United States Patent

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[33] Great Britain
[31] 16640/68

[54] **FUEL INJECTION SYSTEMS FOR INTERNAL COMBUSTION ENGINES**
17 Claims, 8 Drawing Figs.

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[51] Int. Cl. F02m 5/06
[50] Field of Search ..... 123/32, 32.1, 119, 139, 139.11, 139.15, 139.17, 139.18, 140.3, 198 DB

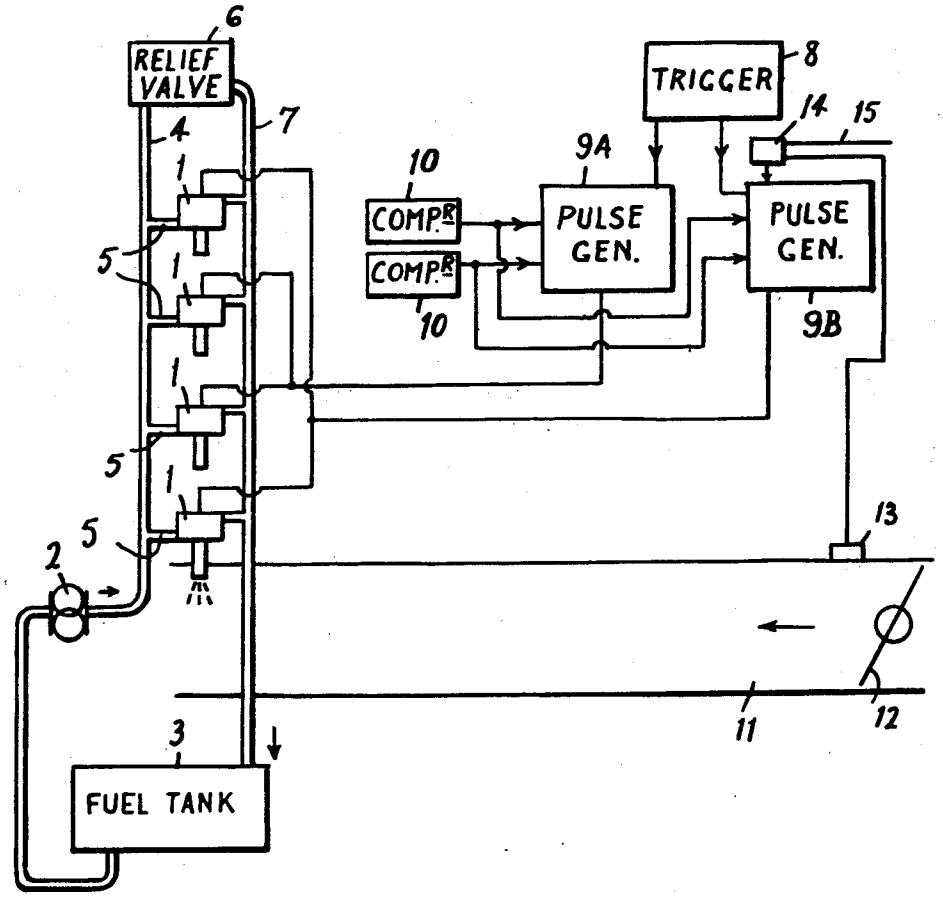
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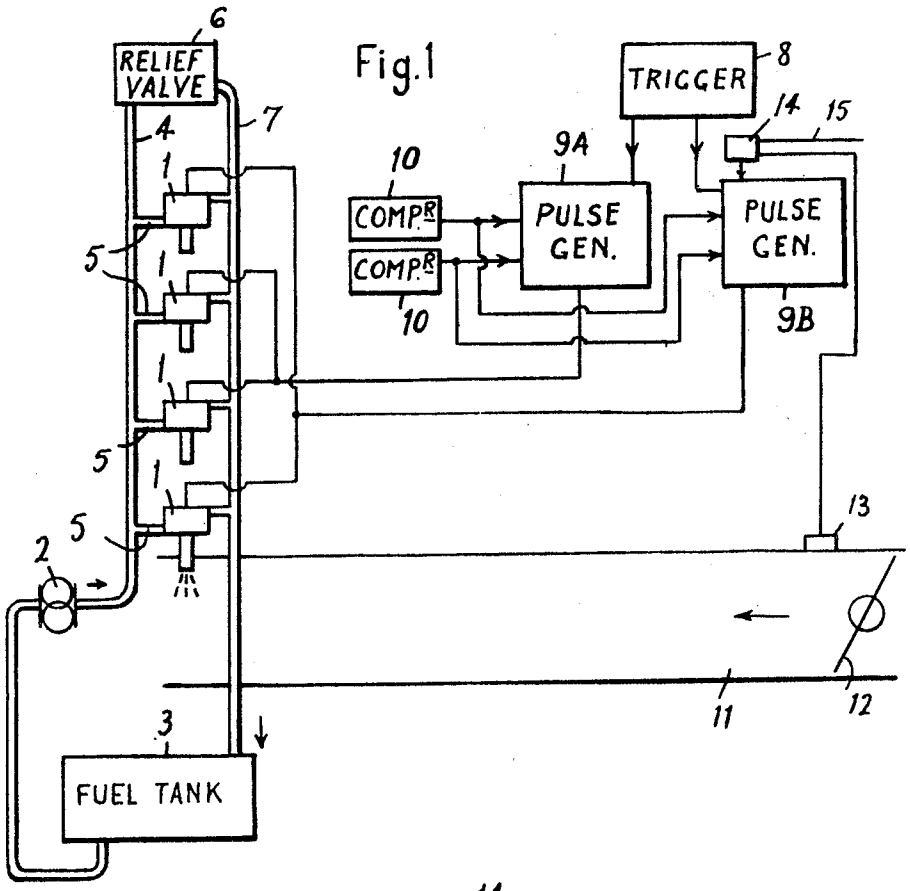
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ABSTRACT: This invention relates to fuel injection systems for internal combustion engines of the kind in which fuel is fed to an engine through one or more electrically operated fuel injection valves or injectors which are opened intermittently. The invention provides means for controlling the injection valve or valves under engine overrun conditions, and also means for controlling the fuel pressure to the injection valves in accordance with the engine induction passage pressure.




