump such as a gear pump, trochoid pump and vane pump or a velocity type pump, preferably having a capacity of two to four times as great as the maximum fuel consumption. Where a pump of the named type is employed, the fuel supply pressure P increases substantially in proportion to the square of the engine speed, as plotted in FIG. 2. In FIG. 2, A₁ represents a fuel pressure at full throttle, A₂ at -200mmHg intake vacuum and A₃ at -400mmHg intake manifold vacuum. It will be readily understood that, since the effective open area of the communication between the inlet and outlet ports 49 and 50, respectively, increases as the intake manifold vacuum increases, a lower fuel pressure obtains in the fuel distributing pipe 15 as a higher vacuum obtains in the intake manifold of the engine.

FIG. 3 is a plot of the quantity Q of the fuel injected against the engine speed N, in which various curves represent different intake manifold vacuums. The values Q are those measured when the pulsewidth and accordingly the opening time duration of the nozzle 20 are kept constant, say, at 5 ms for instance. As is apparent from FIG. 3, the quantity Q of the fuel injected increases linearly as the engine speed N increases. This is because the quantity Q of the fuel injected increases in proportion to the square root of the fuel pressure P which in turn is proportional to the square of the engine speed N.

Reverting to FIG. 1, the electronic control unit 26 which is connected to the electrical power supply 25 is adapted to receive a plurality of signals indicative of the engine operating conditions such as the engine speed, crankshaft rotational position, throttle valve position and cooling water temperature. The engine driven triggering device 28 incorporated in the distributor 27 generates a pulse signal indicative of both the

engine speed and the crankshaft rotational position. The signal, which occurs at the rate of two pulses for each cycle of the engine operation, is fed to the electronic control device 26 alternately through lines 70 and 71 to provide for discrimination of the firing order of the engine 10. Another signal which is indicative of the throttle valve position is produced by a throttle position detector 72 ganged with the throttle valve 33 and is fed to the electronic control device 26 through a line 73 to cause fuel cutoff during coasting or to increase the richness of the air-fuel mixture during acceleration. The mixture is enriched by causing the electronic control device 26 to apply an additional pulse or a pulse having a greater width to the solenoid actuated valve 24 so as to increase the injection time duration.

The cooling water temperature is sensed by a sensor 74 having a temperature-sensitive resistance which is located in the cooling water. The temperature of the cooling water may be approximated by the temperature of the cooling oil, exhaust gases or engine body, if preferred. The signal indicative of the cooling water temperature is fed to the electronic control unit 26 via a line 75 to provide for starting and warm-up fuel mixture enrichment. The enrichment of the fuel mixture is accomplished by causing the electronic control device 26 to apply an additional pulse or a pulse having a greater width to the solenoid actuated valve 24. Since two-cylinder, simultaneous injection system is shown to be employed in this embodiment, the electronic control unit 26 generates an electric pulse at the rate of two for each cycle of the engine operation in response to the signals produced in the above described manner. The pulse is fed to the solenoid-actuated injection valve 24 through lines 76 and 77 to provide for fuel injection. The line 76 is connected to the injection valve associated with the first and third cylinders and the line 77 is connected to the injection valves associated with the second and fourth cylinders, so that fuel injection takes place simultaneously in the first and third cylinders, followed by simultaneous fuel injection in the second and fourth cylinders. Then, the electric pulse is passed alternately through the lines 76 and 77 to injection valve 24.

A block diagram of the electronic control unit 26 is shown in FIG. 4. The engine driven triggering device 28 which is enclosed within a broken line comprises a cam 80 mounted on a distributor shaft 81 rotating at one-half of the crankshaft speed. Two movable contacts 82 and 83 are attached respectively to pivoted contacts 84 and 85 which are grounded and adapted to be oscillated by the cam 80 once for each rotation thereof. Stationary contacts 86 and 87 are associated with the movable contacts 82 and 83, respectively, and are connected to the electrical power supply such as a battery 88 by way of resistors 89 and 90, respectively. The two sets of contacts 82 and 86, 83 and 87 are adapted to be opened and closed for every rotation of the cam 80. The stationary contacts 86 and 87 are connected to a pulsewidth calculating circuit 91 through lines 92 and 93, respectively.

