United States Patent [19]

Hoshi

[11] **3,923,016**

[45] **Dec. 2, 1975**

[54] **ELECTRONIC FUEL INJECTION APPARATUS FOR A FUEL INJECTION**

[75] Inventor: **Yoshikazu Hoshi**, Hitachi, Japan

[73] Assignee: **Hitachi, Ltd.**, Japan

[22] Filed: **May 9, 1974**

[21] Appl. No.: **468,527**

[30] **Foreign Application Priority Data**

May 9, 1973 Japan 48-50731

[52] **U.S. Cl.** .... **123/32 EA**; 123/119 R

[51] **Int. Cl.²** **F02D 5/02**

[58] **Field of Search** .... 123/32 EA

[56] **References Cited**

UNITED STATES PATENTS

3,745,768	7/1973	Zechnall et al.	123/32 EA
3,782,347	1/1974	Schmidt et al.	123/32 EA
3,815,561	6/1974	Seitz	123/32 EA
3,824,967	7/1974	Gordon	123/32 EA
3,831,564	8/1974	Schmidt et al.	123/32 EA

Primary Examiner—Charles J. Myhre
Assistant Examiner—Joseph A. Cangelosi
Attorney, Agent, or Firm—Craig & Antonelli

[57] **ABSTRACT**

In a closed-loop fuel injection apparatus for an internal combustion engine which comprises an air detector for measuring air flow into the engine, an oxygen detector for measuring the oxygen quantity in the exhaust gas from the engine, and a fuel control means for determining the fuel amount in accordance with the outputs of the air detector and the oxygen detector. The output of the oxygen detector is integrated by a capacitor and the amount of injection fuel is determined by the product of the charging quantity of the capacitor and the output of the air detector.