6
RELIEF VALVE
Fig.1
TRIGGER
8
14
15
7
4
10
9A
COMPR
COMPR
PULSE GEN.
PULSE GEN.
10
9B
1
5
13
2
11
12
3
FUEL TANK

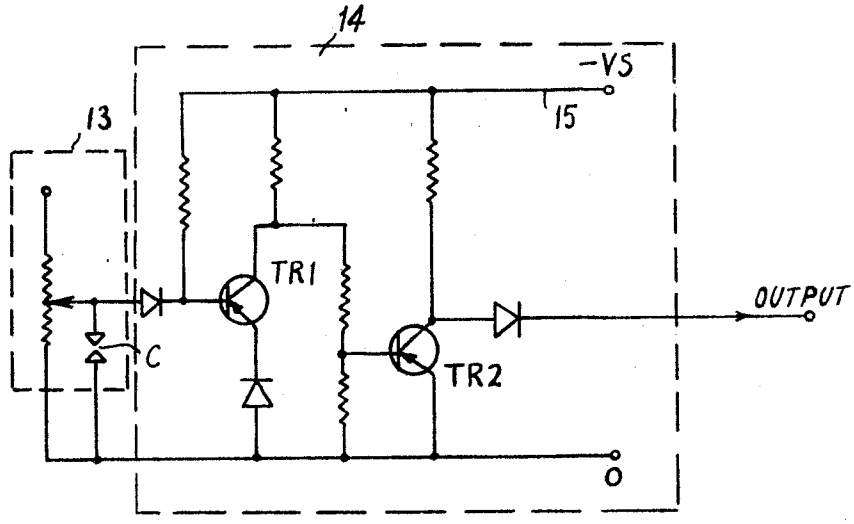

14
-VS
15
13
TR1
OUTPUT
C
TR2
0

Fig.2

Fig.4

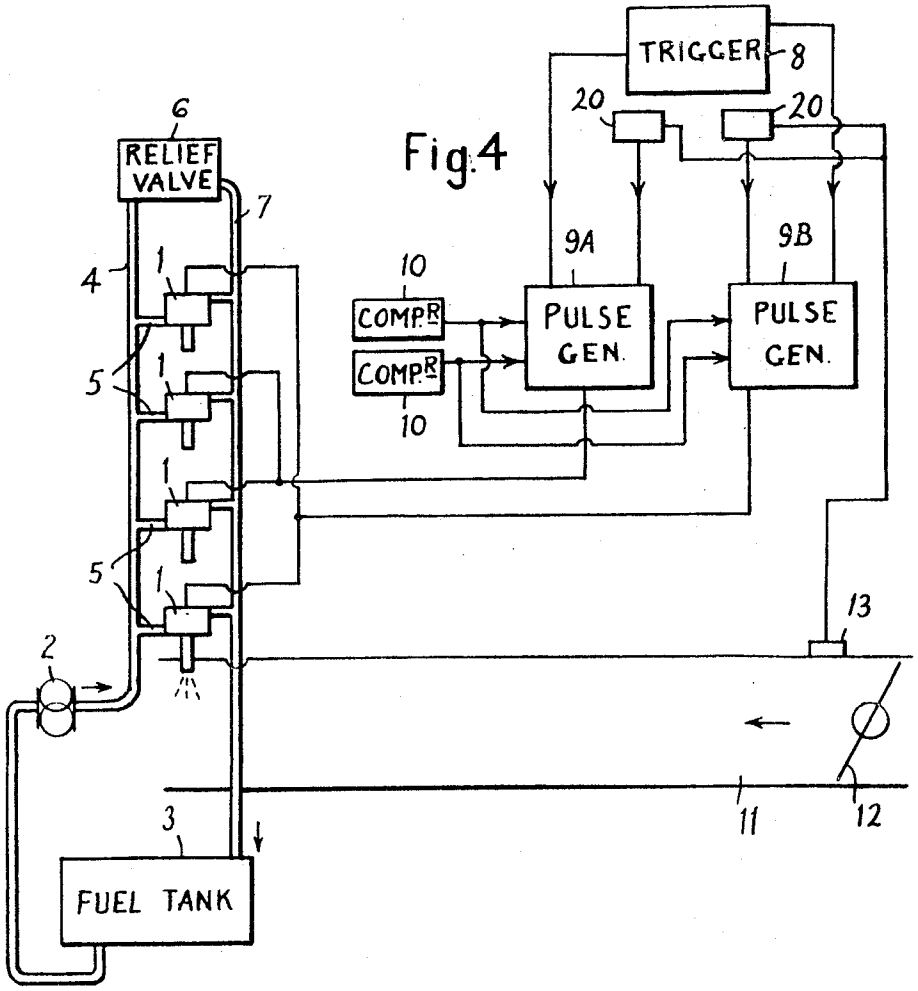
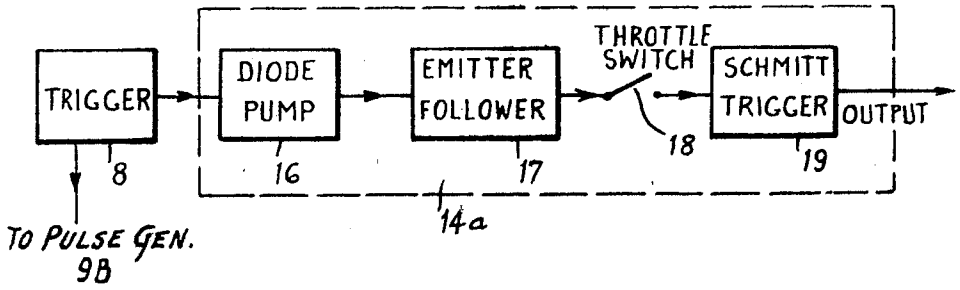