The pulsewidth calculating circuit 91 is adapted to receive the signal indicative of the engine speed and crankshaft position from the engine driven triggering device 28 and the signal indicative of cooling water temperature from the cooling water temperature sensor 74. On the basis of those signals, the circuit 91 calculates a proper pulsewidth and generates a pulse hav-

ing such width at the rate of two pulses for each rotation of engine operation. The pulses are passed alternately to injection pulse amplifiers 94 and 95 for amplification. The pulses thus amplified are further passed alternately through lines 96 and 97 to the solenoid means 98 and 99 which actuate valves associated with injection nozzles 100 and 101, respectively. The nozzles 100 and 101 are alternately opened by energization of the solenoids 98 and 99, respectively, once for each cycle of engine operation to provide for fuel injection.

The electronic control unit 26 includes an acceleration circuit 102 and a fuel cutoff circuit 103 in addition to the above-mentioned circuits. The output of the acceleration circuit 102 is connected to the injection pulse amplifiers 94 and 95 via lines 104 and 105, respectively, so that, when the acceleration signal issues from the throttle position detector 72 with the throttle valve 33 opened for acceleration, the injection pulse amplifiers 94 and 95 increase the width of the pulse passed from the pulsewidth calculating circuit 91 to the solenoid means 98 and 99 or apply an additional pulse to the solenoid means 98 and 99 so as to increase the injection time duration for acceleration enrichment. The output of the fuel cutoff circuit 103 is connected to the injection pulse amplifiers 94 and 95 through lines 106 and 107, respectively. This circuit 103 has its input connected to the engine driven triggering circuit 28 through lines 108 and 109 to receive a signal indicative of the engine speed and connected to the throttle valve position detector 72 through a line 73 to receive a signal indicative of the throttle valve position. If the engine speed reaches a certain value during coasting and if the throttle valve 33 is in an idle position, the fuel cutoff circuit 102 disables the injection pulse amplifiers 94 and 95 to close the nozzles 100 and 101 so as to stop delivery of fuel to the individual cylinders.

FIG. 5 shows circuit connections of the pulse-width calculating circuit 91 which forms a major part of the electronic control unit 26 shown in FIG. 1. In FIG. 5, only a half of the whole circuit generating a pulse to be applied to the injection pulse amplifier 94 is shown for clarity of illustration. The stationary contact 86 is connected to the base of a transistor 111 the emitter of which is directly grounded. The base of the transistor 111 is connected via a resistor 112 to a bus line 113 leading to the battery 88. The collector of the transistor 111 is connected to a charging circuit 114 comprising a rectifier 115, a resistor 116 and a capacitor 117, all of which are serially connected between the bus line 113 and the ground. Connected to a point 118 between the resistor 116 and capacitor 117 is the base of a transistor 119, the emitter 120 of which is grounded via a resistor 121. The emitter 120 is also connected to a point 122 between the rectifier 115 and resistor 116 via a capacitor 123. The collector of the transistor 119 is connected directly to the bus line 113. The charging circuit 114 and the transistor 119 comprise a saw-tooth wave generator 124.

The output of the saw-tooth wave generator 124 is connected to the input of a Schmidt circuit 125 comprising two transistors 126 and 127. To the input of the Schmidt circuit 125 is also connected the output of the cooling water temperature sensor 74. The transistor 126 has its base connected to the bus line 113 via a resistor 128 and grounded via a resistor 129. The collector of the transistor 126 is connected to the bus line

113 via a resistor 130 and to the base of the transistor 127 via a parallel circuit of a capacitor 131 and a resistor 132. The emitters of the two transistors 126 and 127 are connected together to ground via a resistor 133. The transistor 127 has its collector connected to the bus line 113 via a resistor 134 and to the injection pulse amplifier 94.

The operation of the pulsewidth calculating circuit 91 is shown in FIG. 6. As shown, (a) and (b) show the square wave voltage appearing at points X and X' leading to the stationary contacts 86 and 87, respectively. When the contacts 82 and 86 are closed by the action of the cam 80, the voltage at X turns to zero level, causing the transistor 111 to be cutoff. At this moment, the capacitor 117 starts to be charged and simultaneously the voltage at Y point leading to the emitter 120 of the transistor 119 starts to increase, as shown in (c) of FIG. 6. When, thereafter, the contacts 82 and 86 are opened by the cam 80, the transistor 111 is rendered conducting, causing the transistor 119 to be cutoff to thereby reduce the voltage at point Y to zero level.

