United States Patent

Jackson

[15] **3,683,870**

[45] **Aug. 15, 1972**

[54] **FUEL INJECTION SYSTEMS**

[72] Inventor: **Harold Ernest Jackson,** Devon, England

[73] Assignee: **Petrol Injection Limited,** Devon, England

[22] Filed: **June 15, 1970**

[21] Appl. No.: **46,201**

[30] **Foreign Application Priority Data**

June 27, 1969 Great Britain..........32,531/69
Sept. 17, 1969 Great Britain..........45,806/69

[52] **U.S. Cl.**.....**123/32 EA,** 123/119 R, 123/139 AW
[51] **Int. Cl.**..**F02m 51/00**
[58] **Field of Search**......123/119, 32 EA, 139.17, 32, 123/139

[56] **References Cited**

UNITED STATES PATENTS

3,314,407	4/1967	Schneider	123/148 E
3,543,739	12/1970	Mennesson	123/32 EA
3,429,302	2/1969	Scholl	123/32 EA
2,644,094	6/1953	Douglas	123/32 EA
3,430,616	3/1969	Glockler	123/32 EA
3,482,558	12/1969	Casey et al.	123/119 R
2,785,669	3/1957	Armstrong	123/119 R
2,948,272	8/1960	Woodward et al.	123/32 EA

Primary Examiner—Laurence M. Goodridge
Assistant Examiner—Cort Flint
Attorney—Holcombe, Wetherill & Brisebois

[57] **ABSTRACT**

A fuel injection system in which fuel flow through the injector nozzles is controlled by electrically operable interrupter valves. Electrical pulses to operate the interrupter valves are generated at constant frequency and the length of the pulses is varied with an engine operating parameter, for example engine air intake. Suitable pulse generating circuits and an arrangement for varying the pulse length with air intake are described.

13 Claims, 12 Drawing Figures

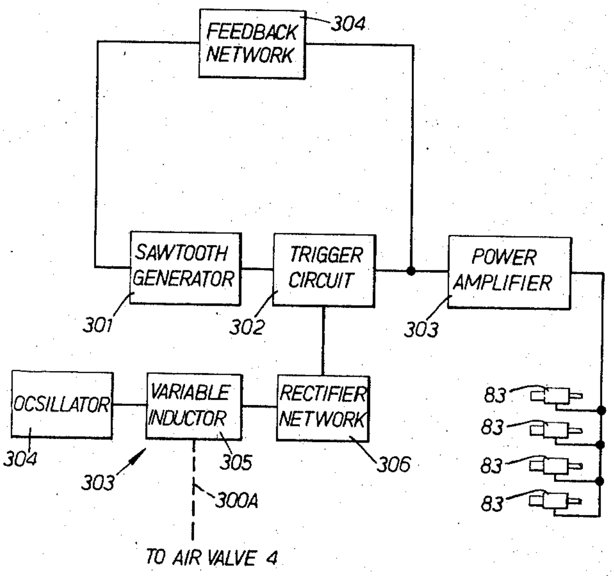
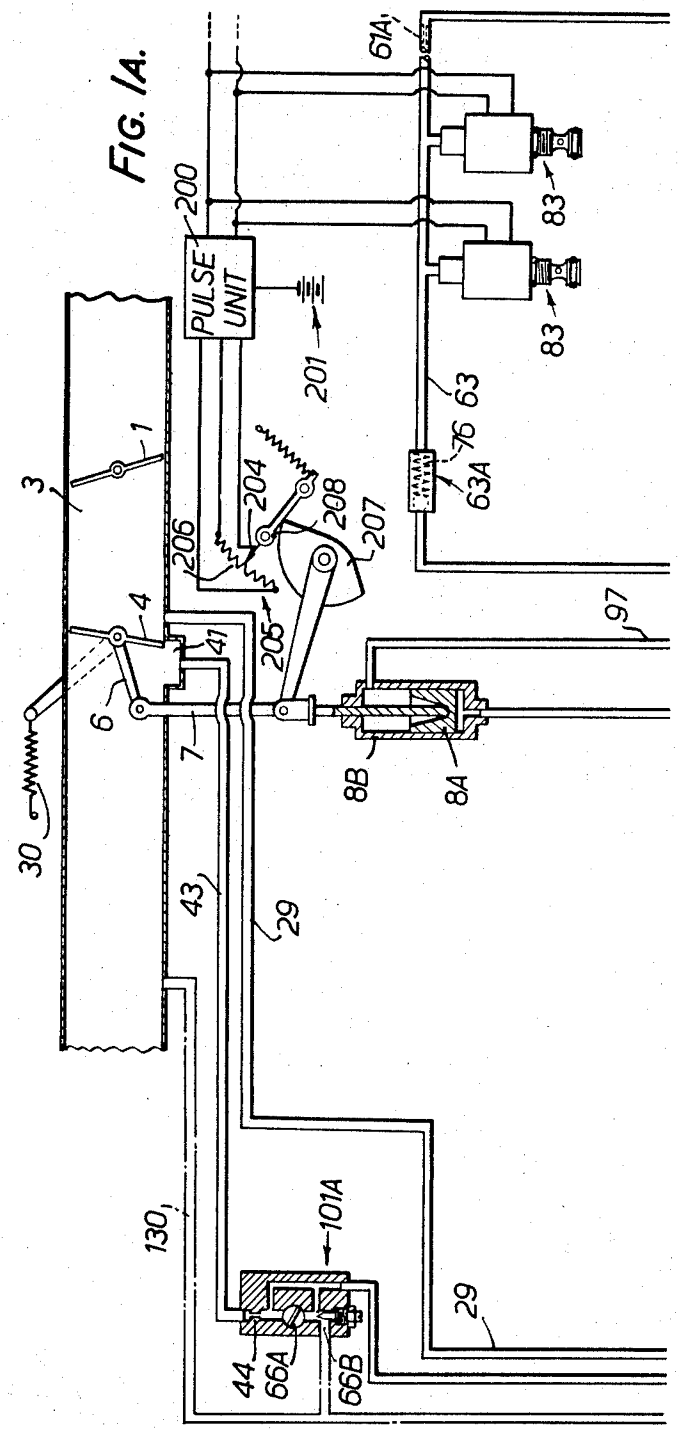


FIG. 1A.


