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[11] **3,851,635**

[45] **Dec. 3, 1974**

[54] **ELECTRONICALLY CONTROLLED FUEL-SUPPLY SYSTEM FOR COMPRESSION-IGNITION ENGINE**

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[62] Division of Ser. No. 36,814, May 13, 1970, Pat. No. 3,742,918.

[30] **Foreign Application Priority Data**

May 14, 1969 France 69.15592

[52] **U.S. Cl.** ..... **123/139 E,** 123/32 AE, 123/32 EA

[51] **Int. Cl.** **F02m 51/00,** F02d 5/04

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

[56] **References Cited**

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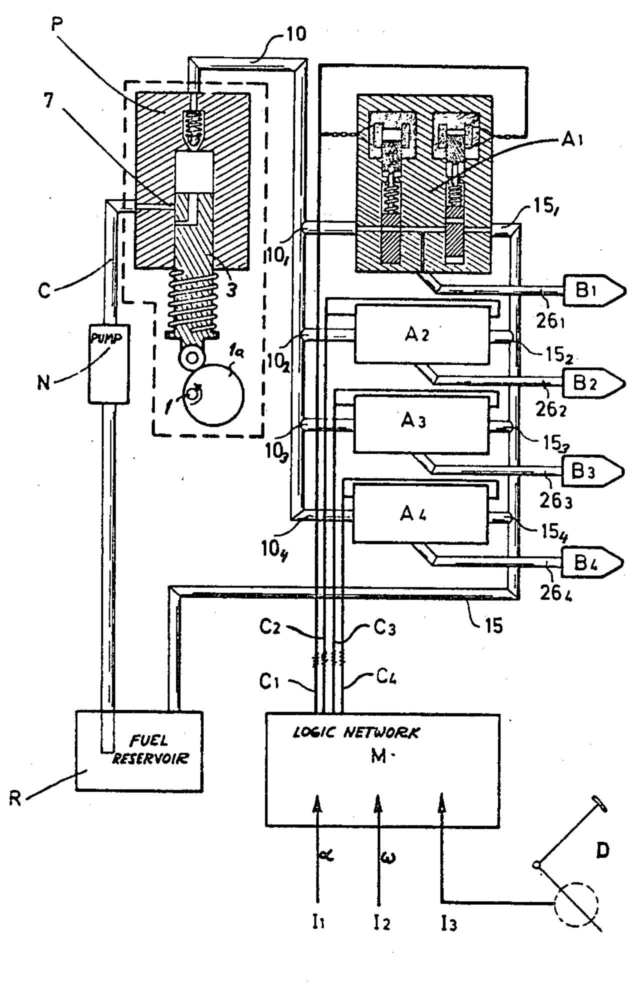
Primary Examiner—Charles J. Myhre
Assistant Examiner—Cort Flint
Attorney, Agent, or Firm—Karl F. Ross; Herbert Dubno

[57] **ABSTRACT**

One or more cylinders of a compression-ignition engine are connected to respective supply conduits through control valves normally spring-biased into a closed position. A feed pump periodically delivers fuel under pressure, from a reservoir, to a distributing channel leading to the supply conduit or conduits, this channel also having a return conduit for each cylinder with a bypass valve closed during all or part of the compression stroke of the pump. The closure of this bypass valve, during a gating interval established by an electronic network, causes a pressure buildup in the supply conduit sufficient to open the control valve against the force of its loading spring so that fuel under pressure enters the injector throughout the gating interval whose timing and duration may be determined by one or more operating parameters, such as throttle position and engine speed, fed into the network.