10 Claims, 6 Drawing Figures

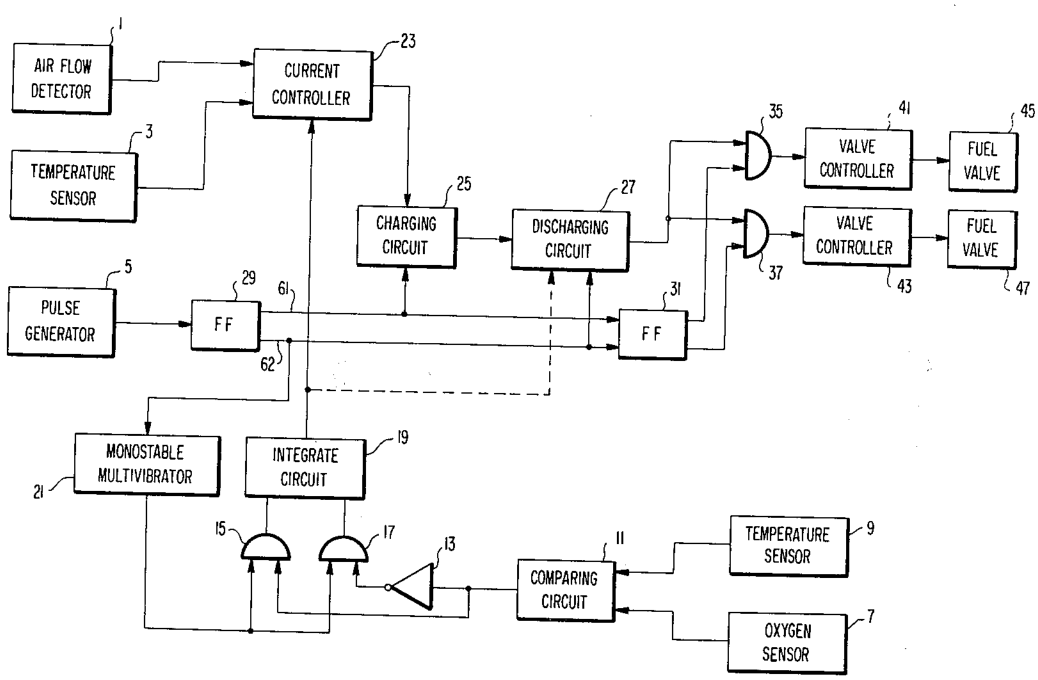
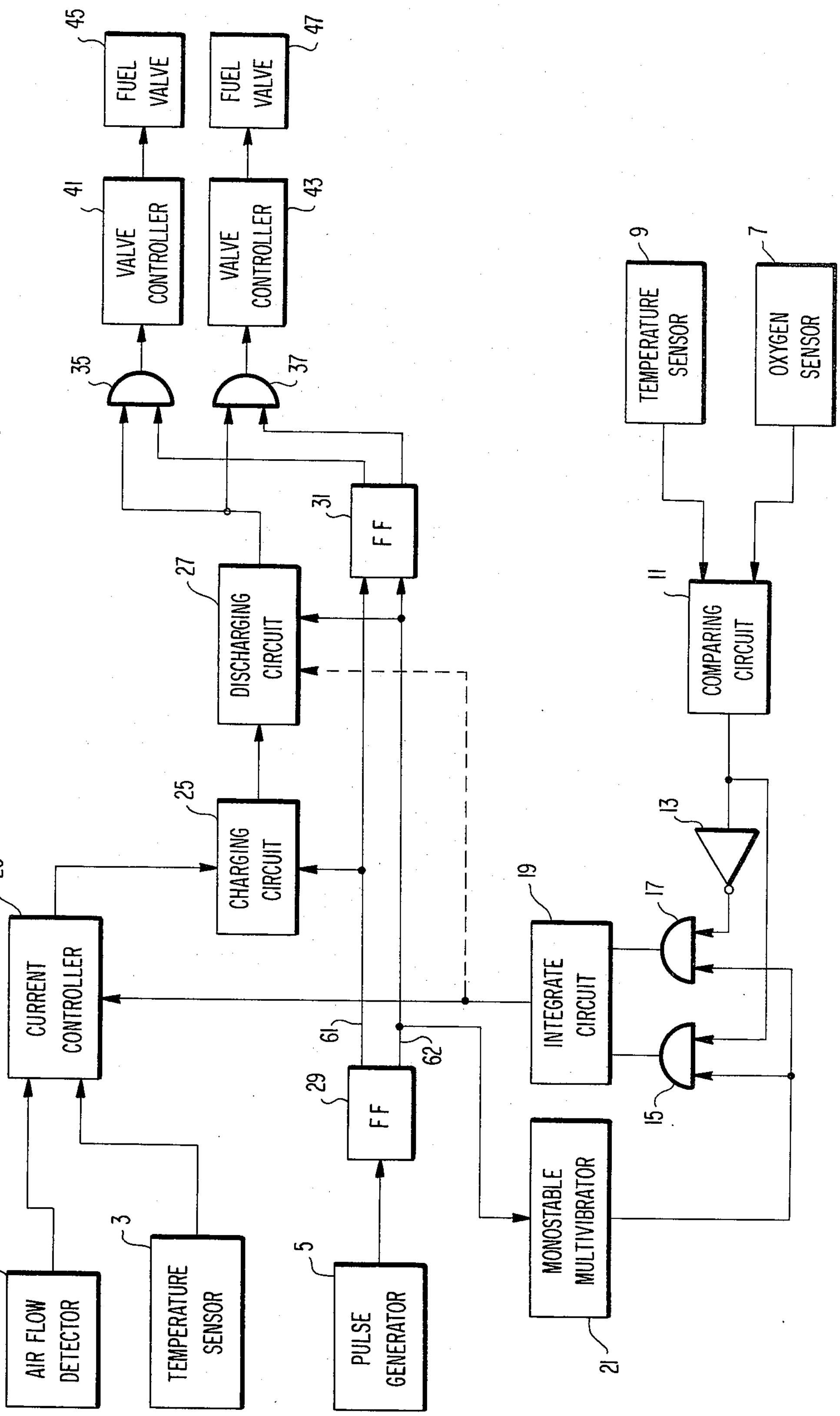


FIG 1


FUEL VALVE
45
FUEL VALVE
47
VALVE CONTROLLER
41
VALVE CONTROLLER
43
35
37
TEMPERATURE SENSOR
9
OXYGEN SENSOR
7
DISCHARGING CIRCUIT
27
FF
31
COMPARING CIRCUIT
11
CHARGING CIRCUIT
25
13
CURRENT CONTROLLER
23
INTEGRATE CIRCUIT
19
17
15
61
62
FF
29
MONOSTABLE MULTIVIBRATOR
21
AIR FLOW DETECTOR
1
TEMPERATURE SENSOR
3
PULSE GENERATOR
5