TRIGGER
8
20
20
6
RELIEF VALVE
7
9A
9B
10
COMPR
COMPR
10
PULSE GEN.
PULSE GEN.
4
5
1
5
2
13
3
11
12
FUEL TANK

Fig.3


TRIGGER
8
DIODE PUMP
16
EMITTER FOLLOWER
17
THROTTLE SWITCH
18
SCHMITT TRIGGER
19
OUTPUT
14a
TO PULSE GEN. 9B

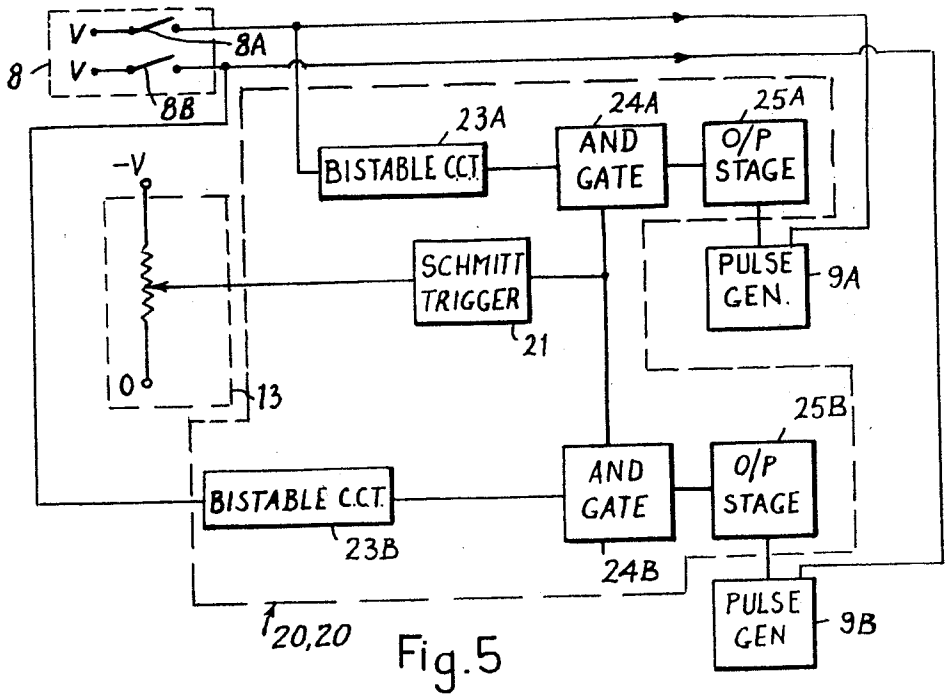

V
V
8A
8B
8
23A
BISTABLE CCT
24A
AND GATE
25A
O/P STAGE
-V
SCHMITT TRIGGER
21
PULSE GEN.
9A
0
13
25B
BISTABLE C.C.T.
23B
AND GATE
24B
O/P STAGE
PULSE GEN
9B
20,20