PULSE UNIT
200
201
1
3
4
6
7
30
41
43
29
204
205
206
207
208
8A
8B
97
63
63A
76
61A
83
83
101A
130
29
44
66A
66B

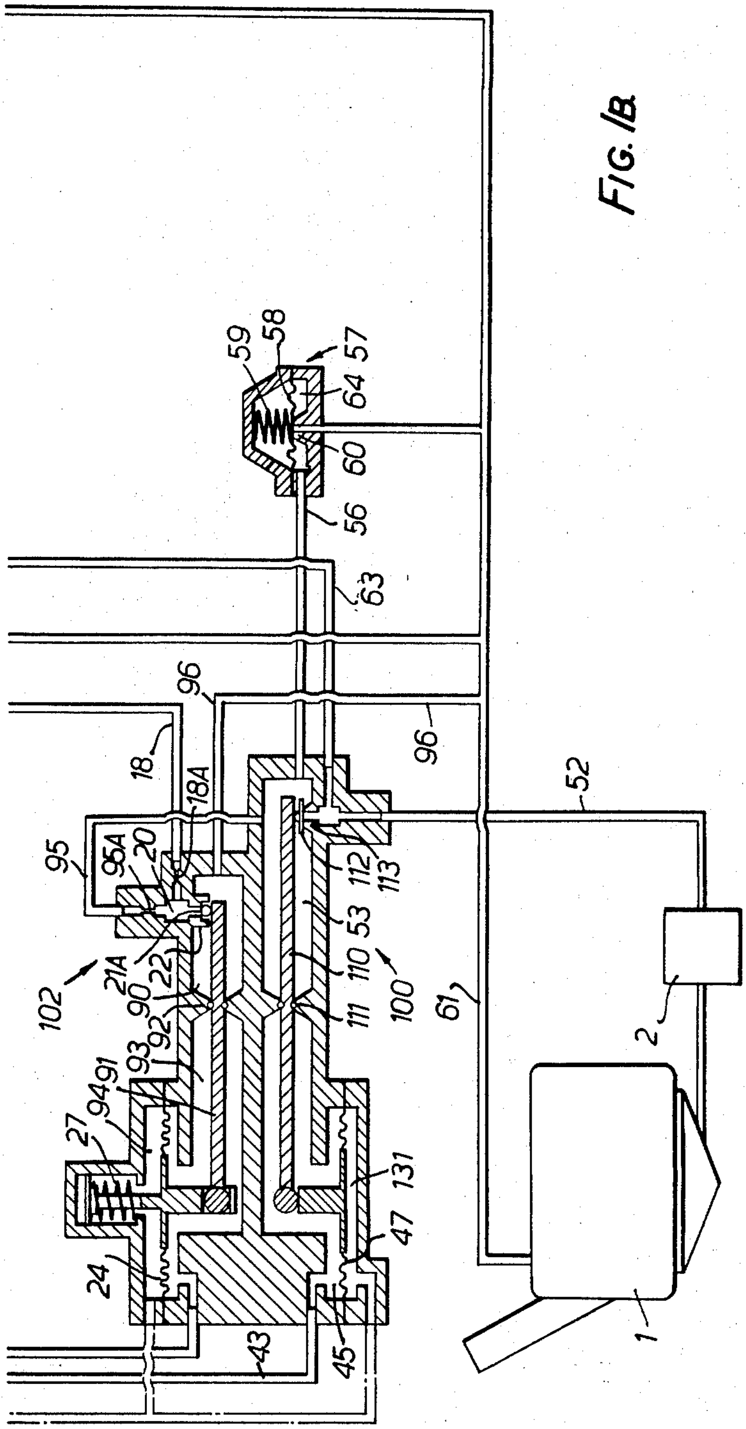

57
58
59
64
60
56
63
96
96
18
18A
95
95A
20
21A
22
90
92
93
91
94
27
24
43
45
47
131
102
112
113
53
110
111
100
61
52
2
1

FIG. 1B.

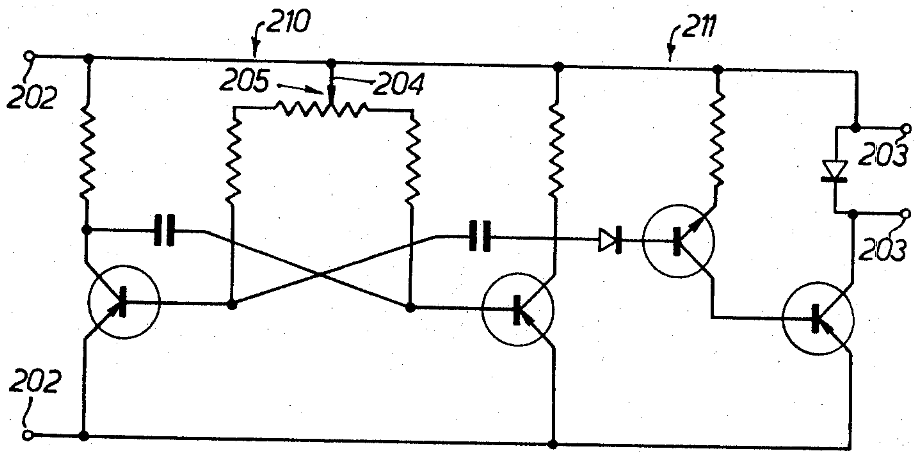

210
211
202
205
204
203
203
202

FIG. 2.

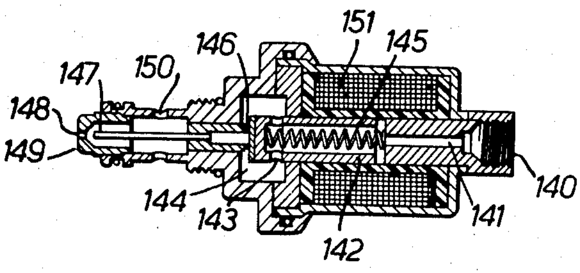

151
145
146
150
147
148
149
144
143
142
141
140

FIG. 3.

