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Hobo et al.

[11] **3,797,465**

[45] **Mar. 19, 1974**

[54] **FUEL INJECTION SYSTEM FOR INTERNAL COMBUSTION ENGINES**

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[73] Assignee: **Nippondenso Co., Ltd.,** Aichi-ken, Japan

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[21] Appl. No.: **156,439**

[30] **Foreign Application Priority Data**

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July 4, 1970 Japan 45-58457

[52] **U.S. Cl.**..... **123/32 EA,** 123/119 R, 123/139 E, 123/179 G

[51] **Int. Cl.** **F02m 51/00**

[58] **Field of Search** .... 123/32 EA, 32 AE, 139 E, 123/139, 179 HG

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Primary Examiner—Laurence M. Goodridge
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

A fuel injection system for internal combustion engines is disclosed, in which there are provided fuel injection patterns for engine starting and for full-load engine operations. Cold starting of the engine is facilitated by injecting fuel according to the fuel injection control pattern required by the engine at the time of starting, and once after the engine has been started or when engine has been warmed up the fuel injection is made according to the fuel control pattern required for full-load operation, so that no black smoke generates even if the engine is rotated at a low speed with the full-load, thereby ensuring optimum fuel supply over the entire engine speed and engine load ranges without sacrificing the engine output for full-load operation of the engine.