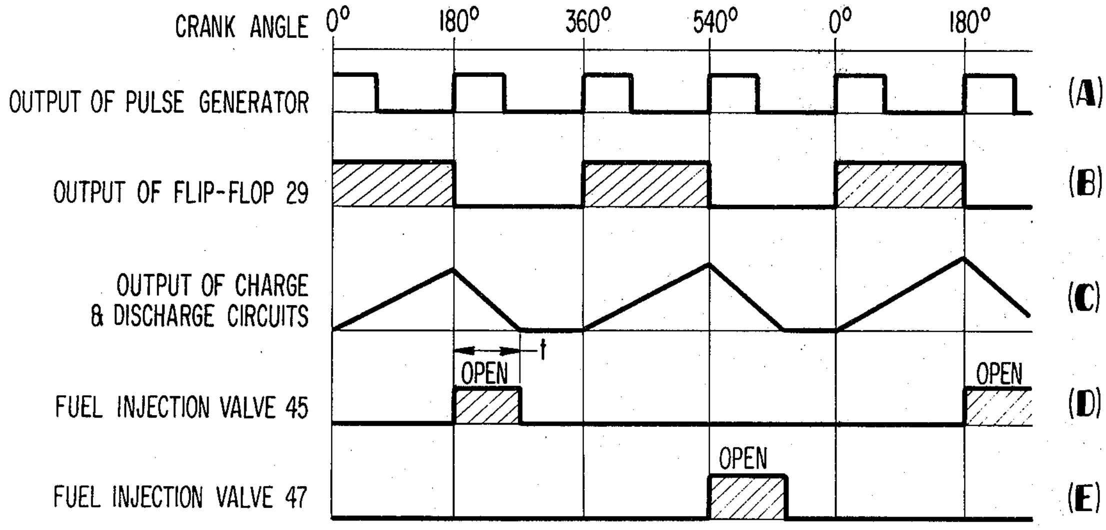


FIG. 2

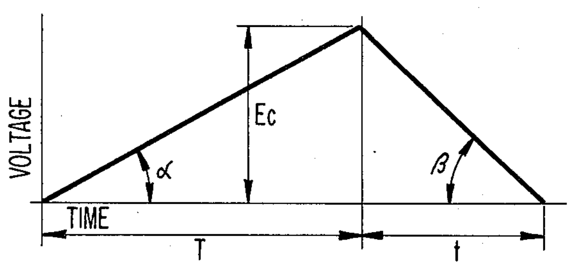


FIG. 3

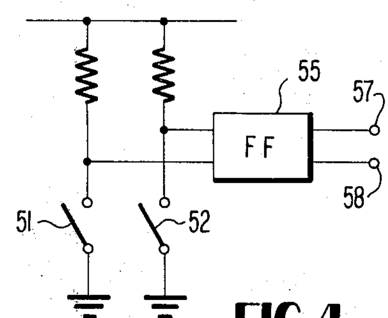
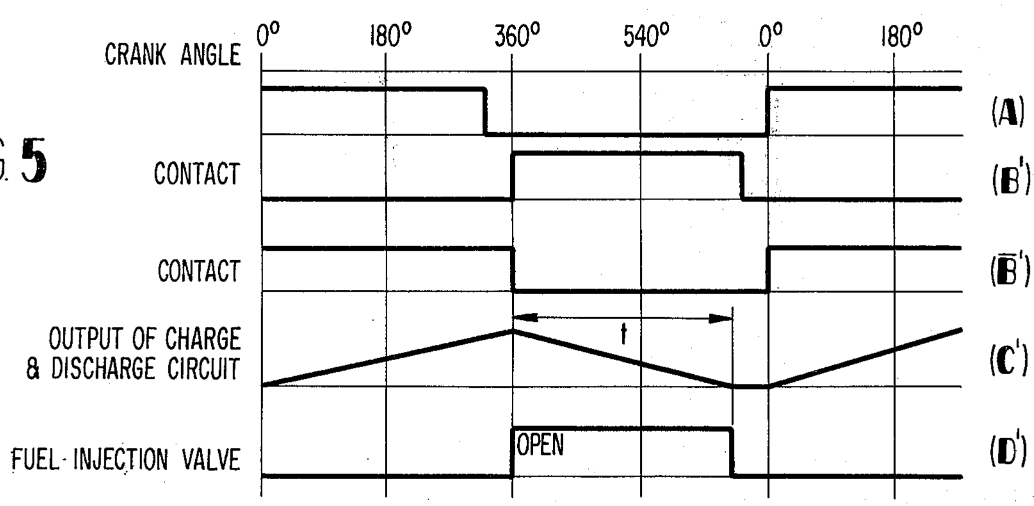