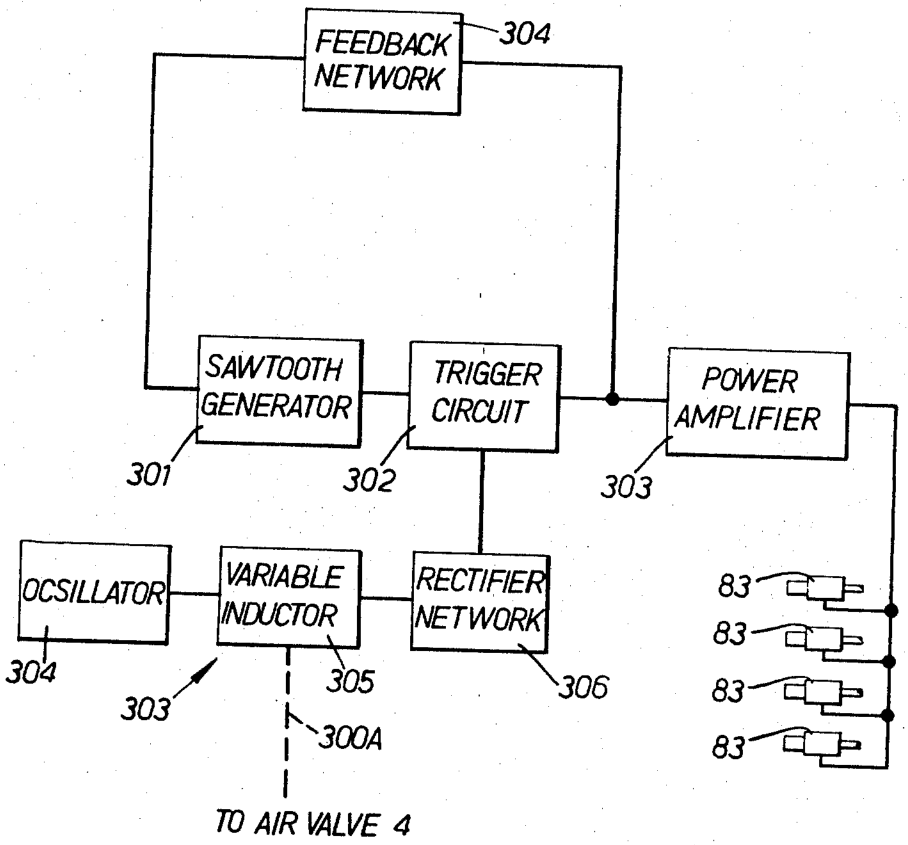

FEEDBACK NETWORK
304
SAWTOOTH GENERATOR
301
TRIGGER CIRCUIT
302
POWER AMPLIFIER
303
OCSILLATOR
304
303
VARIABLE INDUCTOR
305
RECTIFIER NETWORK
306
300A
TO AIR VALVE 4
83
83
83
83

FIG. 4.

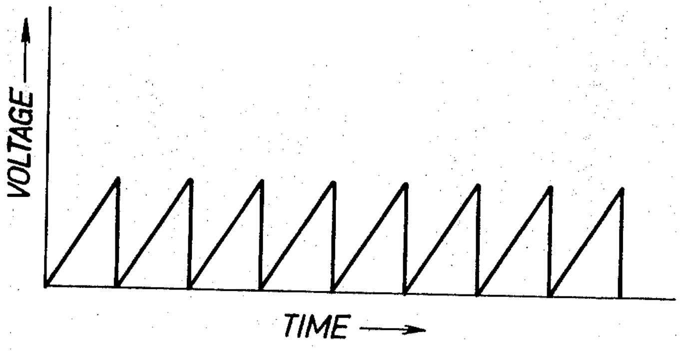


FIG. 5.

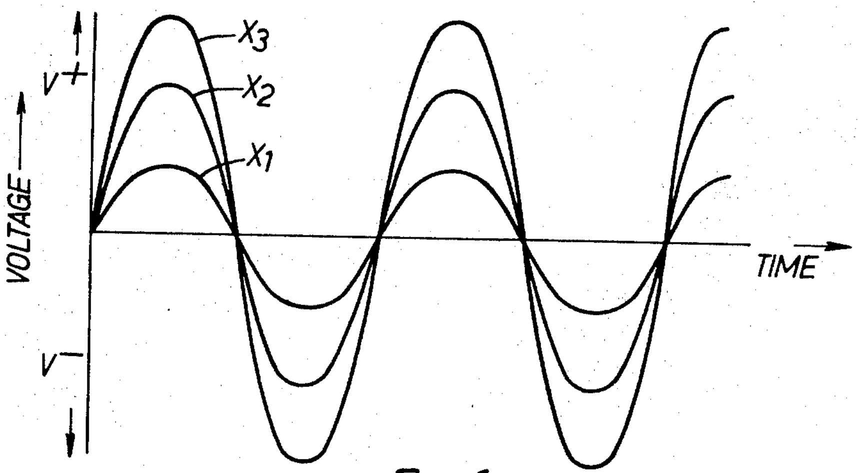


FIG. 6.

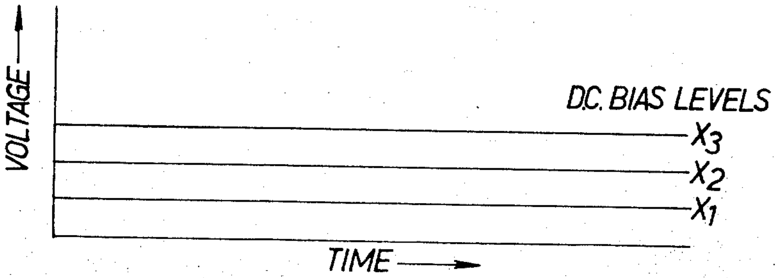


FIG. 7.

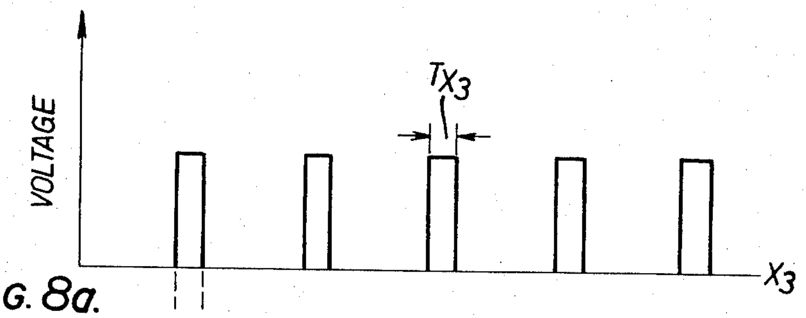


FIG. 8a.