Fig.5

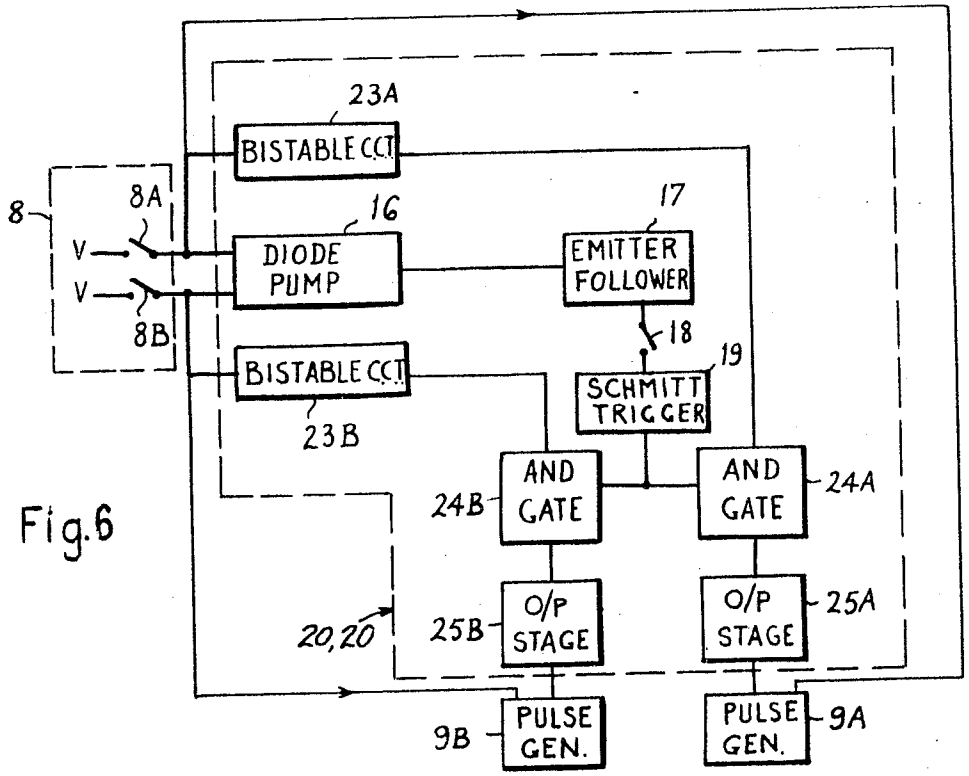

23A
BISTABLE CCT
8
8A
V
V
8B
16
DIODE PUMP
17
EMITTER FOLLOWER
18
19
BISTABLE CCT
23B
SCHMITT TRIGGER
AND GATE
24B
AND GATE
24A
20,20
25B
O/P STAGE
O/P STAGE
25A
9B
PULSE GEN.
PULSE GEN.
9A