The Schmidt circuit 125 compares the input voltage with a certain reference voltage as shown in (d) of FIG. 6. When the input voltage is built up to this reference voltage, transistor 126 is rendered conducting, causing the transistor 127 to become nonconducting. Hence, a pulse appears at the collector of the transistor 127, the width of which pulse is equal to the time duration in which the input voltage is higher than the predetermined reference voltage, as shown in (e) of FIG. 6. As the engine speed rises, the number of the square-wave pulses appearing at points X and X' for a certain period of time increases, resulting in certain reduction in the pulsewidth. It therefore follows that the width of the pulse obtained at the collector of the transistor 127 decreases as the engine speed increases, as shown in (e) of FIG. 6 and in FIG. 7.

The signal which is indicative of the cooling water temperature is applied to the input of the Schmidt circuit 125 so as to increase the pulsewidth for starting and warm-up fuel mixture enrichment.

FIG. 8 shows the ranges of the required quantity Q_1 of the fuel injected against the engine speed N , the shown ranges being determined in relation to an increase in the engine output power at full throttle and to a decrease in the fuel consumption and the quantity of the unburned exhaust emission at part throttle. Such ranges may be determined otherwise for the purpose of achieving different purposes. The relationship between the quantity of the fuel injected and the engine speed may fall within the ranges B_1 , B_2 and B_3 , which correspond to full throttle, -200mmHg and -400mmHg intake vacuum conditions, respectively. These ranges remain substantially unchanged irrespective of the variation in the engine speed but take the form of arcuate strips which are convex around the middle of the entire speed range.

As described above and shown in FIG. 3, the quantity Q of the fuel injected with the injection nozzle kept open for a certain period of time is substantially proportional to the engine speed N . However, as represented by the solid line c in FIG. 7, the width of the pulse applied to the solenoid-actuated valve decreases inversely proportionally with an increase in the engine speed. Thus, the quantity Q_1 of the fuel injected for each cycle of the engine operation remains substantially unchanged irrespective of the variation in the en-

gine speed, as indicated by the solid lines c_1 , c_2 and c_3 in FIG. 8. When the pulsewidth decreases linearly as the engine speed increases as indicated by the chain center line d of FIG. 7, the quantities of the fuel injected for each cycle of the engine operation at full throttle, -200mmHg and -400mmHg intake vacuums are shown by the dotted lines d_1 , d_2 and d_3 , respectively, in FIG. 8. The lines c_1 , c_2 , c_3 , d_1 , d_2 and d_3 fall within the ranges B_1 , B_2 and B_3 of FIG. 8 which are calculated from different engine requirements.

FIG. 9 shows the range of the required quantity Q_1 of the fuel injected in terms of the intake manifold vacuum P . The relationship between the quantity Q_1 of the fuel injected and the intake manifold vacuum P may fall within the hatched area defined between the upper and lower limits lines e_1 and e_2 , respectively. With a view to increasing the output power at full throttle and decreasing the fuel consumption and the quantity of unburned exhaust at part throttle, the air-fuel mixture should be enriched at full throttle and leaned off at part throttle, as previously noted. It is thus required that the quantity of the fuel injected be increased abruptly as the intake vacuum decreases from ΔP , as shown in FIG. 9. This purpose can be achieved by the use of the two springs 55 and 56 having different spring constants. At and near the full throttle position, only the less stiff one of the two springs 55 and 56 acts upon the diaphragm 53, while as the intake vacuum reaches the point ΔP , not only both of the springs act upon the diaphragm 53.

Although the quantity of the fuel injected may be adjusted in accordance with the variations in an atmospheric pressure and a temperature of the atmospheric air (or of the intake air) by using an atmospheric pressure sensor and an intake air temperature sensor the outputs of which are applied to the electronic control unit 26 for controlling the pulsewidth, the bellows 65 is employed to adjust the fuel pressure in relation to the variations in an atmospheric pressure and a temperature the atmospheric air. When the atmospheric pressure is relatively low and the atmospheric temperature is relatively high, the rod 64 attached to the bellows 65 is held in its protracted position, so that the piston rod 48 is moved upward to increase the effecting open area of the communication between the inlet and outlet ports 49 and 50 with the result that the pressure in the fuel distributing pipe 15 decreases accordingly. Conversely, when the atmospheric pressure is relatively high and the atmospheric temperature is relatively low, a relatively high fuel pressure prevails in the pipe 15.