5 Claims, 17 Drawing Figures

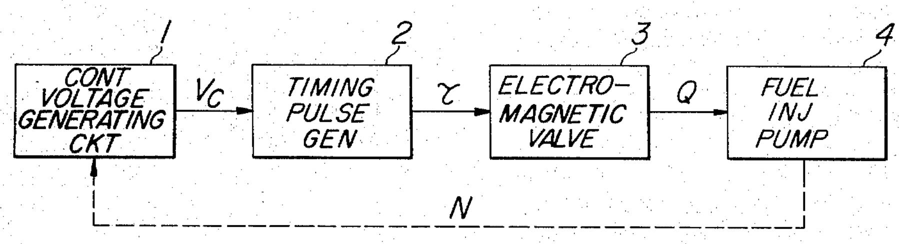

FIG. 1

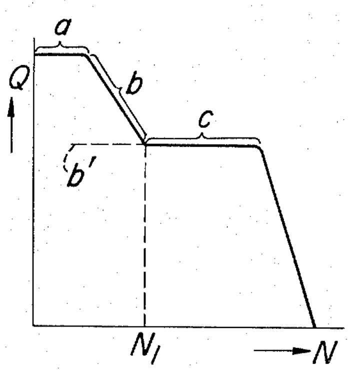

FIG. 4

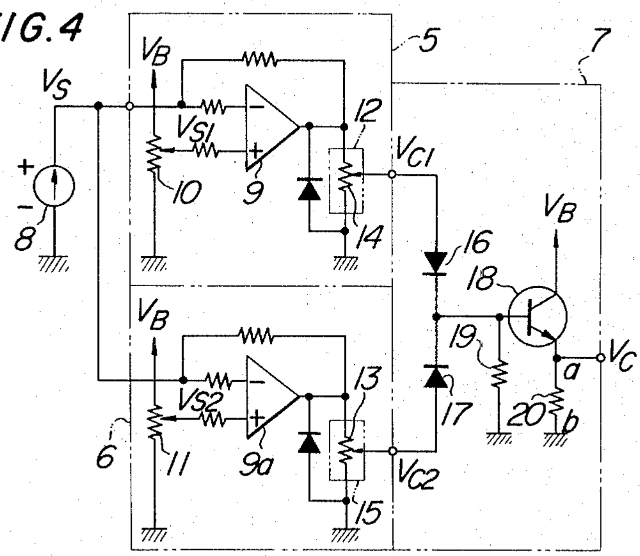

FIG. 2

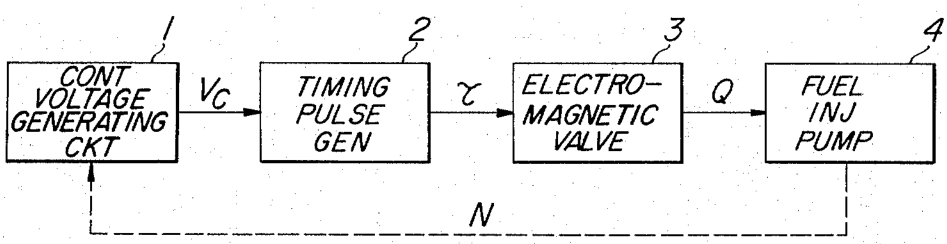

FIG. 3a

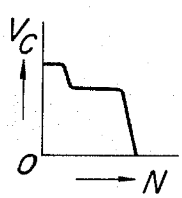

FIG. 3b

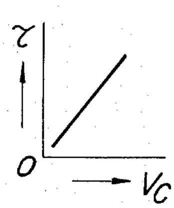

FIG. 3c

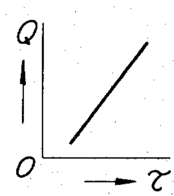

FIG. 3d

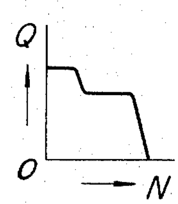

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FIG.5a

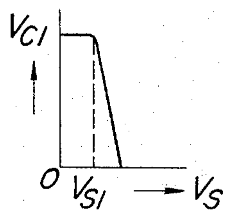

FIG.5b

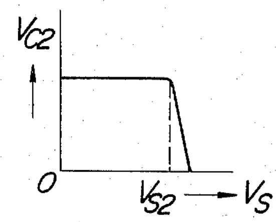

FIG.5c

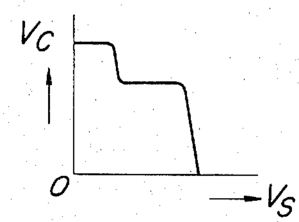

FIG.6

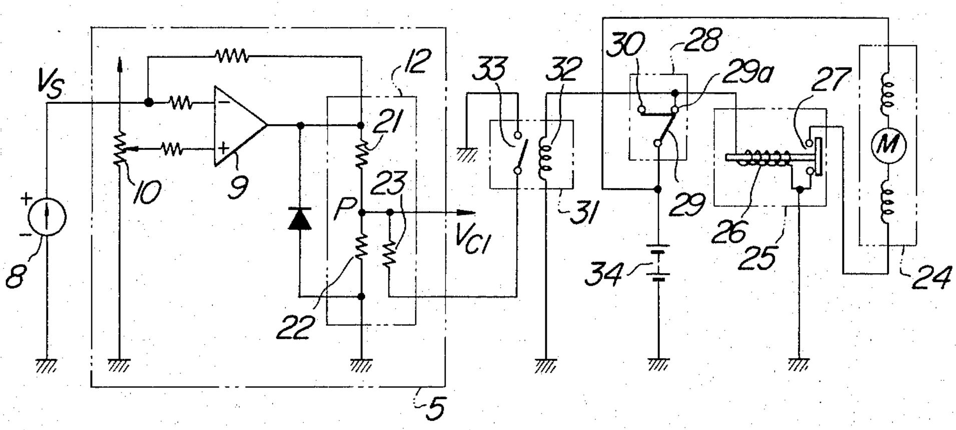

FIG.7

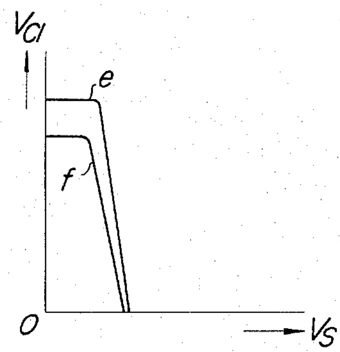

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FIG. 8

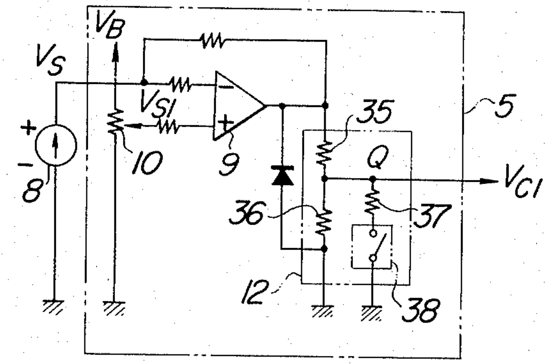


FIG. 10

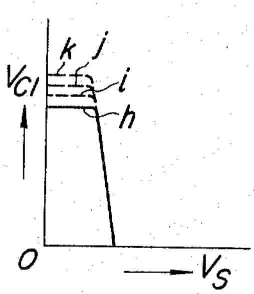


FIG. 9

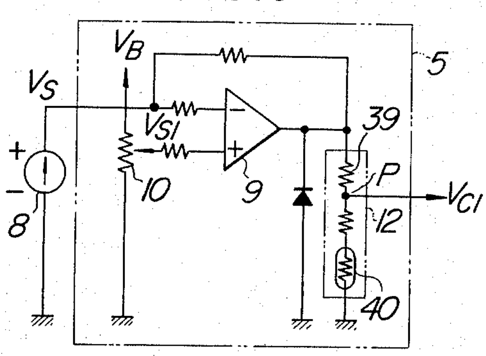


FIG. 12

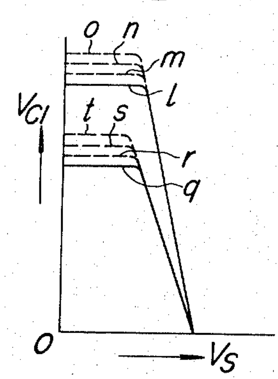
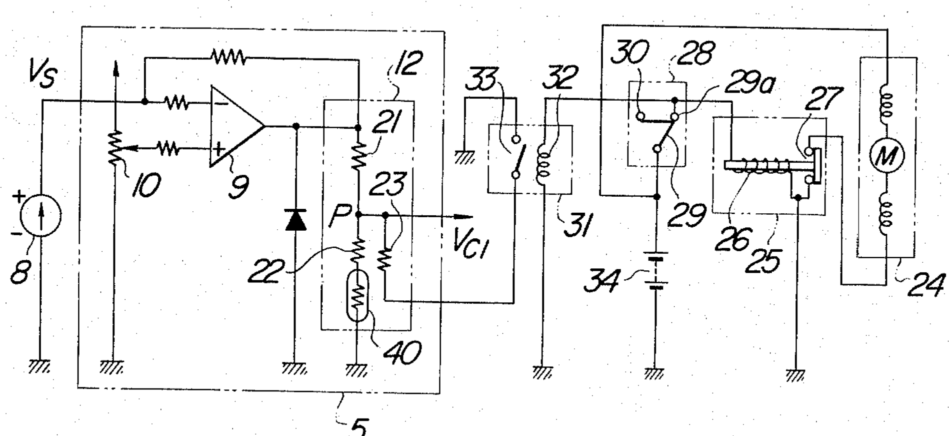


FIG. 11



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FUEL INJECTION SYSTEM FOR INTERNAL COMBUSTION ENGINES

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

This invention relates to fuel injection systems for compression ignition engines in which excessive air is introduced into each cylinder and output power is controlled by varying the quantity of pressurized fuel injected into each cylinder. More particularly, the invention concerns fuel injection systems having an electronic fuel control means.

2. DESCRIPTION OF THE PRIOR ART

Some prior-art fuel injection systems comprise a reciprocal fuel pump having a reciprocating piston for drawing and discharging fuel and provided with a normally closed electromagnetic valve. When the electromagnetic valve is open, fuel under a comparatively low constant pressure is admitted through it into a compression chamber defined between the piston and cylinder of the fuel pump. A separately provided electronic control means provides electric pulses to the electromagnetic valve to open it. The electromagnetic valve controls the quantity of fuel supplied to the compression chamber mentioned above according to the duration of the electric pulse delivered to it. The fuel supplied to the compression chamber is further pressurized by the reciprocating piston and then delivered through pressurized fuel piping to each fuel injection nozzle, from which it is injected into the associated engine cylinder.

A different type of prior-art fuel injection system from the above-mentioned one is similar to the commonly termed unit injector. In this type of fuel injection system, each engine cylinder is provided with a fuel injection port, and the fuel to be injected is supplied to a compression chamber in the unit injector through a normally closed electromagnetic valve in proportion to the duration of the open state of the electromagnetic valve exactly controlled from an electronic control means. The fuel supplied to the compression chamber is pressurized by a piston operated with cam member usually provided on the engine cylinder head and driven from the engine crankshaft, and the pressurized fuel is injected into each cylinder.