FIG. 4

FIG. 5



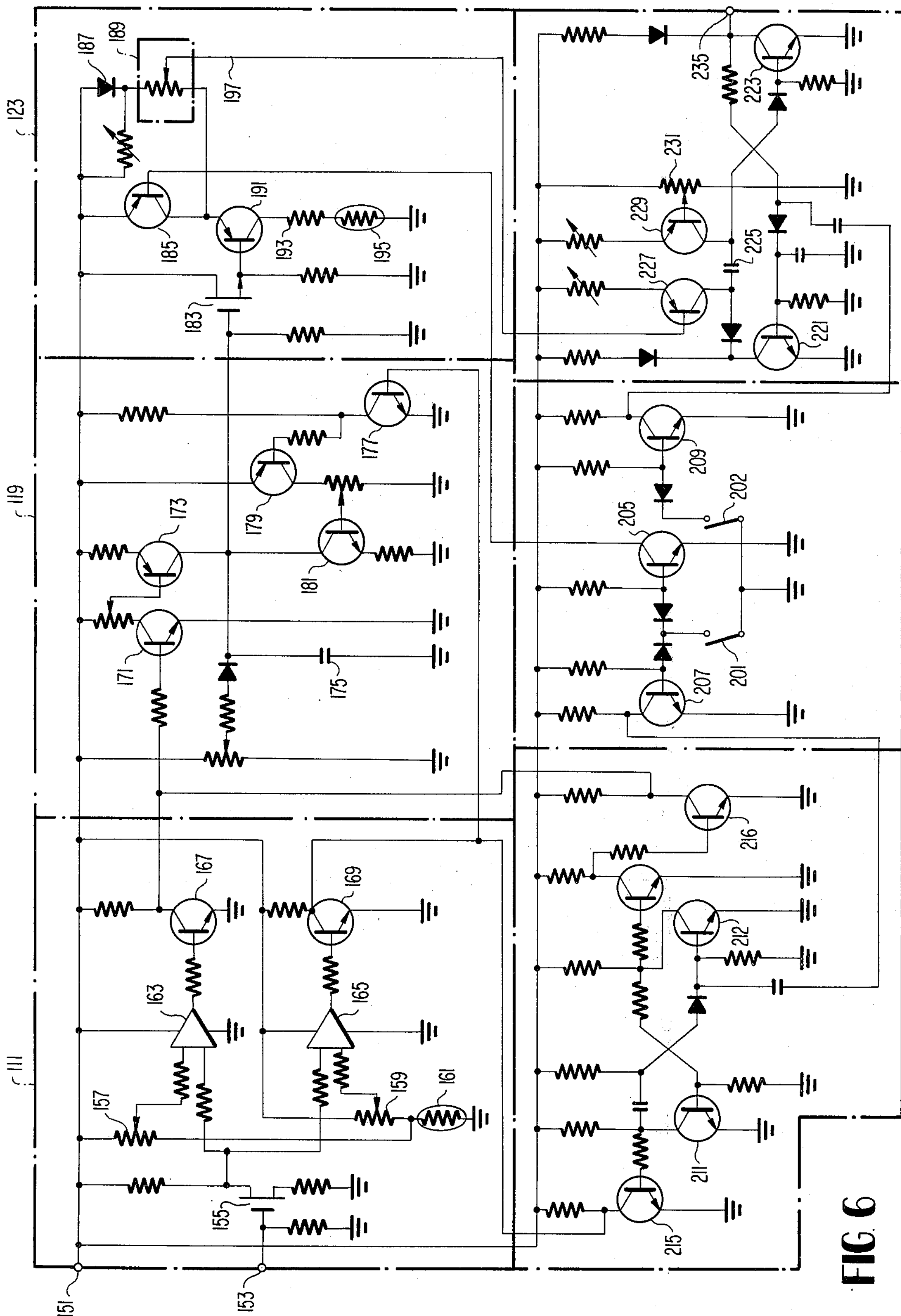

123
187
189
197
185
191
193
195
183
119
173
177
179
181
171
175
111
163
165
167
169
157
159
161
155
151
153
127
235
223
231
229
225
227
221
129
209
202
205
201
207
121
216
212
211
215

FIG 6

ELECTRONIC FUEL INJECTION APPARATUS FOR A FUEL INJECTION

Background of the Invention

This invention relates to a control apparatus for a fuel injection system and, more particularly, to a closed-loop type fuel injection control apparatus in which the quantity of injected fuel is compensated in accordance with quantity of oxygen in the exhaust gas.

Description of the Prior Art

There is a definite relation between the amount of fuel consumed and the amount of air, since carbon and hydrogen, being elements of fuel, combine with oxygen in accordance with a prescribed relationship. In general, air is introduced into a cylinder by engine suction and the amount of fuel needed is determined in response to the amount of the introduced air or oxygen. However, it is very difficult to measure the amount of air with high accuracy. Therefore, the introduced air-fuel ratio can be determined by detecting the characteristics of the exhaust gas and it is possible to compensate the fuel quantity so as to obtain a suitable air-fuel ratio. Still, a conventional injection control apparatus tends to be very complicated.