Unless it is desired to adjust the fuel supply pressure in accordance with the atmospheric pressure and temperature, the actuating rod 54 may be connected directly to the piston rod 48.

A bellows within which a near-vacuum develops may be used in lieu of the diaphragm unit 45 having two springs 55 and 56. In this instance, the bellows is coupled with the intake manifold collector 59 so as to be controlled by the absolute pressure therein which substantially corresponds to the engine loads. Such bellows may be controlled in accordance with the atmospheric pressure simultaneously as fuel pressure is controlled.

What is claimed is:

1. A fuel injection system for a multi-cylinder internal combustion engine having an intake manifold, and

an intake manifold branch passage leading from said intake manifold, said fuel injection system comprising, in combination, a fuel pump having a fuel outlet and driven by said engine for delivering pressurized fuel to said fuel outlet at a pressure substantially proportional to the engine speed, a fuel distributing pipe connected to said fuel pump, pressure regulating means connected to said fuel distributing pipe for regulating the pressure of said pressurized fuel in said fuel distributing pipe, said pressure regulating means having diaphragm means communicating with said intake manifold and responsive to an intake manifold vacuum to cause said pressure regulating means to regulate the pressure of said pressurized fuel in said fuel distributing pipe in dependence on the intake manifold vacuum, a fuel injection nozzle communicating with said fuel distributing pipe and opening into said intake manifold branch passage for injecting fuel therein, a fuel injection control valve associated with said fuel injection nozzle and having solenoid means for selectively opening and closing said fuel injection nozzle, and an electronic control circuit electrically connected to said solenoid means of fuel injection control valve, said electronic control circuit including an engine driven triggering device for producing a pulse signal dependent upon the engine speed and the crankshaft position and a pulse with calculating circuit connected to said engine driven triggering device and responsive to said pulse signal for producing a fuel injection pulse signal to be supplied to said solenoid means of said fuel injection control valve, said pulse width calculating circuit having means for decreasing the pulse width of said fuel injection pulse signal in proportion to the engine speed, whereby the pressure of said pressurized fuel to be injected into said intake manifold branch passage is increasing substantially proportionally with an increase in the engine speed whereas the pulse width of said fuel injection pulse signal decreases proportionally with an increase in the engine speed, and the quantity of the fuel to be injected for each cycle of the engine operation remains substantially unchanged irrespective of the variation in the engine speed.

2. A fuel injection system for an internal combustion engine having an intake manifold, and an intake manifold branch passage leading to an engine cylinder, said fuel injection system comprising, in combination, a fuel tank for storing a fuel to be supplied to said engine cylinder, a fuel pump connected to said fuel tank and driven by said engine to pump the fuel from said fuel tank at a pressure substantially proportional to the engine speed, a fuel distributing pipe connected to said fuel pump, pressure regulating means connected to said fuel distributing pipe for regulating the pressure of fuel therein, said pressure regulating means having first and second chambers, said first chamber having an inlet port communicating with said fuel distributing pipe and an outlet port communicating with said second chamber, said second chamber storing fuel flowing therein and connected to said fuel tank for discharging the fuel in said second chamber to said fuel tank, a spool valve slidably received in said first chamber for controlling the degree of communication between said inlet and outlet ports thereby to regulate the pressure of fuel in said fuel distributing pipe, and diaphragm means associated with said pressure regulating means for controlling the movement of said spool valve, said diaphragm means including a housing having therein a vacuum

chamber communicating with said intake manifold, a diaphragm secured to said housing and responsive to an intake manifold vacuum, said diaphragm being interconnected to said spool valve of said pressure regulating means and spring means disposed in said vacuum chamber for biasing said diaphragm to a position in which said spool valve is moved to decrease the degree of communication between said inlet and outlet ports of said pressure regulating means, a fuel injection nozzle connected to said fuel distributing pipe and opening into said intake manifold branch passage for injecting fuel thereinto, a control valve associated with said fuel injection nozzle and having solenoid means for opening and closing said fuel injection nozzle, and electronic control means electrically connected to said solenoid means of said control valve, said electronic control means including an engine driven triggering device for producing a pulse signal dependent upon the engine speed and the crankshaft position and a pulse width calculating circuit connected to said engine driven triggering device and responsive to said pulse signal for producing a fuel injection pulse signal to be supplied to said solenoid means of said control valve, said pulse width calculating circuit having means for decreasing the pulse width of said fuel injection pulse signal in proportion to the engine speed, whereby the pressure of said fuel to be injected into said intake manifold branch passage is increasing substantially proportionally with an increase in the engine speed whereas the pulse width of said fuel injection pulse signal decreases proportionally with an increase in the engine speed, and the quantity of the fuel to be injected for each cycle of the engine operation remains substantially unchanged irrespective of the variation in the engine speed.