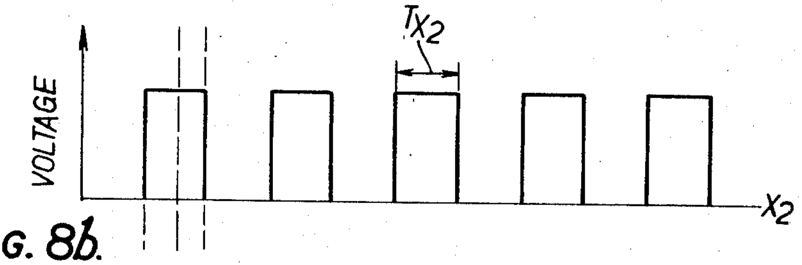


FIG. 8b.

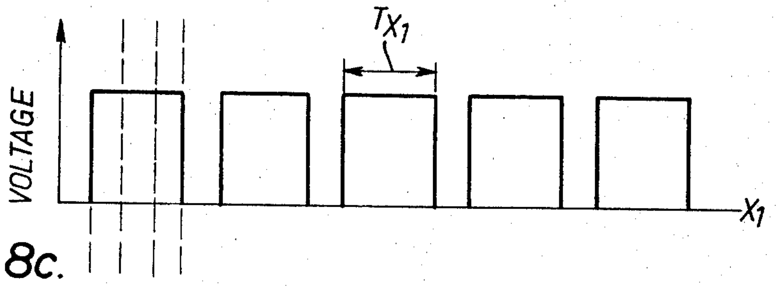


FIG. 8c.

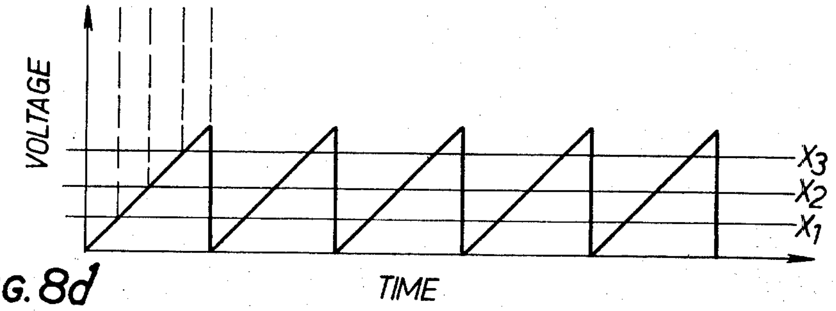


FIG. 8d

FUEL INJECTION SYSTEMS

This invention relates to fuel injection systems for internal combustion engines and, in particular, to systems in which the injection of fuel is intermittent rather than continuous.

In known systems employing intermittent injection, fuel is injected in timed relation to engine operation, the injection being controlled by an engine-driven mechanical or electrical device.

The present invention provides a fuel injection system for an internal combustion engine, including at least one fuel injection nozzle connected to receive fuel from a fuel flow path, at least one fuel interrupter valve actuable to control fuel flow through the injector nozzle(s), and an interrupter valve control mechanism operable to trigger the interrupter valve(s) into actuation at regular time intervals and responsive to at least one engine operating parameter to adjust the period of time for which the or each interrupter valve is actuated in response to variations in the said engine operating parameter(s).

During operation of the system, fuel supplied to an injector nozzle is discharged intermittently, the period of time over which discharge occurs, and hence the amount of fuel supplied to the engine being dependent on at least one engine operating parameter. The control mechanism may, for example, be operable to open the interrupter valve(s) to permit fuel flow through the injector nozzle(s) and to adjust the period of time for which the or each interrupter valve remains open.

The control mechanism may be operable to generate electrical operating pulses to actuate the interrupter valve(s). The control mechanism may, for example, be operable to generate operating pulses at the said regular time intervals, and to adjust the pulse length in response to variations in the said engine operating parameter(s).

The control mechanism may include an operating pulse generating circuit at least one component of which is responsive to the said one engine operating parameter and adjustable in response to variations in that parameter to adjust the operating pulse length. In an embodiment of the invention, the operating pulse generating circuit is an astable multivibrator circuit including at least one resistive component which is responsive to the said one engine operating parameter and is adjustable in response to variations in that parameter to adjust the operating pulse length.

In another form of the invention, the control mechanism includes a reference voltage generator operable to generate a reference voltage which varies periodically with time, a control signal generator operable to generate a control signal which varies in response to variations in the said one engine operating parameter, and an operating pulse generator responsive to the reference voltage and the control signal to generate an operating pulse when the reference voltage bears a predetermined relationship to the control signal. In an embodiment of this form of the invention the reference voltage generator is a sawtooth waveform generator and the control signal generator is operable to generate a bias voltage the level of which varies in response to variations in the said one engine operating parameter, the operating pulse generator being operable to generate an operating pulse when the reference voltage exceeds the bias voltage.

The said one engine operating parameter to which the interrupter valve control mechanism is responsive may be engine air intake. The system may, for example, include an engine air intake responsive mechanism operable to produce a control pressure differential in the engine air supply path and adjustable to maintain the control pressure differential at a substantially constant value, the interrupter valve control mechanism being operable to adjust the interrupter valve actuation period in response to adjustment of the air intake responsive mechanism.

The system may also include a fuel pressurizing device connected in the fuel flow path and operable to pressurize fuel in dependence on at least one engine operating parameter, for example engine air intake.

By way of example, a fuel injection system constructed in accordance with the invention will be described with reference to the accompanying drawings, in which:

FIG. **1** is a diagram of the system;

FIG. **2** is a circuit diagram of a component of the system;

FIG. **3** is a cross-section through the nozzle;

FIG. **4** is a block circuit diagram of an alternative form of the component illustrated in FIG. **2**, and

FIGS. **5** to **8** illustrate the variation of voltage with time at various points in the circuit of FIG. **4**.