It is also well known that more fuel is required when starting the engine at a relatively low temperature than is necessary when the engine has been warmed up. Further, it is well known that the fuel injection pattern is determined so as to supply to the engine sufficient fuel quantity available for engine starting even when the engine is at a lowest possible temperature that would be encountered, with an engine speed of about 200 rpm, at the time of cranking, and under a condition substantially equivalent to full load condition with the accelerator pedal depressed to the utmost, and, subsequently, the fuel quantity gradually reduced to the one determined by smoke limit for an engine speed slightly higher than that at the time of cranking, usually 1,200 rpm, so as to ensure smooth starting of the engine.

However, with such a fuel injection pattern, in which the quantity of fuel supply is predetermined with respect to just the smoke limit for an engine speed of, for instance, 1,200 rpm, a great deal of black smoke inevitably results when the engine having warmed up is operated under the full-load condition at a lower speed, for instant about 1,000 to 800 rpm. This problem encountered in the conventional fuel injection system of either mechanical or pneumatic control type for internal combustion engines, cannot be solved unless the construction of the system is made extremely complicated. At present, therefore, it is usual to predetermine the quantity of fuel supplied for low-speed engine operation with respect to a quantity less than the smoke limit by making the fuel increase for the starting of the engine as small as possible even with slight sacrifice in the full-load engine output so as to reduce the black smoke when the engine having warmed up is operated at low speeds. Therefore, it has heretofore been impossible to always operate the engine under the optimum fuel supply condition irrespective of the engine speed and engine load.

SUMMARY OF THE INVENTION

An object of the invention is to provide a fuel injection system for internal combustion engines comprising an engine starting control voltage generator to provide a control voltage meeting the fuel control pattern required for the cold starting of the engine, a full-load engine operation control voltage generator to provide a control voltage meeting the fuel control pattern required for the full-load operation of the engine, a selecting circuit to select the higher of the output control voltage of both said control voltage generators, a monostable timing pulse generator to provide timing pulses with a pulse duration corresponding to said selected output control voltage, and a fuel injection pump provided with an electromagnetic valve to control the quantity of fuel discharged from said fuel injection pump is each cycle thereof in accordance with the pulse duration of the timing pulse delivered from the timing pulse generator, at least said engine starting control voltage generator, being provided with means to control the control voltage according to the engine operation.

Another object of the invention is to provide means to generate the output control voltage of two preset control patterns of said engine starting control voltage generator, namely a higher voltage pattern and a lower voltage pattern, and select a control voltage of said higher voltage pattern only when the engine is being cranked or before the engine has been warmed up.

Further object of the invention is to provide means to produce an output control voltage of the control pattern of said engine starting control voltage generator which may be changed corresponding to the instant engine temperature.

According to the invention, in case there are provided two preset voltage patterns, namely a high voltage pattern and lower voltage pattern, for the control voltage of the engine starting control voltage generator, which is provided with means to select an output control voltage of said high voltage pattern out of said two preset voltage patterns by detecting the cranking of the engine or by detecting a predetermined tmeperature of the engine warmed up, the fuel to be injected at the time of the cranking of the engine is controlled according to the high voltage pattern of the output control voltage of the engine starting control voltage generator meeting the fuel control pattern required at the time of cranking of the engine, thus ensuring extremely smooth starting of the engine.

Also, after the engine has been cranked, or when the engine has been warmed up according to the lower voltage pattern selected for the control voltage of the engine starting control voltage generator, and the fuel injection pattern determined by the control voltage output of the full-load engine operation control voltage generator, the fuel to be injected is controlled so that no black smoke generates even if the engine is rotated at a low speed with the full-load, thus ensuring operation of the engine under the optimum fuel supply condition over the entire engine speed and engine load ranges without sacrificing the full-load engine output.

Further, according to the invention, a starter switch is used for a means to detect the cranking of the engine, so that selection of the low voltage pattern is reliably and automatically effected whenever the engine is being cranked by the simple on-off operation of the starter swtich of extremely simple construction.

Still further, according to the invention, a bimetal switch is used for a means to detect a predetermined temperature of the engine warmed up so that selection of the lower voltage pattern is reliably and automatically effected whenever the engine has been warmed up.

Still further, according to the invention, a semiconductor temperature-sensitive element having a negative resistance characteristic is used for a means to detect the instant engine temperature and be able to change the voltage pattern corresponding to the detected temperature so that the engine may be started smoothly even if the engine is at a low temperature since the fuel is supplied according to said voltage pattern.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a graph showing a fuel injection pattern to be provided by an electronic control means in the system according to the invention.