SUMMARY OF THE INVENTION

Objects of the Invention

It is an object of the invention to provide a simple fuel control apparatus of the closed-loop type.

It is a further object of the invention to provide a fuel control apparatus of which the operation is very stable.

It is still another object of the invention to provide a fuel control apparatus having a high response.

A fuel control apparatus of the present invention includes an integrating circuit for integrating current in response to the output from an oxygen detector. The output of the integrating circuit compensates for the amount of injected fuel. If the integrating circuit has a large time constant, the operation of the apparatus is very stable, but the response is inferior; for a small time constant, the response is good, but the operation itself is unstable. The integrating operation of the integrating circuit is controlled so as to operate during a predetermined duration independent of engine speed. The time constant of the integrating circuit is small, yet the operation of the injection control apparatus is very stable.

Brief Description of the Drawings

FIG. 1 is a block diagram of an embodiment of the present invention;

FIG. 2 is an explanatory drawing illustrating the operation state of FIG. 1;

FIG. 3 is a wave form of a charged voltage produced by the charging and discharging circuit of FIG. 1;

FIG. 4 is a modification of a pulse generator 5 and a flip-flop 29 of FIG. 1;

FIG. 5 is an explanatory drawing illustrating the operation state in accordance with the modification of FIG. 4; and

FIG. 6 is a detailed circuit of the block diagram of FIG. 1.

Detailed Description

With reference to FIG. 1, an air flow detector 1 serves to detect the average value of air flow from the

air filter to an engine cylinder. One of the most frequently used air flow detectors comprises a movable air plate inserted into an air passage and a variable resistor a slidable contact of which is moved by the displacement of the air plate. Therefore, the resistance of the variable resistor represents the average of the air flow and is changed in response to the change of air flow.

A temperature sensor 3 detects the temperature of the engine, and since the amount of fuel to be injected is affected by the temperature of the engine, the sensor 3 is needed to compensate the injected amount of fuel.

A pulse generator 5 generates timing pulses in response to the rotation of the crankshaft. The timing pulse is applied to a flip-flop 29 for generating a duration pulse proportional to the engine operation.

An oxygen sensor 7 detects a characteristic of the exhaust gas, especially the density of oxygen in the exhaust gas. In general, an oxygen sensor consists of a zirconium dioxide and electrodes provided on its surface. When the oxygen density on one side of the zirconium dioxide is different from the density on the other side, a voltage is generated between the two sides in response to the difference of the oxygen density. When the one side is inserted into the exhaust gas and the oxygen density on the other side is kept constant, the change of the generated voltage corresponds to the variation of the oxygen density in the exhaust gas.

The temperature sensor 9 is provided to detect the temperature of the oxygen sensor 7. Since the output of the oxygen sensor 7 is also affected by temperature, it is needed to compensate the output voltage. The comparing circuit 11 receives the outputs of the oxygen sensor 7 and the temperature sensor 9. When the oxygen density in the exhaust gas exceeds a predetermined value, a positive current is applied to an integrating circuit 19 through an AND gate 15. When the oxygen density is below a predetermined value, a negative current is applied to the integrating circuit 19 through an inverter 13 and an AND gate 17. When positive current is applied, the output voltage of the integrating circuit 19 is increased, and it is decreased by applying a negative current.

The operation of the gates 15 and 17 are controlled by a monostable multivibrator 21. Since the effect of the oxygen sensor is restricted by the monostable multivibrator 21, the integrating circuit 19 has large time constant.

A current controller 23 serves to control the charging current of a charging circuit 25 in such a way that the differential of the charging current is determined by total differential of the outputs of the air flow detector, the temperature sensor and the integrating circuit. The output of the charging circuit 25 is discharged by a discharging circuit 27, in order to change the charged voltage to a function of time which represents the valve opening duration of the fuel injection valve. It is necessary to identify generating timing of the output of the discharging circuit 27 with fuel injection timing. Therefore, the operations of the charging and discharging circuits are controlled by the flip-flop 29. A flip-flop 31 serves to distribute the output of the discharging circuit 27 to valve controllers 41 and 43 through AND gates 35 and 37. Fuel valves 45 and 47 are driven by the valve controllers 41 and 43, respectively.

With reference now to FIG. 2, the operation of the circuit depicted in FIG. 1 will be explained. For purposes of simplification, it will assumed that the output of the temperature sensor 3 is negligible.