In the system shown in FIG. **1**, fuel is drawn from a tank **1** and supplied by any suitable form of pump **2**, for example an electric, gear pump, to a supply conduit **52**. Fuel passes from the conduit **52** to a further supply conduit **63** at a pressure determined by a control valve mechanism **100**, and excess fuel is returned to the tank **1** via a chamber **53** in mechanism **100**, a conduit **56**, a relief valve **57** and a conduit **61**. The conduit **63** leads to the fuel injector nozzles **83** via a check valve **63A** and excess fuel is returned from the nozzles to the tank **1**, via a restrictor **61A** and the conduit **61**.

The injectors **83** are air-bled solenoid-operated nozzles and will be described below. Operation of the nozzles to discharge fuel is controlled by a unit **200** in dependence on a suitable engine operating parameter: in the system illustrated, the parameter is engine air intake as will be described below. The pressure control mechanism **100** also operates in dependence on engine air intake and the operation of this mechanism will also be described below.

The system also includes a fuel/air mixture enrichment valve **101A** which, although an advantageous feature, is not essential to the operation of the system.

The function of the injector control unit **200** will now be described. The unit is designed to produce a pulsating D.C. voltage when connected to a suitable source of electrical power **201**, the pulses occurring at a suitable constant frequency. The pulses are applied to the operating solenoids of the injectors **83** which are connected, as shown, to the output terminals of the unit **200**. The injectors **83** are thus caused to open at regular intervals (determined by the commencement of each one of the pulses from unit **200**) to discharge fuel supplied through the conduit **63**. The fuel is discharged into the mixture induction manifold of the engine, to be drawn into the engine cylinders, and when the operating pulse from unit **200** terminates, the injectors close and fuel discharge ceases. As will be described below, the length of the pulses generated by unit **200** and hence the period for which the injectors remain open is dependent on engine air intake.

A circuit diagram of the unit **200** is shown in FIG. **2**. The unit is, as can be seen from FIG. **2**, a combination of a conventional astable multivibrator stage **210** and a complementary power output stage **211** and, when the power source **201** is connected across the input terminals **202** a pulsating D.C. voltage is produced at the output terminals **203**. The circuit shown in FIG. **2**, being formed of conventional components, will not be described further, but it will be noted that the length (but not the frequency) of the output pulses can be adjusted, in known manner, by varying the position of the slider **204** of the potentiometer **205** in the multivibrator stage **210**. A suitable output pulse frequency is 50 cycles/sec. Preferably, the control unit **200** (without the potentiometer **205**) is formed as a unit which is easily removable from the system and replaceable in case of failure. It is not essential for the pulse-generating circuit of unit **200** to take the form shown in FIG. **2** and any other suitable pulse-generating circuit could be used. Other forms of control unit are also possible and one suitable alternative form will be described below with reference to FIGS. **4** to **8**.

In FIG. **1** the potentiometer **205** comprising slider **204** and resistor **206** is shown located outside the unit **200** to demonstrate the adjustment of the unit in dependence on engine air intake. The position of slider **204** is controlled by a cam **207** which co-operates with a follower **208** on which the slider **204** is mounted. The cam **207** is coupled to the control lever **7** of an air valve **4** located in the conduit **3** which feeds air to the engine in the direction left to right as seen in the drawings. The function of the air valve **4** will be described below. Also located in conduit **3** is the customary throttle valve **1**.

The lever **7** is also coupled to one side of a piston **8A** located in a cylinder **8B**. On the other side of the piston, the cylinder **8B** is connected, by a conduit **18** including a restrictor **18A**, to a chamber **20** in a manifold depression control unit **102**. The unit **102** functions through the air valve **4** to maintain a constant depression in the air intake conduit **3** between the air valve **4** and the throttle valve **1**. The manner of operation of the unit **102** is exactly the same as that of the mechanism **102** described in my copending U.S. Pat. application Ser. No. 31,316 filed Apr., 23, 1970.

The chamber **20** of manifold depression control unit **102** can communicate with a further chamber **90** in the unit under the control of a ball valve **21A** co-acting with a seat **22**. A control rod **91** extending from the chamber **90** through an O-ring seal **92** and into a chamber **93** couples the ball valve **21A** to a diaphragm **24** which separates the chamber **93** from a further chamber **94** (open, in the absence of conduit **130**, to atmosphere). The rod **91** is capable of rocking movement in the seal **92** and a spring **27** located in chamber **94** acts on the diaphragm **24** and hence on rod **91** to urge the ball valve **21A** away from the seat **22**. A conduit **29** joins chamber **93** to the air intake conduit **3** between the valves **1** and **4**, and a conduit **95** including a restrictor **95A** connects the chamber **20** to the chamber **53** of the pressure control valve mechanism **100**.

It was mentioned above that chamber **53** receives excess fuel from the supply conduit **52** and is connected, via relief valve **57** to the fuel tank **1**. The chamber **53** is, in fact, connected to a chamber **64** of the relief valve **57**, and the chamber **64** can communicate, under the control of a diaphragm **58**, with the conduit **61** leading back to the fuel tank **1**. The diaphragm **58** is loaded, by a spring **59**, against a valve seat **60** separating chamber **64** from conduit **61**, and thereby maintains a substantially constant fuel pressure in chamber **64** and hence in chamber **53**.

In operation of the system, the air valve **4** is urged towards a closed position by a spring **30**. When the throttle valve **1** is opened (the air valve **4** being in the closed position) there is created a depression in the conduit **29** which draws down the diaphragm **24**, so closing the ball valve **21A**. The substantially constant pressure determined by the relief valve **57** is then applied fully, via conduit **18**, on the piston **8A** causing the latter to move upward (as seen in FIG. **1**) and, through lever **7** to open the air valve **4**. Any leakage of fuel across the piston **8A** is returned to the tank **1** through a conduit **97**. The opening of air valve **4** reduces the depression in conduit **29** and, through diaphragm **24** opens the ball valve **21A** allowing fuel to leak from chamber **20** into chamber **90** and to be returned to the tank **1** via conduit **96**. The fuel pressure acting on piston **8A** is thereby reduced and the piston moves downwards (as seen in FIG. **1**) to close the air valve **4**. In this manner, the position of the air valve **4** adjusts to maintain a substantially constant depression in that portion of the conduit **3** between the valves **4** and **1**, the depression being determined by the setting of the control mechanism **102** and, in particular, by the strength of the spring **27**. It is to be noted that, provided the pressure in chamber **93** required to drive the ball valve **21A** fully open is less than the substantially constant relief valve pressure, the strength of spring **30** and the effects of friction in the piston **8A**, the linkage **6**, **7** etc. are in no way effective in altering the constant depression in the conduit **3** by any substantial amount. The valve of the restrictor **95a** is chosen to give a desired opening speed to the ball valve **21A**.