Fig.6

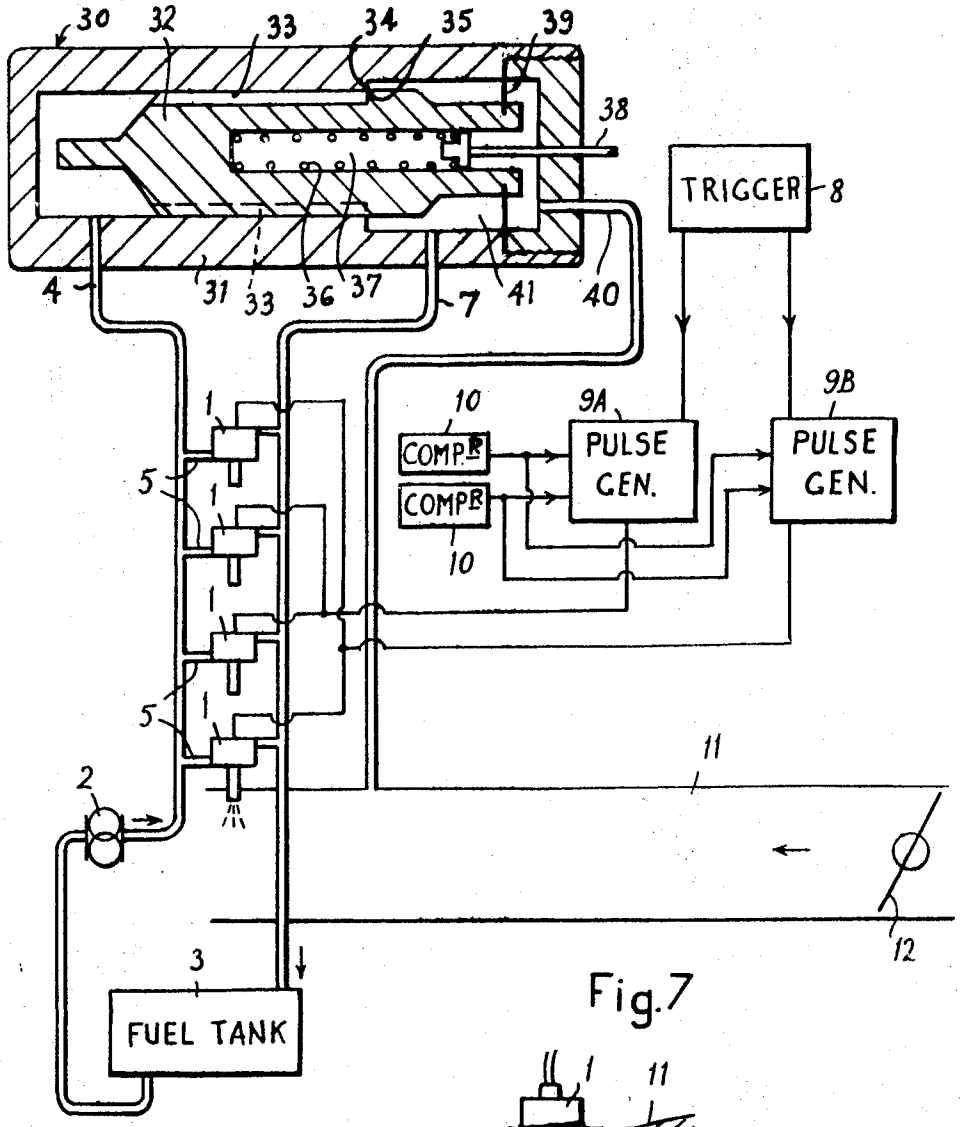

30
32
33
34
35
39
38
TRIGGER
8
4
31
33
36
37
7
41
40
1
10
9A
9B
COMPR
COMPR
PULSE GEN.
PULSE GEN.
5
5
2
11
12
3
FUEL TANK

Fig.7

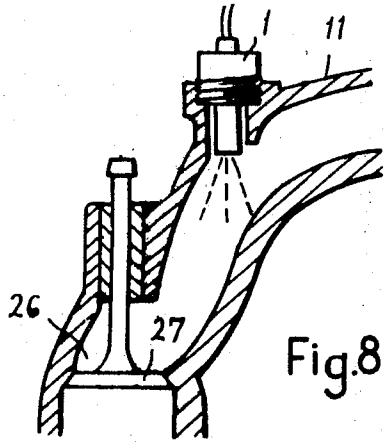

1
11
26
27

Fig.8

FUEL INJECTION SYSTEMS FOR INTERNAL COMBUSTION ENGINES

This invention relates to fuel injection systems for internal combustion engines, of the kind (hereinafter referred to as "of the kind described") in which fuel is fed to an engine through one or more electrically operated fuel injection valves or injectors which are opened intermittently.

From one aspect, the invention provides a fuel injection system of the kind described, having a plurality of fuel injection valves arranged in at least two groups, and wherein means are provided which operate in response to engine overrun conditions in order to maintain the valve or valves of at least one such group (but not of all the groups) closed under said overrun conditions.

From another aspect, the invention provides a fuel injection system of the kind described, wherein means are provided which are responsive to overrun conditions and which operate to open the valve or valves only once every n^{th} cycle of engine operation, where n is a number greater than one, under said overrun conditions.

The term "overrun conditions" refers to the conditions in which the load temporarily drives the internal combustion engine. Such a condition may, for example, be found in the internal combustion engine of a vehicle when the vehicle is descending a hill and the throttle is closed. Engine overrun conditions may be detected when the rotational speed of the engine is above a certain value and the throttle valve is closed; or by monitoring the induction passage pressure downstream of the throttle valve.

The invention will now be further described, by way of example, with reference to the accompanying drawings, in which:

FIG. **1** is a simplified diagram of one embodiment of a fuel injection system according to the invention,

FIG. **2** shows a detailed circuit of part of the system of FIG. **1**,

FIG. **3** is a block diagram of an alternative arrangement to FIG. **2**,

FIG. **4** is a simplified diagram of a further embodiment according to the invention,

FIG. **5** is a block diagram of part of the system of FIG. **4**,

FIG. **6** is a block diagram of an alternative arrangement to FIG. **5**,

FIG. **7** is a simplified diagram of another embodiment according to the invention, and

FIG. **8** is a view of part of an induction passage of an engine.

Referring to FIG. **1**, a fuel injection system is shown as applied to a four-cylinder internal combustion engine, having one fuel injection valve or injector **1** for each cylinder. Fuel is supplied by a pump **2** from a tank **3** to a common rail **4**, from which a supply line **5** runs to each injector **1**. The pressure in the common rail **4** is controlled by a relief valve **6**, excess fuel from the relief valve and from the injectors being returned to the tank **3** through a return rail **7**. The relief valve **6**, which will hereinafter be described in more detail with reference to FIG. **7**, is connected to receive a pressure signal from the engine induction passage **11** via a conduit **6***a*.

The fuel injectors **1** are opened intermittently by electrical pulses generated in the pulse generators **9A** and **9B** and which are normally fed to each injector once per engine cycle. For this purpose, there is provided a trigger device **8** which operates at the firing frequency of the engine and which, in a four-stroke engine operates once per cycle for each cylinder. The trigger device may be a contact assembly driven by the engine and which is fed with a voltage to produce a trigger pulse each time that the contacts close. The trigger device may be constructed as described in application Ser. No. 767,218, filed Oct. 14, 1968. The pulses from the trigger device **8** trigger the two pulse generators **9A** and **9B**, each of which controls a group of two fuel injectors **1**. The fuel injectors **1** are normally positioned so as to inject into the engine induction passage **11** just upstream of the inlet valve of the respective cylinders of the engine. Control signals are fed to the pulse generators in dependence on engine-operating variables such as manifold pressure, rotational speed, ambient temperature, and these control signals may also include components ensuring, for example, enrichment on acceleration or on cold starting. The control signals are provided by computer circuits **10**, and determine the duration of the pulses delivered by the pulse generators. The pulse generators and computer circuits may be constructed as described in U.S. Pat. No. 3,272,187, dated Sept. 13, 1966. The injectors may be constructed as in U.S. Pat. No. 3,247,833, dated Apr. 26, 1966.