The output of the air flow detector **1** corresponds to an average of the air flow in an air passage (not shown) as explained previously. Since the quantity of air introduced into one of the cylinders of the engine is determined by the opening time of an air-intake valve and the air flow quantity therethrough, it is possible to represent the quantity of air in the cylinder by the electrical output of the air flow detector **1** during the valve opening. Since the flip-flop **29** is operated by the output of the pulse generator **5**, which is connected to the toggle input of the flip-flop, the duration of the pulse from the flip-flop **29** will be proportional to the valve opening.

As is shown in FIG. **2**, in each 180° rotation of the crankshaft, a pulse will be produced by the pulse generator **5**, the duration of the pulse being a portion of the 180° rotation. This is shown at curve (A) in FIG. **2**.

The "set" output of flip-flop **29** is shown at (B) in FIG. **2**, this output appearing on line **61** shown in FIG. **1**. Of course, the "reset" output will appear on line **62** at periods alternating between the "set" output of flip-flop **29**.

Now, since the "set" output of the flip-flop **29** is connected to the charging circuit **25**, during the generation of the output on line **61**, i.e., signal (B) of FIG. **2**, the charging circuit **25** will store a charge in accordance with the output of the air flow detector **21**, which is connected to the charging circuit by way of current controller **23**. This charged voltage represents the quantity of air introduced into a cylinder.

Since the quantity of fuel injection is controlled by the opening time of fuel valve **45** or **47**, shown in FIG. **1**, it is necessary to produce a signal as a function of time, which becomes the basis of the opening time of the fuel valve **45** or **47**. Then, the charged voltage is discharged with a predetermined current value by the discharging circuit **27**.

Namely, as is shown at (C) in FIG. **2**, the charging circuit **25** produces a ramp output corresponding to the output of the air flow detector **1** during the time that the "set" output of flip-flop **29** is high. Then, by the way of the "reset" output of the flip-flop **29**, on line **62**, discharging circuit **27** is activated and the charge previously stored in charging circuit **25** is discharged during a period of time t, i.e., during the period of time of the negatively sloped ramp of signal (C) of FIG. **2**.

The output of the discharging circuit **27** is coupled by way of AND gates **35** and **36** to the respective valve controllers **41** and **43** for the fuel valves **45** and **47**, respectively. Connected to the other respective inputs of the AND gates are the "set" and "reset" outputs of the flip-flop **31**, which is connected by way of lines **61** and **62** to the "set" and "reset" outputs of flip-flop **29**.

As a result, during alternate periods of time that the discharging circuit supplies the negatively-sloped ramp output, the fuel injection valves **45** and **47** will be correspondingly alternately opened, as shown at (D) and (E) of FIG. **2**.

The current to be charged is also effected by the output of the integrating circuit **19** which represents a characteristic of the exhaust gas. As a result, the charging current is represented as a function of the air flow in the air passage and the amount of oxygen in the exhaust gas. The discharging time will be affected by the output of the integrating circuit **19** and the quantity of injected fuel is compensated by the density of oxygen in the exhaust gas.

With reference to FIG. **3**, which depicts the respective positive- and negative-sloped wave form (C) of FIG. **2**, the tangent of the angle α is determined as a function of the outputs of the air flow detector **1**, the temperature sensor **3** and the integrating circuit **19**, all of which are supplied to the current controller **23**. The duration of the negatively-sloped ramp, i.e., time t, is proportional to the opening time of the air-intake valve of the engine. Thus, the tangent β is constant and is determined by the discharging current. While tan α is changed by the output of the integrating circuit, it is possible to change tan β in response to the characteristics of the exhaust gas, in order to compensate the quantity of injected fuel.

In some instances, one fuel valve may be employed to simultaneously supply fuel to two cylinders. In this case, the quantity of injected fuel must be doubled. This necessity is achieved by doubling the charging time of the charging circuit **25**.

More specifically, referring to FIG. **4**, switches **51** and **52** are provided to operate in synchronism with the rotation of the crankshaft to produce pulses, the same as the output of the flip-flop **29**. The flip-flop **55** doubles the pulse duration of the switches **51** and **55** and the output **57** and **58** of the flip-flop **55** are supplied to lines **61** and **62** of FIG. **1**. Since the duration of the pulses supplied to the charging circuit **25** is doubled, the operation time of the charging circuit is doubled as shown in FIG. **5**.

In FIG. **5**, the wave forms (A') — (D') correspond to the wave forms (A) — (D) in FIG. **2**, with the wave forms for each of the lines of flip-flop **55** shown at (B') and ($\overline{B'}$).