The air valve **4**, as mentioned above, coupled to the potentiometer **205** of the control unit **200** so that, as the air valve **4** opens, the length of the operating pulses applied to the injectors **83** increases and more fuel is fed to the engine.

The construction of the manifold depression control unit **102** is such that the O-ring seal **92** serves the purpose of sealing chamber **93** (which is exposed to the depression produced in the air intake conduit **3** between the valves **1** and **4**) from the chamber **90** (which contains fuel). The seal **92** is partly located in a groove in the rod **91** and partly in a groove in the housing of the unit and this particular construction permits rocking movement of the rod **91** as described above but prevents axial movement and minimizes friction and wear. In particular, the need for sliding or rotating seals between depression zones and pressurized fuel zones is overcome.

An injector nozzle **83** is shown in greater detail in FIG. **3**. The nozzle has a fuel inlet **140** which, in use, is connected to the fuel supply conduit **63**. The inlet **140** communicates, via a passage **141** with the interior of a tubular interrupter valve member **142**, which, in turn, communicates through ports **143** in the valve member wall with a chamber **144**. A spring **145** seated on an end portion of the valve member **142** biases the valve member against a seating **146**, in which position communication between the chamber **144** and a fuel tube **147** is cut-off by the valve member. The fuel tube **147** is a small diameter stainless steel tube and is aligned with an outlet orifice **148** in an outer jacket **149** surrounding the tube. The space between the tube **147** and the jacket **149** is vented through ports **150**. Movement of the valve member **142** is controlled by a solenoid **151** within which the valve member is partly located. The valve member **142**, or at least that portion of the valve member which is located within the solenoid is formed of a magnetizable material so that energization of the solenoid **151** moves the valve member away from the seating **146** and allows fuel to flow into the fuel tube **147**. Fuel is discharged through the outlet orifice **148** into the mixture induction manifold of the engine, air being drawn into the jacket **149** through the ports **150**. In use of the injector in the system shown in FIG. **1**, the solenoid **151** is connected to the output terminals of the control unit **200**, the valve member **142** thereby being moved to an open position at regular time intervals and held in that position for a length of time determined by the length of the output pulses from unit **200**.

The use of air-bled nozzles as shown in FIG. **3** is advantageous in that the effect on fuel flow of the depression in the manifold in which the nozzles are located is thereby eliminated. If air-bled nozzles are not employed, the effect may be eliminated by subjecting the upper surface (as seen in the drawing) of the diaphragm of relief valve **57** to the manifold depression. The nozzle shown in FIG. **3** has the further advantage that the fuel tube **147** acts as a fuel restrictor and, when a plurality of nozzles are connected in a system, serves to equalize fuel distribution between the nozzles. It will be appreciated that the use of the nozzle shown in FIG. **3** is not restricted to the system shown in FIG. **1**.

It was mentioned above that valve mechanism **100** controls the pressure at which fuel is supplied to injectors **83**. The mechanism **100** is exactly the same as the pressure control mechanism **100** described in my copending U.S. Pat. application Ser. No. 31,316 filed Apr. 23, 1970 and functions to increase the pressure of fuel supplied to the injectors **83** as the air flow through conduit **3** increases. To this end, the conduit **3** includes a closed end slot **41** which communicates with a conduit **43** leading, via a restrictor **44**, to a chamber **45** in the control mechanism **100**. A diaphragm **47**, bounding the chamber **45**, is coupled to one end of a control rod **110** (similar to rod **91** in the manifold depression control unit **102**) which extends through a seal **111** into the chamber **53** and carries, at its other end, a pressure control valve member **112**. The valve member **112** cooperates with a seating **113** to control fuel flow from the supply conduit **52** into the chamber **53**. The rod **110** is capable of rocking movement in the seal **111** and movement of the valve member **112** is controlled, through the rod, by the diaphragm **47**. The chamber **53** is connected, by conduit **56** to the relief valve **57**, as described above, the chamber **53** thereby being pressurized to the substantially constant relief valve pressure.

When the engine is not running, atmospheric pressure exists throughout the air intake conduit **3**, and hence in the chamber **45**. A chamber **131** on the other side of the diaphragm **47** to chamber **45** is also, in the absence of conduit **130**, exposed to atmospheric pressure so that there is no pressure differential across the diaphragm. The pressure in supply conduits **52** and **63** is then the same as that in chamber **53**. When the engine is running with its air consumption at a minimum (which is the idling mode of operation) the position of the air valve **4** is such that the right hand end of slot **41** lies just on the right side of air valve **4** (this position being shown in FIG. **3**). As a result, a small proportion of the constant depression developed in conduit **3** between the valves **1** and **4** is applied to conduit **43**.

The enrichment valve **101A** (which will be described below) is normally open and, for the present, it is sufficient to state that, under these circumstances and in the absence of conduit **130**, atmospheric air can pass via restrictors **66A** and **66B** in the valve **101A** into the conduit **43** so weakening the depression signal applied to diaphragm **47**. The weakened depression signal applied to diaphragm **47** acting through rod **110** urges the valve member **112** towards the seat **113** and, as a result, the fuel pressure in supply conduits **52** and **63** rises until equilibrium is restored. As the air consumption of the engine increases, air valve **4** opens further and, in doing so, exposes a greater length of the slot **41** to the constant depression between valves **4** and **1**. The increased depression (again weakened by atmospheric air admitted through restrictors **66A** and **66B** in valve **101A**) is applied to diaphragm **47** and results in an increased closing force on valve member **112** causing a further rise in fuel pressure in supply conduits **52** and **63**. During acceleration, if the throttle valve **1** is suddenly opened the depression between the valves **4** and **1** rises suddenly. The increase is effective immediately, through diaphragm **47** and valve member **112** to raise the fuel pressure in supply conduits **52** and **63**.