The engine induction passage **11** includes a throttle valve **12**, and downstream of the throttle valve is a pressure-responsive transducer **13**, This transducer comprises a casing containing a diaphragm responsive to induction passage pressure and also a pair of contacts which are opened or closed with movement of the diaphragm responsive to changes in induction passage pressure.

A switching device **14** is connected to control the operation of the pulse generator **9B** feeding one group of fuel injectors. The device **14** is energized by a line **15** from a power source, such as the vehicle electrical system, and operates to inhibit the operation of the pulse generator **9B**, and hence of the associated group of fuel injectors, when the transducer **13** senses an induction passage pressure corresponding to overrun conditions.

Thus on overrun conditions, the two cylinders supplied by the last-mentioned group of fuel injectors will take in substantially no fuel, whereas the two other cylinders can be supplied through their fuel injectors with a richer mixture than would otherwise be desirable.

The switching device **14** is shown in detail in FIG. **2** and comprises a circuit incorporating two transistors TR1 and TR2 arranged so that TR1 is normally conducting and TR2 is normally cutoff. The input to the base of transistor TR1 includes a pair of normally open contacts C incorporated in the pressure-responsive transducer **13**. Under overrun conditions, when the induction passage pressure reaches a predetermined low value (e.g. 5 inches Hg) the contacts C close which has the effect of turning off transistor TR1 and thereby causing transistor TR2 to conduct. This latter transistor is connected across the trigger pulse input to the pulse generator **9B** and when it conducts, it shorts out the trigger signals applied to this pulse generator thereby rendering it inoperative during the time that the contacts C are closed.

FIG. **3** shows a circuit **14***a* which provides, to the switching device **14** and which prevents an alternative arrangement the operation of one of the pulse generators when the engine throttle valve is closed and the rotational speed of the engine is above a given value, i.e., corresponding to overrun conditions. In this embodiment trigger signals from trigger device **8** are fed to a diode pump circuit **16** which produces a DC voltage proportional to engine speed. This voltage is fed through a current-amplifying emitter-follower stage **17** and throttle switch **18** to a Schmitt trigger circuit **19**. The throttle switch is closed only when the engine throttle valve is closed. The Schmitt trigger circuit compares the DC voltage proportional to engine speed with a reference voltage, and if the DC voltage is above the reference voltage, the Schmitt trigger circuit produces an output which is employed to short out the trigger signals applied to one of the pulse generators, by switching on a transistor functioning in a manner similar to transistor TR2 in FIG. **2**. This pulse generator is thus rendered inoperative.

It is believed that such a fuel injection system can be designed to give reduced air pollution by the engine exhaust gas, compared with systems in which fuel continues to be supplied to each cylinder on every cycle, while avoiding the difficulties of metering very small quantities of fuel, and also avoiding too great a reduction of power on closing the throttle.

Referring now to the embodiment of FIG. **4**, the fuel injection system is again shown as applied to a four-cylinder inter-

nal combustion engine, having one fuel injector 1 for each cylinder. The system is basically similar to that described with reference to FIG. 1 and corresponding parts bear the same reference numerals. Thus fuel is supplied by a pump 2 from a tank 3 to a common rail 4, from which a supply line 5 runs to each injector 1. The pressure in the common rail 4 is controlled by a relief valve 6, excess fuel from the relief valve and from the injectors being returned to the tank 3 through a return rail 7.

The fuel injectors 1 are opened intermittently by electrical pulses, generated in the pulse generators 9A and 9B and which are normally fed to each injector once per engine cycle. For this purpose, there is provided a trigger device 8 which (in a four-stroke engine) operates once per cycle for each cylinder. The pulses from the trigger device 8 trigger the two pulse generators 9A and 9B, each of which controls a group of two fuel injectors 1. Control signals are fed to the pulse generators, in dependence on engine-operating variables such as manifold pressure, rotational speed, ambient temperature, and these control signals may also include components ensuring, for example, enrichment on acceleration or on cold starting. The control signals are provided by computer circuits 10, and determine the duration of the pulses delivered by the pulse generators 9. The pulse generators and computer circuits may be constructed as described in the aforementioned U.S. Pat. No. 3,272,187, and the injectors may be constructed as in the aforementioned U.S. Pat. No. 3,247,833.

As in the previous embodiment, the engine induction passage 11 includes a throttle valve 12, and downstream of the throttle valve is a pressure-responsive transducer 13. The fuel injectors 1 are normally positioned so as to inject into the induction passage just upstream of the inlet valve of the respective cylinders of the engine.

In this embodiment, the pressure-responsive transducer 13 controls the operation of two switching circuits 20 which are respectively connected to control the operation of the pulse generators 9A and 9B. The arrangement is such that, when the transducer 13 senses an induction passage pressure corresponding to overrun conditions, the switching circuits 20 operate to count or gate the pulses delivered by the trigger device 8 and to inhibit the operation of their respective pulse generators in response to every other trigger pulse.

Thus on overrun conditions, each fuel injector will be opened only once every other cycle. It will be understood that the fuel injection system may be so arranged that the injectors are opened once every desired number of cycles, e.g. every third or fourth cycle, and is not limited to every other cycle.