3. A fuel injection system as claimed in claim 2, further comprising a mechanical linkage operatively interconnecting said diaphragm means with said pressure regulating means, said mechanical linkage having a lever at its one end connected to said diaphragm of said diaphragm means and having a connecting pin attached to the other end of said lever, and angled arm pivotally engaging at its one end with said connecting pin and rotatable about a stationary pivot, a bellows connected with another end of said angled arm for varying the position of said angled arm in response to the atmospheric pressure and temperature, and a spring member provided for biasing said another end of said angled arm against the force of said bellows, said lever being connected at its intermediate portion to said spool valve of said pressure regulating means, whereby movement of said lever caused by changes in the intake manifold vacuum and the atmospheric pressure and temperature varies the relative position of said spool valve thereby to vary the degree of communication between the inlet and outlet ports of said pressure regulating means.

4. A fuel injection system for an internal combustion engine having an intake manifold, and an intake manifold branch passage leading to an engine cylinder, said fuel injection system comprising, in combination, a fuel tank for storing fuel to be supplied to said engine cylinder, a fuel pump connected to said fuel tank and driven by said engine to pump the fuel from said fuel tank at a pressure substantially proportional to the engine speed, a fuel distributing pipe connected to said fuel pump, pressure regulating means connected to said fuel distributing pipe for regulating the pressure of fuel therein, said pressure regulating means having first and

second chambers, said first chamber having an inlet port communicating with said fuel distributing pipe and an outlet port communicating with said second chamber, said second chamber storing fuel flowing thereinto and connected to said fuel tank for discharging the fuel in said second chamber to said fuel tank, a spool valve slidably received in said first chamber for controlling the degree of communication between said inlet and outlet ports thereby to regulate the pressure of fuel in said fuel distributing pipe, and diaphragm means associated with said pressure regulating means for controlling the movement of said spool valve, said diaphragm means having a housing with a vacuum chamber communicating with said intake manifold, a diaphragm secured to said housing and responsive to an intake manifold vacuum, said diaphragm being interconnected to said spool valve of said pressure regulating means and spring means disposed in said vacuum chamber for biasing said diaphragm to a position in which said spool valve is moved to decrease the degree of communication between said inlet and outlet ports of said pressure regulating means, a mechanical linkage operatively interconnecting said diaphragm means with said pressure regulating means, said mechanical linkage having a lever at its one end connected to said diaphragm of said diaphragm means and having a connecting pin attached to the other end of said lever, an angled arm pivotally engaging at its one end with said connecting pin and rotatable about a stationary pivot, a bellows connected with another end of said angled arm for varying the position of said angled arm in response to the atmospheric pressure and temperature, and a spring member provided for biasing said another end of said angled arm against the force of said bellows, said lever being connected at its intermediate portion to said spool valve of said pressure regulating means, a fuel injection nozzle connected to said fuel distributing pipe and opening into said intake manifold branch passage for injecting fuel thereinto, a control valve associated with said fuel injection nozzle and having solenoid means for opening and closing said fuel injection nozzle, and electronic control means electrically connected to said solenoid means of said control valve, said electronic control means having an engine driven triggering device for producing a pulse signal having a pulse width dependent upon the engine speed and the crankshaft position and a pulse width calculating circuit connected to said engine driven triggering device, said pulse width calculating circuit having a switching transistor connected at its base to said engine driven triggering device, a saw-tooth wave generator connected to said switching transistor, and a Schmidt circuit having an input connected to said saw-tooth wave circuit and an output connected to said solenoid means of said control valve, said Schmidt circuit comparing an input voltage received from said saw-tooth wave circuit with a certain reference voltage for producing a fuel injection pulse signal having the pulse width decreasing in proportion to the engine speed, whereby the pressure of said fuel to be injected into said intake manifold branch passage is increasing substantially proportionally with an increase in the engine speed whereas the pulse width of said fuel injection pulse signal decreases proportionally with an increase in the engine speed, and the quantity of the fuel to be injected for each cycle of the engine operation remains substantially unchanged irrespective of the variation in the engine speed.