It will be appreciated however that the use of the pressure control mechanism **100** shown in FIG. **1** is not essential to the system and that other forms of fuel pressurizing device could be employed.

The relief valve **57** which, as mentioned above, maintains a substantially constant pressure in chamber **53** and a predetermined minimum pressure value in supply conduits **52** and **63** is preferably so adjusted that the minimum pressure value is sufficient to ensure that fuel in the system remains liquid at all times, even when fuel temperature rises considerably above normal ambient temperature.

The check valve **63A** located in the fuel supply line to injector devices **83** functions to enrich the fuel/air mixture supplied to the injectors under engine acceleration conditions, as may be seen from the following example:

Suppose that the normal depression between valves **1** and **4** in conduit **3** is 1 inch Hg; that the resultant fuel pressure in supply conduit **63** is 10 p.s.i.; that the substantially constant minimum pressure imposed by relief valve **57** is 15 p.s.i. and that the check valve **63A** is biased by a spring **76** which imposes a substantially constant load equivalent to 17 p.s.i. Under steady conditions the fuel metering pressure is then $10 + 15 - 17 = 8$ p.s.i.

On sudden acceleration, before the position of the air valve **4** has been adjusted, the depression between valves **1** and **4** may rise momentarily, for example to 2 inch Hg. This in turn raises the fuel pressure in conduit **63** to 20 p.s.i. The metering pressure is now 20 + 15 − 17 = 18 p.s.i. Thus, while the depression has changed in the ratio 2/1 the fuel metering pressure has changed in the ratio 2.25/1, providing enrichment during acceleration. When the air valve **4** has opened to restore the 1 inch Hg depression between valves **1** and **4**, the fuel metering pressure reverts to its original value but the new position of the air valve **4** is accompanied by readjustment of the potentiometer **205**.

The check valve **83A** also performs the secondary, but important, function of preventing fuel from being delivered to the injectors when the engine is not turning.

It will be seen from the above description that, in operation of the system fuel is supplied to the injector devices **83** at a pressure that is dependent on engine air intake and that the injectors open at regular time intervals but remain open for a length of time that is also dependent on engine air intake. It will be appreciated, however, that it is not essential for fuel pressure to be controlled by engine air intake and that another engine operating parameter could be employed. Alternatively, several operating parameters of which one may be air intake could be employed. Furthermore, the use of engine air intake to determine the length of time for which the injector nozzles remain open is also not essential and another engine operating parameter could be employed. Alternatively, several operating parameters of which one may be air intake could be employed. When control is effected by engine air intake it will be appreciated that it is not essential for arrangements utilizing the maintenance of a constant depression in the engine air intake to be employed.

It will also be appreciated that the arrangement shown in FIG. 1 for maintaining a constant depression in air intake conduit 3 and for thereby controlling pulse unit **200** and pressure control valve mechanism **100** could be replaced by the mechanism described in my copending U.S. Pat. application, No. 31,315, filed Apr. 23, 1970.

The valve **101A** which has been mentioned above is a manually operated valve which functions to enrich the fuel/air mixture supplied to the engine, for example when the engine is cold. The operation of the valve **101A** will now be described.

When valve **101A** is open, atmospheric air is admitted, as described above, to conduit **43** via restrictors **66A** and **66B** in the valve. The restrictor **66A** can be closed manually to restrict the flow of atmospheric air into conduit **43** and thereby increase the effective depression applied to diaphragm **47** and raise fuel pressure in the supply conduits **52** and **63**. The result is that the engine receives a richer fuel/air mixture. The restrictor **66B** which remains open under all operating conditions is adjustable to vary the setting of valve **101A**.

It will be appreciated that, although valve **101A** was referred to above as having utility under engine starting conditions it is not restricted to use under these conditions and could, being a manually-operated valve, be used whenever a richer fuel/air mixture is required. It will also be appreciated that the valve **101A** is not essential to the functioning of the manifold depression control unit **102** or (except in so far as it provides a restriction **66A**, **66B** through which atmospheric air is admitted to conduit **43**) to the functioning of the pressure control mechanism **100**: the valve **101A** could, accordingly, be omitted.

The conduit **130** which is shown in dotted lines in FIG. **1** and which, in the above description, was assumed to be absent, connects the air intake conduit **3** on the atmospheric side of the valves **1** and **4** to the chamber **94** in the manifold depression control unit **102** and also to the chamber **131** in the pressure control mechanism **100** and the atmospheric air inlet of the enrichment valve **101A**. The purpose of this conduit **130** is to nullify any effect on the depression between valves **1** and **4** of the flow resistance of the air cleaner normally included in the inlet of air intake conduit **3**. This flow resistance could have a particularly noticeable effect under high engine power conditions: the conduit **130** is, however, not essential and, as described above, chambers **131** and **94** and the inlet of valve **101A** could be left open to atmosphere.

The alternative form of control unit mentioned above and shown in FIG. **4** to **8** would, in use, replace the control unit **200** including the potentiometer **205** in FIGS. **1** and **2**. The components of the alternative control unit are illustrated diagrammatically in FIG. **4** and include a sawtooth waveform generator **301** the output of which is connected to the input of a trigger circuit **302**. The trigger circuit **302** produces the operating pulses for the injector devices **83**, the output of the trigger circuit **302** being connected to the operating solenoids of the injector devices **83** through a power amplifier **303**. The output of the trigger circuit **302** is also connected back to the input of the sawtooth waveform generator **301** through a feed back network **304**.

The sawtooth waveform generator **301** produces a constant frequency output voltage as illustrated in FIG. **5**: a suitable frequency is 50 cycles/sec. The trigger circuit **302** produces a square output pulse when the input from the generator **301** exceeds a predetermined value determined by a control circuit **303**. This predetermined value is variable in dependence on engine air intake, as will be described below, to adjust the length of the trigger circuit output pulse. The output frequency of the trigger circuit **302** is, however, constant and corresponds to the output frequency of generator **301**.