FIG. 5 shows one circuit arrangement of both the switching circuits 20. The transducer 13, which comprises a voltage divider controlled by a pressure-sensitive diaphragm responsive to inductive passage pressure, produces a voltage proportional to manifold pressure which is fed to a Schmitt trigger circuit 21. When the voltage from transducer 13 falls to a valve corresponding to, say, 5 inches Hg, the Schmitt trigger circuit 22 changes state to produce a positive going output signal.

Trigger pulses produced by the trigger contacts 8A and 8B of the trigger device 8 are respectively fed to bistable circuits 23A and 23B which produce positive going outputs at half the frequency of the trigger input pulses. These outputs are respectively fed to AND gates 24A and 24B which also each receive an input from the Schmitt trigger circuit 21. When each AND gate receives both positive-going signals from the bistable circuit and the Schmitt trigger circuit it produces an output signal which is fed via an output stage, 25A and 25B respectively to inhibit the operation of the associated pulse generator 9A or 9B. Thus upon engine overrun conditions, each fuel injector will be energized only every other cycle of engine operation.

FIG. 6 shows a circuit 20*a* which provides an alternative to the circuit of FIG. 5 and which operates to inhibit every other pulse from the pulse generators 9A and 9B when the engine throttle valve is closed and the rotational speed of the engine is above a given value. The circuit includes the arrangement of trigger contacts 8A, 8B, bistable circuits 23A, 23B, AND gates 24A, 24B and output stages 25A and 25B, feeding the pulse generators 9A and 9B similar to FIG. 5. However, instead of using a Schmitt trigger circuit 21 controlled by the output of a pressure-sensitive transducer 13, as in FIG. 5, an arrangement similar to FIG. 3 is employed comprising a diode pump 16 and emitter follower 17 feeding a Schmitt trigger circuit 19 through the throttle operated switch 18. This part of the circuit operates as described with reference to FIG. 3. Once again the Schmitt trigger circuit produces a positive-going output signal under overrun conditions, which in conjunction with the output from the bistable circuits, operates the AND gates and their output stages to cause each pulse generator only to produce energizing pulses at half its normal repetition rate, whereby each fuel injector will be energized only once every other cycle of engine operation.

It is believed that such a fuel injection system can be designed to give reduced air pollution by the engine exhaust gas, compared with systems in which fuel continues to be supplied to every cylinder on every cycle, while avoiding sudden changes of power on opening or closing the throttle.

Referring now to the embodiment of FIG. 7, the fuel injection system is once again shown as applied to a four-cylinder engine and comprises a number of basic parts similar to those in FIGS 1 and 2, which bear the same reference numerals. Fuel from a fuel tank 3 is fed by a fuel pump 2 to a common fuel rail 4. A number of fuel injectors 1 are provided, one such valve being shown for each cylinder, and these are each connected by a supply line 5 to the fuel rail 4. Excess fuel from each injector is returned to the fuel tank 3 through the return rail 7. A pressure-relief valve 30 which will be described in detail later is connected between the common fuel supply rail 4 and the return rail 7 and controls the fuel pressure in the common rail 4.

As in the preceding embodiments, each fuel injector 1 is opened intermittently by electrical pulses generated in the pulse generators 9A and 9B. Each pulse is initiated by the closing of a trigger switch be 8 which operates once per cycle for each cylinder. The trigger switch 8 is connected to the pulse generators 9A and 9B each of which controls two fuel injectors 4.

The duration of each pulse fed to an injector is controlled by the pulse generators under the control of voltages fed to the pulse generators from computer circuits 10. One voltage may, for example, b e function of the engine manifold pressure and rotational speed, and the other voltage may be a function of ambient temperature and the engine cooling water temperature. Thus for any given set of operating conditions the pulse duration, and consequently the time which a fuel injector 1 is open, will be the same. Once again the pulse generators and computer circuits may be constructed as described in specification 3,272,187, and the injectors as in specification 3,247,833.

As mentioned above, the fuel pressure in the fuel valve comprises a valve body 31 defining a cavity in which is slidably arranged a valve member 32 having splines 33 which engage with the walls of the body 31. A shoulder 34 in the body cooperates with a shoulder 35 on the valve member, at the end of the splines, to form a metering throat and so control the amount of fuel passing between the supply rail 4 and return rail 7. A spring 36 is located in a cavity 37 in the valve member 32 and is provided with a threaded adjuster member 38 which is threaded in the wall of the valve body 31, to adjust the force of the spring acting on the valve member 32. The valve member 32 is also attached to a diaphragm 32 extending between this member and the valve body 31. One side of the diaphragm is subjected to the pressure in the induction passage 11 downstream of the throttle valve 12, by means of the conduit 40. The other side of the diaphragm is subjected to the fuel pressure in the space 41 communicating with the return rail 7.

The relief valve 6 is so arranged that upon an increase of the engine induction passage pressure, the diaphragm is urged by

the increase in pressure applied through conduit **40** acting with the force of spring **36**, in the sense of closing the metering throat between shoulders **34** and **35**, thereby increasing the fuel pressure in the supply rail **4**. Conversely, a decrease in the induction passage pressure causes the valve **6** to pass more fuel and thereby decrease the fuel pressure in the supply rail **4**.