FIG. **2** is a block diagram outlining an embodiment of the fuel injection system according to the invention.

FIGS. **3***a* to **3***d* show characteristic curves of various parts of the system of FIG. **2**.

FIG. **4** is a circuit diagram showing an example of the control voltage generator circuit in the system of FIG. **2**.

FIGS. **5***a* to **5***c* show characteristic curves illustrating the operation of the circuit of FIG. **4**.

FIG. **6** is a circuit diagram showing part of the system according to the invention.

FIG. **7** is a graph to illustrate the operation of the circuit of FIG. **6**.

FIG. **8** is a circuit diagram showing part of the system according to the invention.

FIG. **9** is another circuit diagram showing part of the system according to the invention.

FIG. **10** is a graph to illustrate the operation of the circuit of FIG. **9**.

FIG. **11** is still further circuit diagram showing part of the system according to the invention.

FIG. **12** is a graph to illustrate the operation of the circuit of FIG. **11**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The invention will become more apparent from the following description of a preferred embodiment with reference to the accompanying drawing.

FIG. **1** shows one of fuel characteristics of internal combustion engines for vehicles, namely a fuel characteristic required when the accelerator pedal is depressed to the utmost. In the Figure, the ordinate represents the quantity Q of fuel injected and the abscissa represents the engine speed N. Reference character *a* indicates the quantity of fuel required at the time of cold starting of the engine, character *b* indicates a fuel characteristic at the time of operation of the starter motor, and character *c* indicates the quantity of fuel required for the full-load engine operation. N_1 indicates an engine speed corresponding to the smoke limit. For a full-load low-speed engine operation after the engine has been started, a fuel characteristic as indicated at *b'* determined from the smoke limit consideration is required instead of the character *b*.

FIG. **2** shows a fuel injection system according to the invention. A control voltage generating circuit **1** provides control voltage Vc whose voltage pattern corresponds to the fuel characteristics required by the engine.

FIG. **3***a* shows a control voltage pattern provided (with the ordinate representing the control voltage Vc and abscissa representing the engine speed N).

The control voltage Vc is fed to a timing pulse generator **2**, which also receives trigger pulses from a trigger pulse generator coupled to the drive shaft of a fuel injection pump **4** to produce timing pulses. It may consist of a monostable multi-vibrator. The duration of the timing pulse is controlled in proportion to the control voltage Vc of the control voltage generating circuit **1**.

FIG. **3***b* shows the duration τ of the timing pulse plotted against the control voltage Vc.

The output of the timing pulse generator **2** is applied across an electromagnetic coil of an electromagnetic valve **3**, which is held open during the presence of a timing pulse, that is, held open for the duration of the timing pulse. While the electromagnetic valve is held open, it admits fuel from a fuel supply pump to be drawn into the fuel injection pump **4**.

FIG. **3***c* shows the quantity of fuel drawn into the fuel injection pump **4**, which is plotted against the duration τ of the timing pulse.

The quantity of the fuel discharged from the fuel injection pump **4** in each cycle thereof is equal to the quantity of fuel admitted thereto in each cycle of the electromagnetic valve **4**. The relation between the quantity of fuel discharged from the fuel injection pump **4** and the engine speed is substantially the same as the control voltage pattern shown in FIG. **3***a*.

FIG. **3***d* shows the quantity Q of the discharged fuel plotted against the engine speed N.

FIg. **4** shows the control voltage generating circuit in detail. Reference numeral **5** generally designates an engine starting control voltage generator, numeral **6** a full-load engine operation control voltage generator, and numeral **7** a selecting circuit including a current amplifier. Numeral **8** designates a speed voltage generator generating a voltage corresponding to the speed of rotation of the drive shaft of the fuel injection pump **4** (hereinafter referred to as speed voltage). It may be a d-c generator coupled to the drive shaft of the fuel injection pump **4**.

The engine starting and full-load engine operation control voltage generators **5** and **6** include respective two-input differential amplifiers **9** and **9***a*. The speed voltage from the speed voltage generator **8** consitiutes an inversion input to the differential amplifiers 9 and 9a, and voltages V_{S1} and V_{S2} corresponding to turning points in the respective control voltage patterns at the time of engine starting and at the time of full-load engine operation are fed as non-inversion input to the respective differential amplifiers through potentiometers 10 and 11. The outputs of the differential amplifiers 9 and 9a are divided by respective voltage dividers 12 and 15 respectively consisting of potentiometers 14 and 13.