The control circuit **303** also includes an oscillator **304**, a variable inductor **305** and a rectifier network **306**. The oscillator **304** produces an output of fixed frequency, for example 1,000 cycles/sec. which is fed to the variable inductor **305**. The inductor **305** is coupled, in any suitable manner, (as indicated at **300A** in FIG. **4**) to the air valve **4** in the engine air intake conduit **3** (FIG. **1**) whereby movement of the air valve **4** to maintain a constant depression in the intake conduit **3** as described above will adjust the inductor **305**. The inductor **305** may, for example, be coupled to the air valve lever **7** through a cam and cam follower in the manner described above and illustrated in FIG. **1** for the potentiometer **205**. Adjustment of the inductor **305** changes the amplitude of the output of oscillator **304** and the modified output is fed to the rectifier network **306**. In this network the signal is rectified and smoothed to produce a d.c. bias signal which is applied to the trigger circuit **302**. The level of the d.c. bias signal is dependent on the amplitude of the input to the rectifier network **306** and hence on engine air intake.

FIGS. 5 to 8 illustrate the variation of voltage with time at various points in the circuit shown in FIG. 4. FIG. 5 shows the output of the sawtooth generator **301** and FIG. 6 shows the input to the rectifier network **306** for three values X_1, X_2 and X_3 of the inductance **305** (that is, for three values of engine air intake). FIG. 7 shows the output of the rectifier network **306** for the same three values of inductance.

FIG. 8 illustrates the manner in which the d.c. bias signal from the control circuit **303** controls operation of the trigger circuit **302**. In FIG. 8*d* the d.c. bias signals for inductance values X_1, X_2 and X_3 are shown superimposed on the output of generator **301**. The trigger circuit **302** produces an output pulse when the output of generator **301** exceeds the bias signal from control circuit **303**: FIGS. 8*a*, 8*b* and 8*c* show the output of trigger circuit **302** for inductance values X_3, X_2 and X_1 respectively from which it can be seen that the output frequency of the trigger circuit remains constant but that the length of the trigger circuit output pulses decreases as the d.c. bias level applied by control circuit **303** increases. The length of the trigger circuit output pulses determines the length of time for which the injector nozzles **83** are open. The length of time for which the injector nozzles **83** are open is thus dependent on engine air intake, as with the control unit shown in FIG. 2.

The components illustrated diagrammatically in FIG. 4, that is, generator **301**, trigger circuit **302** etc. are well known and need not, therefore, be described in detail. It will be appreciated, however, that the sawtooth generator **301** could be replaced by a generator of any other suitable reference voltage waveform. In addition, other arrangements could be employed (instead of the oscillator **304** and variable inductor **305** illustrated) to generate an oscillating control signal the amplitude of which is dependent on engine air intake.

Preferably this alternative form of control unit is also a unit which is easily removed from the fuel injection system and can be replaced in case of failure.

Finally, it should be appreciated that although the systems described above employ a plurality of injector devices **83** each incorporating a solenoid-operated interrupter valve, that is not essential and the plurality of solenoid-operated injector devices could, for example, be replaced by a single solenoid-operated interrupter valve operable intermittently by the control unit **200** (FIG. 1) to feed fuel to a plurality of open injector nozzles via respective pressure-responsive control valves. An arrangement of this type is disclosed in my copending U.S. Pat. application Ser. No. 91,937 filed Nov. 23, 1970.

I claim:

1. A fuel injection system for an internal combustion engine, including a source of fuel under pressure, a fuel flow path, at least one fuel injector nozzle connected to receive fuel from the fuel flow path, at least one electrically operable fuel interrupter valve actuable to control fuel flow through the injector nozzle(s), and an electrical control circuit arrangement operable to generate electrical operating pulses at a continuous constant frequency independent of engine operation and connected to apply said pulses to the interrupter valve(s) to actuate the interrupter valves(s), said control circuit arrangement including means electrically connected in said circuit arrangement and responsive to at least one engine operating parameter to adjust the length of said operating pulses, and thereby adjust the period of time for which the or each interrupter valve is actuated, in response to variations in the said engine operating parameter(s).

2. A system as claimed in claim **1**, in which the control circuit arrangement is operable to generate the operating pulses to open the interrupter valve(s) to permit fuel flow through the injector nozzle(s).

3. A system as claimed in claim **1**, in which the control circuit arrangement is an astable multivibrator circuit including at least one resistive component which is responsive to the said one engine operating parameter and is adjustable in response to variations in that parameter to adjust the operating pulse length.

4. A system as claimed in claim **1**, in which the control circuit arrangement includes a reference voltage generator operable to generate a reference voltage which varies periodically with time, a control signal generator operable to generate a control signal which varies in response to variations in the said one engine operating parameter, and an operating pulse generator responsive to the reference voltage and the control signal to generate an operating pulse when the reference voltage bears a predetermined relationship to the control signal.

5. A system as claimed in claim **4**, in which the reference voltage generator is a sawtooth waveform generator and the control signal generator is operable to generate a bias voltage the level of which varies in response to variations in the said one engine operating parameter, the operating pulse generator being operable to generate an operating pulse when the reference voltage exceeds the bias voltage.

6. A system as claimed in claim **4**, in which the control signal generator includes means operable to generate an oscillating voltage the amplitude of which varies in response to variations in the said one engine operating parameter.

7. A system as claimed in claim **6**, in which the oscillating voltage generator includes an inductive component which is responsive to the said one engine operating parameter and is adjustable in response to variations in that parameter to vary the amplitude of the oscillating voltage.

8. A system as claimed in claim **1**, in which the said one engine operating parameter is engine air intake.

9. A system as claimed in claim **8**, including an engine air intake responsive mechanism operable to produce a control pressure differential in the engine air supply path and adjustable to maintain the control pressure differential at a substantially constant value, the control circuit arrangement being operable to adjust the interrupter valve actuation period in response to adjustment of the air intake responsive mechanism.

10. A system as claimed in claim **1**, including a fuel pressurizing device connected in the fuel flow path and operable to pressurize fuel in dependence on at least one engine operating parameter.

11. A system as claimed in claim **10**, in which the said one engine operating parameter is engine air intake.

12. A system as claimed in claim 11, including an engine air intake responsive mechanism operable to produce a control pressure differential in the engine air supply path and adjustable to maintain the control pressure differential at a substantially constant value, the fuel pressurizing device being operable to vary the pressure at which fuel flows to the injector nozzle(s) in response to adjustment of the air intake responsive mechanism.

13. A system as claimed in claim 1, including a plurality of interrupter valves each actuable to control fuel flow through a respective injector nozzle.

* * * * *