In this way the pressure in the common fuel supply rail **4** is increased when the induction passage pressure is relatively high and is reduced when the induction passage pressure is relatively low, whereby the pressure difference causing the fuel to flow through each injection valve orifice is maintained more nearly constant.

Referring to FIG. **8**, part of the induction passage **11** of the engine is shown, to indicate that the fuel injection valves **1**, of which there are in this case one per cylinder, are located with respect to the cylinders so that the fuel is injected directly into the induction port **26** of each cylinder, to be drawn into the cylinder on opening of the inlet valve **27**.

It will be appreciated that in the embodiments of FIG. **4**, the number of pulse generators may be varied, from a single unit upwards, depending on the number of cylinders of the engine, but preferably the fuel injectors of the engine are divided into a number of groups, each controlled by a separate pulse generator.

It will be understood that the fuel injection systems herein described may be applied to engines having more or less than four cylinders.

It will also be understood that each "group" of fuel injection valve may only comprise a single injection valve.

I claim:

1. A fuel injection system for an internal combustion engine, comprising at least two electromagnetically operable fuel injection valve and a pulse generator for intermittently energizing each valve in timed relation to the engine-operating cycle, wherein there is provided an overrun control circuit comprising means responsive to an engine-operating parameter indicative of an engine-overrun condition and an electronic switching circuit connected to be operated by the overrun-responsive means, the overrun switching circuit being connected to the pulse generator so as to prevent a constant portion, but not all, or the valve energizations throughout the overrun condition.

2. A system as claimed in claim **1**, including a plurality of fuel injection valves wherein the fuel injection valves are arranged in at least two groups and wherein means are provided which operate in response to an engine-operating parameter indicative of an engine-overrun condition in order to prevent energization of the valve or valves of at least one such group (but not of all the groups) under said overrun condition.

3. A system as claimed in claim **1**, wherein the engine-operating parameter is the induction passage pressure downstream of the throttle valve of the engine.

4. A system as claimed in claim **1**, wherein the engine-operating parameter is the rotational speed of the engine when the engine throttle valve is closed.

5. A system as claimed in claim **2**, including a separate pulse generator for each group of fuel injection valves, a trigger device for triggering the pulse generators in timed relation to the engine-operating cycle, means for feeding one or more control signals to the pulse generators, which control signals vary as a function of parameters of engine operation in order to control the duration of the output pulses from the pulse generators and means for feeding the output pulses from each pulse generator to energize the injection valve or valves associated with that pulse generator.

6. A system as claimed in claim **5**, wherein an electronic switching device is connected to at least one pulse generator, and means for controlling said switching device during the engine overrun conditions to inhibit the operation of said at least one pulse generator.

7. A system as claimed in claim **6**, including a pressure-responsive transducer arranged in the induction passage of the engine downstream of the engine throttle valve, which transducer controls the electronic operation of the switching device.

8. A system as claimed in claim **6**, including a throttle-operated switch is closed when the engine throttle valve is closed and which then passes a signal indicative of the rotational speed of the engine to control the operation of the electronic switching device.

9. A system as claimed in claim **6**, for a four-cylinder internal combustion engine having one fuel injection valve for each cylinder, wherein the injection valves are divided into two groups each having two valves and two pulse generators are provided each of which supplies the energizing pulses to a group of two injection valves, and wherein an electronic switching device is connected to one of the pulse generators.

10. A fuel injection system as claimed in claim **1**, including at least one electrically operated fuel injection valve which is opened intermittently, wherein means are provided which are responsive to an engine-operating parameter indicative of an engine-overrun condition and which operate to open the valve or valves only once every n^{th} cycle of engine operation, where n is a number greater than one, under said overrun conditions.

11. A system as claimed in claim **10**, wherein the engine parameter is the induction passage pressure downstream of the throttle valve of the engine.

12. A system as claimed in claim **10**, wherein the engine parameter is the rotational speed of the engine when the engine throttle valve is closed.

13. A system as claimed in claim **10**, including at least one pulse generator producing pulses for energizing the fuel injection valve or valves and which is controlled by at least one control signal varying as a function of a parameter of engine operation to control the duration of the output pulses fed to the fuel injection valve or valves.

14. A system as claimed in claim **13**, wherein at least one pulse generator is triggered by a trigger device which operates in timed relation with the operating cycle of the engine, and an electronic switching device is connected to the or each pulse generator and is controlled during the engine-overrun condition so that it permits the operation of the or each pulse generator only in response to every n^{th} trigger pulse to trigger the pulse generator.

15. A system as claimed in claim **14**, wherein there is provided a plurality of fuel injection valves divided into at least two groups and a separate pulse generator is provided to energize each group of valves, a separate electronic switching device being connected to each pulse generator.

16. A system as claimed in claim **14**, wherein operation of the or each electronic switching device is controlled by a pressure-responsive transducer arranged in the induction passage of the engine downstream of the throttle valve.

17. A system as claimed in claim **14**, including a throttle-operated switch which is closed when the engine throttle valve is closed and which passes a signal generated under engine-overrun conditions to control the operation of the or each electronic switching device.