The selecting circuit 7 comprises diodes 16 and 17, a transistor 18 and resistors 19 and 20. Of the two voltages V_{c1} and V_{c2} appearing at the output of the respective voltage dividers 12 and 15, the higher one is selectively fed through either diode 16 or 17 to the emitter follower of transistor 18 and resistors 19 and 20 for current amplification to produce an amplified output across the resistor 20 as the control voltage Vc.

FIG. 5a shows the voltage V_{c1} appearing at the output of the voltage divider 12 of the engine starting control voltage generator 5 plotted against the speed of the drive shaft of the fuel injection pump 4 represented by the speed voltage V_S.

FIG. 5b shows the voltage V_{c2} appearing at the output of the voltage divider 15 of the full-load engine operation control voltage generator 6.

FIG. 5c shows the resultant control voltage Vc appearing at the output of the selecting circuit 7 selectively current amplifying the higher one of the voltages V_{c1} and V_{c2}. The pattern of the control voltage Vc shown in FIG. 5c is made the same as that of the fuel characteristic shown in FIG. 1, and hence the same as the pattern of the fuel discharged by the fuel injection pump 4.

To change the fuel injection pattern at the time of starting the engine and at other times, the control voltage pattern of the control voltage generating circuit 1 may be changed accordingly.

FIG. 6 shows an example of engine starting control voltage generator 5, whose voltage divider 12 consists of resistors 21, 22 and 23. Numeral 24 designates a starter motor, numeral 25 a relay having a relay coil 26 and normally open contacts 27, numeral 28 a key switch having movable contacts 29, ignition terminals 30 and a starter terminal 29a, numeral 31 a relay having a relay coil 32 and normally closed contacts 33, and numeral 34 a battery.

In operation, for starting the engine the movable contacts 29 of the key switch 28 are thrown to the starter terminal 29a, whereupon the normally open contacts 27 of the relay 26 are closed to start the starter motor 24, thus starting the engine. At the same time, the normally closed contacts 33 of the relay 31 are opened, so that the control voltage appearing at the voltage dividing point p takes a high voltage pattern as indicated at *e* in FIg. 7. With the high voltage pattern selected, the duration of the timing pulse produced by the monostable timing pulse generator 2 is increased to increase the quantity Q of fuel discharged from the fuel injection pump 4, thus achieving rapid starting of the engine.

When the engine has been cranked, the movable contacts 29 of the key switch 28 are detached from the starter terminal 29a to open the normally open contacts 27 of the relay 25, thus stopping the starter motor 24. At the same time, the normally closed contacts 33 of the relay 31 are closed to connect the resistor 23 in parallel with the resistor 22 in the voltage divider 12, so that the control voltage appearing at the voltage dividing point p takes a low voltage pattern as indicated at *f* in FIG. 7. Thus, the subsequent resultant control voltage Vc of the control voltage generating circuit 1 is mainly determined by the control voltage V_{c2} of the full-load engine operation control voltage generator 6, and the quantity Q of fuel discharged from the fuel injection pump 4 is controlled according to a fuel injection pattern mainly determined by the control voltage V_{c2} of the full-load engine operation control voltage generator 6.

FIg. 8 shows another example of the engine starting control voltage generator 5, whose voltage divider 12 comprises resistors 35, 36 and 37 and a bimetal switch 38. The bimetal switch 38 is made to open and close by detecting a predetermined engine temperature. When the engine temperature is lower than a predetermined temperature, the bimetal switch 38 is open. Under this condition, a higher voltage patterns as shown by curve *e* in FIG. 7 is provided for the voltage V_{c1} appearing at the voltage dividing point *p*. When the engine temperature exceeds the predetermined temperature, the bimetal switch 38 is closed to provide a lower voltage pattern as shown by curve f for the voltage V_{c1}.

In the preceding embodiments, the engine starting control voltage generator 5 is adapted to provide two alternative voltage patterns for its control voltage V_{c1}. If desired, the full-load engine operation control voltage generator 6 may also be adapted to provide two alternative voltage patterns for its control voltage output V_{c2}.