Referring now to FIG. **6**, a detailed circuit diagram of portions of the circuit of FIG. **1** are shown. In the figure, portion **111**, corresponding to block **11** of FIG. **1**, compares the output of an oxygen sensor with a predetermined level. Circuit portion **119** is an integrating circuit, corresponding to block **19** of FIG. **1**, portion **123** is a current controller, corresponding to block **23** of FIG. **1**, portion **121** is a monostable multivibrator, corresponding to block **21** of FIG. **1**, portion **129** is a pulse generator, corresponding to pulse generator **5** of FIG. **1**, and portion **127** is a charging and discharging circuit, corresponding to blocks **25** and **27** of FIG. **1**.

A voltage supply potential is connected to terminal **151** and the output of the oxygen sensor (not shown) is applied to terminal **153** and amplified by field-effect transistor **155**, the gate resistance of which is very large. The output of the transistor **155** is applied to operational amplifiers **163** and **165**. When the output of the transistor **155** exceeds a predetermined level established by the variable resistor **159**, the output of the operational amplifier **165** will turn transistor **169** "off." On the other hand, when the output of the field-effect transistor **155** is below the predetermined level set by resistor **157**, the output of the operational amplifier **163** will turn transistor **167** "off."

Since the voltage generated by the oxygen sensor changes in response to variations in temperature, a temperature sensor **161** is provided in series with the variable resistors **157** and **159**, in order to stabilize the predetermined levels set by the variable resistors **157** and **159**.

Now, when transistor **169** is "off," the potential at the terminal **151** will be resistively coupled to the base of transistor **177** which, in conjunction with transistor

179, will turn transistor **181** "on," thereby discharging capacitor **175** therethrough.

When the transistor **167** is "off," as a result of the potential applied to terminal **151** being resistively coupled to the base of transistor **171**, transistor **173**, which is resistively connected to the collector of transistor **171**, will be turned "on," thereby providing a charging path through the transistor **173** to the capacitor **175** to charge the same. The voltage across transistor **175** is amplified by transistor **183** and supplied to the base of the transistor **191**.

A diode **187**, variable resistor **189**, transistor **191**, resistor **193** and temperature detector **195**, for detecting the temperature of the engine, are connected in series between the voltage source terminal **151** and ground. The arm of the variable resistor **189** is displaced by the air-plate which receives the air flow. The output line **197** will supply the voltage which changes as a function of the air flow, the voltage across capacitor **175** and the temperature of the engine, to the base of transistor **227**, the operation of which will be discussed hereinafter.

During the rotation of the crankshaft of the engine, switch terminal contacts **201** and **202** will alternately open and close. When the switch **201** is open, transistor **205** will be "on," and transistor **185** will be "on." When transistor **185** is turned "on", the voltage at the collector thereof will become "high", thereby forcing the voltage on line **197** to a "high" level, so that the operation of the charging circuit within circuit portion **127** is interrupted.

In the monostable multivibrator **121**, transistors **211** and **212** are operated in response to the voltage on the collector of transistor **207** within pulse generator circuit **129**. Transistors **215** and **216** provide the output of the transistors **167** and **169** to the integrating circuit when the trigger from the switch **201** is applied to the base of the transistor **212**.

Within the charging and discharging circuit **127**, transistors **221** and **223** operate as a monostable multivibrator. Transistor **227** and capacitor **225** operate as the charging circuit portion, while transistor **229** and capacitor **225** operate as discharging circuit. The charging current of the capacitor **225** is determined by the voltage supplied to the base of the transistor **227** by way of line **197**, as discussed above. The discharging current is determined by the voltage applied to the base of the transistor **229**, which is determined in accordance with the voltage across variable resistor **231**, a slidable arm of which is supplied to the base of transistor **229**.

A duration pulse corresponding to the charging time of the capacitor **225** is produced at the collector of the transistor **223** and supplied by way of output terminal **235** to a valve controller for controlling the operation of a fuel injection valve.

In the above circuit, the voltage of the capacitor **175** in the integrating circuit **119**, which represents the oxygen density in the exhaust gas, compensates the charging current delivered to the capacitor **225** within a charging and discharging circuit portion **127**. However, it is possible to compensate the discharging current. In this case, the diode **187**, the variable resistor **189**, the resistor **193** and the temperature sensor **195** are connected in series between the voltage source terminal **151** and ground. The drain electrode of the field-effect transistor **183** is then connected to the base of transistor **229**. The charging current is determined by the air flow average and temperature of the engine, and the discharging current is determined by the voltage across capacitor **175**.

While I have shown several embodiments in accordance with the present invention, it is understood that the same is not limited thereto but also contemplates numerous changes and modifications as would be known to those skilled in the art given the present disclosure of the invention, and I therefore do not wish to be limited thereto but intend to cover all such changes and modifications.