To change the fuel injection pattern especially at the time of cold starting, the control voltage of the control voltage generating circuit 1 may be changed sequentially according to the engine temperature.

FIG. 9 shows further example of the engine starting control voltage generator 5, in which a semiconductor temperature-sensitive element 40 having a negative resistance characteristic such as thermistor is connected in series with the resistor 39 of the voltage divider 12. The temperature-sensitive element 40 is placed within the engine clyinder block or cooling water passage so as to detect the engine temperature.

In the operation of this example, when the engine temperature is low the resistance of the temperature-sensitive element 40 is high, so that the lower the engine temperature the higher the voltage V_{c1} appearing at the voltage dividing point p, as shown by broken curves *i*, *j*, and *k* in FIG. 10.

With a higher voltage pattern for the voltage V_{c1} the pulse length of the timing pulse produced by the timing pulse generator 2 is increased to increase the quantity Q of fuel discharged from the fuel injection pump 4. With an increase in the engine temperature the voltage V_{c1} is progressively decreased to eventually provide a voltage pattern for normal running as shown by solid curve h.

It will be apparent that the voltage divider 15 in the full-load operation control voltage generator 6 may, if necessary, be provided with a semiconductor temperature-sensitive element having a negative resistance characteristic like the voltage divider 12 in the preceding example of the engine starting control voltage generator 5.

FIG. 11 shows still further example of the engine starting control voltage generator 5, whose voltage divider **12** comprises resistors **21, 22** and **23,** and a semiconductor temperature-sensitive element **40** having the same characteristics as the one shown in FIG. **9.** The resistor **23** is connected at one end thereof to the means to detect the engine cranking which consists of the relay **31,** the key switch, the relay **25** and the starter motor as mentioned in FIG. **6.**

In the operation of this example, when the engine is being cranked, the lower is the engine temperature, the higher is the voltage V_{c1} appearing at the voltage dividing point P, as shown by broken curves *m*, *n* and *o* in FIG. **12.** And after the engine has been started, the voltage V_{c1} appearing at the voltage dividing point P moves from higher levels shown by curves *m*, *n* and *o* to the lower levels shown by curves *r*, *s* and *t*, respectively, so that the generation of black smoke can be prevented even if the engine is rotated at a low speed with the full-load at a low temperature, namely before the engine has been warmed up.

We claim:

1. A fuel injection system for internal combustion engines comprising:

circuit means for generating an engine starting control voltage, said control voltage varying according to the fuel control pattern required for cold starting of an engine, said engine starting control voltage being relatively high for low engine speeds, circuit means for generating a full-load engine operating control voltage, said control voltage varying according to the fuel control pattern required for a full-load operation of the engine, said full-load control voltage being relatively low for high engine speeds, wherein as the speed of said engine increases to full-load operation, said engine starting control voltage decreases to said full-load control voltage,

a selecting circuit responsively coupled to each of said aforementioned circuit means for selecting the higher one of the control voltages generated by said control voltage generating circuit means,

a monostable timing pulse generator connected to said selecting circuit for providing timing pulses having a pulse duration corresponding to the selected control voltage, and

a fuel injection pump responsive to said timing pulses having an electromagnetic valve to control the quantity of fuel discharged from said fuel injection pump in each cycle thereof in accordance with the pulse duration of the timing pulse delivered from the timing pulse generator, said engine starting control voltage generating means including means for changing the control voltage in response to a selected condition of engine operation.

2. The fuel injection system of claim **1** wherein said engine starting control voltage generating circuit means includes means for generating the control voltage in accordance with two preset control patterns, namely, a first higher voltage pattern and a second lower voltage pattern, and means for selecting the control voltage of said first voltage pattern in response to an engine cranking condition only.

3. The fuel injection system of claim **1** wherein said engine starting control voltage generating circuit means includes means for generating the control voltage in accordance with two preset control patterns, namely, a first higher voltage pattern and a second lower voltage pattern, and means for selecting the control voltage of said higher voltage pattern in accordance with a cold engine condition only.

4. The fuel injection system of claim **1** wherein said engine starting control voltage generating circuit means includes means for varying the control voltage of the control pattern to be changed in response to an instantaneous engine temperature condition.

5. The fuel injection system of claim **2** wherein said engine starting control voltage generating circuit means includes,

means for changing each control voltage of both the higher and lower voltage patterns in response to an instant engine temperature condition.

* * * * *