What I claim is:

1. An electronic control apparatus for a fuel injection system comprising:

first means for generating a first signal representative of the flow of air supplied to an engine cylinder;

second means for generating pulses in response to the engine rotation;

third means for generating a second signal representative of the level of the quantity of oxygen in the engine exhaust gas;

fourth means, responsive to said second signal, for generating a third signal representative of the integration of said second signal;

fifth means, coupled to said first means and said fourth means, for generating a charging current in response to said first and third signals;

sixth means, coupled to said second means and said fifth means, for discharging said charging current in response to said pulses generated by said second means;

seventh means, coupled to said sixth means, for generating a fuel injection valve opening signal in accordance with the time required for said charging current to discharge by said sixth means; and

eighth means, responsive to the pulses generated by said second means, for generating a pulse having a predetermined duration, for controlling the operation of said fourth means.

2. An electronic control apparatus according to claim **1**, wherein said fourth means includes

a comparing circuit which compares said second signal with a predetermined value and generates one of a positive and negative valued signal in dependence upon said second signal exceeding said predetermined value, and

a charge-discharge circuit which integrates the output of said comparing circuit in response to said predetermined duration pulse generated by said eighth means.

3. An electronic control apparatus according to claim **2**, wherein said eighth means comprises a monostable multivibrator.

4. An electronic control apparatus according to claim **2**, wherein said fifth means includes a voltage divider network having at least two variable resistance means and an output terminal connected in series across a constant voltage source, the resistance value of one of said variable resistance means being varied in accordance with the voltage integrated by the charge-discharge circuit of said fourth means, and the resistance value of the other of said variable resistance means being varied in accordance with the value of said first signal representative of air flow, the charging current generated by said fifth means varying in response to the voltage at said output terminal.

5. An electronic control apparatus for a fuel injection system comprising:

first means for generating a first signal representative of the flow of air supplied to an engine cylinder;

second means for generating pulses in response to engine rotation;

third means for generating a second signal representative of the quantity of oxygen in the engine enhaust gas;

fourth means for storing or discharging a charge in response to the output of said third means;

fifth means for storing a charge in response to the output of said first means;

sixth means for discharging the charge stored by said fifth means through a resistance means, the value of which is dependent upon the output of said fourth means;

seventh means for activating fuel injection valves in response to the output of said sixth means; and

eighth means comprising a monostable multivibrator for operating said fourth means in response to the pulses generated by said second means.

6. An electronic control apparatus for a fuel injection system comprising:

first means for generating a first signal representative of the flow of air supplied to an engine;

second means for generating pulses in response to the engine rotation;

third means for generating a second signal representative of the level of the quantity of oxygen in the engine exhaust gas;

fourth means, responsive to said second signal, and coupled to said second means, for generating a third signal representative of the integration of said second signal;

fifth means, coupled to said first means, said second means and said fourth means, for generating a fourth signal, a first component of which is representative of the storing of a charge over a first prescribed portion of said engine rotation, and a second component of which is representative of the discharging of said charge during a second prescribed portion of said engine rotation subsequent

to said first prescribed portion, in response to said first and third signals; and

sixth means, coupled to said fifth means and said second means, for generating a fuel injection valve opening signal in accordance with the duration of the second component of said fourth signal.

7. An electronic control apparatus for a fuel injection system according to claim **6,** wherein said second signal generated by said third means has a first component of a first polarity representative of the density of oxygen in said engine exhaust gas exceeding a prescribed level, and a second component of a second polarity, opposite to said first polarity, representative of the density of oxygen in said engine exhaust gas failing to exceed said predetermined level.

8. An electronic control apparatus for a fuel injection system according to claim **6,** wherein the amplitude of the first component of said fourth signal at the termination of said first prescribed portion of said engine rotation is representative of the level of the density of oxygen in said exhaust gas, while the duration of said second component of said fourth signal is representative of the length of time required for the value of charge corresponding to said amplitude to discharge during said second prescribed portion of said engine rotation at a predetermined rate of discharge.

9. An electronic control apparatus for a fuel injection system according to claim **7,** wherein the amplitude of the first component of said fourth signal at the termination of said prescribed portion of said engine rotation is representative of the level of the density of oxygen in said exhaust gas, while the duration of said second component of said fourth signal is representative of the length of time required for the value of charge corresponding to said amplitude to discharge during said second prescribed portion of said engine rotation at a predetermined rate of discharge.

10. An electronic control apparatus for a fuel injection system according to claim **6,** further including a monostable multivibrator, coupled to the output of said second means, for controlling the operation of said fourth means.

* * * * *