3 Claims, 9 Drawing Figures



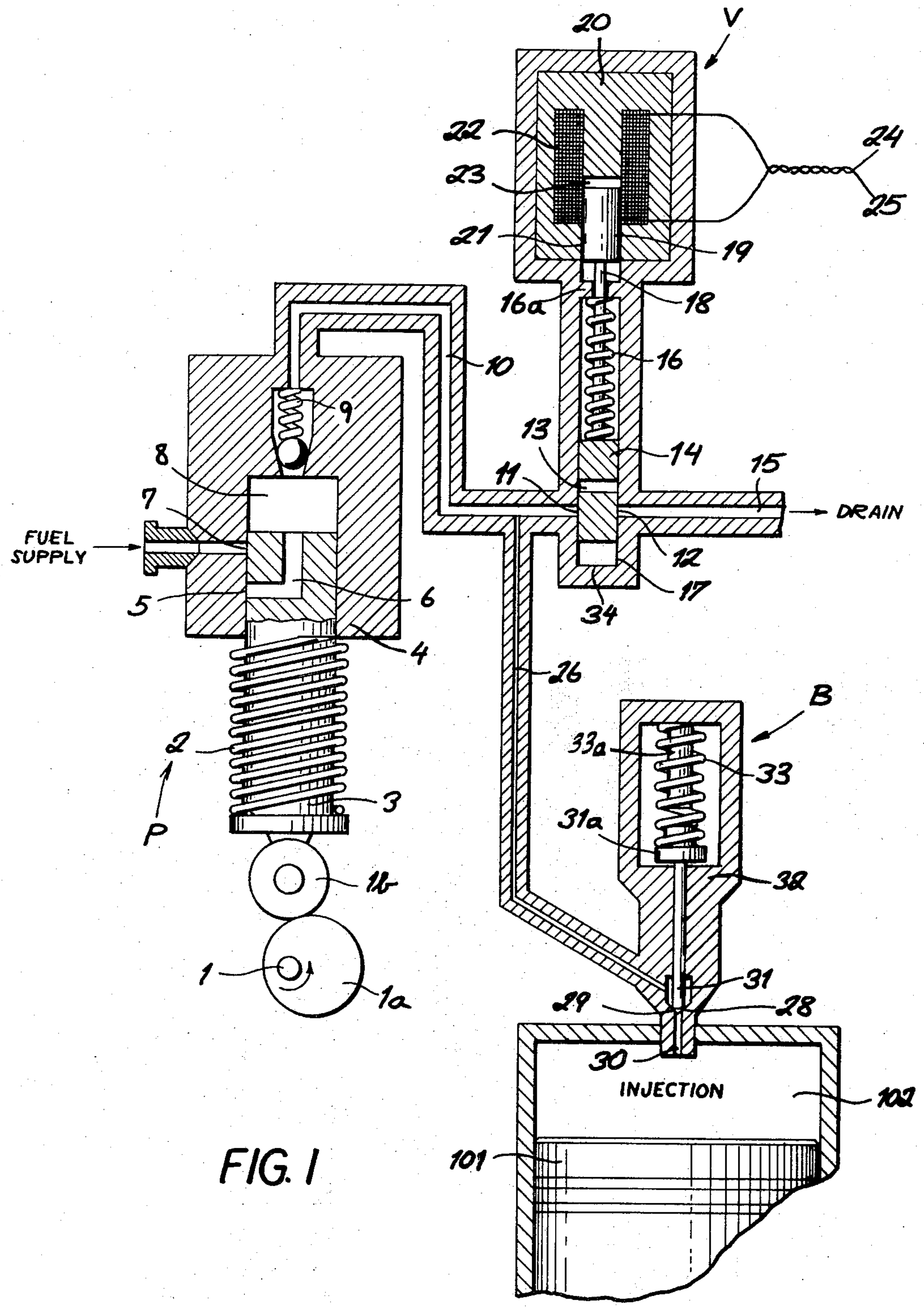

20
V
22
23
21
24
25
19
18
16a
16
10
9
8
7
FUEL SUPPLY
5
6
4
13
14
15
11
DRAIN
12
17
34
26
B
2
P
3
33a
33
31a
32
1b
1
1a
31
29
28
30
INJECTION
102
101

FIG. 1

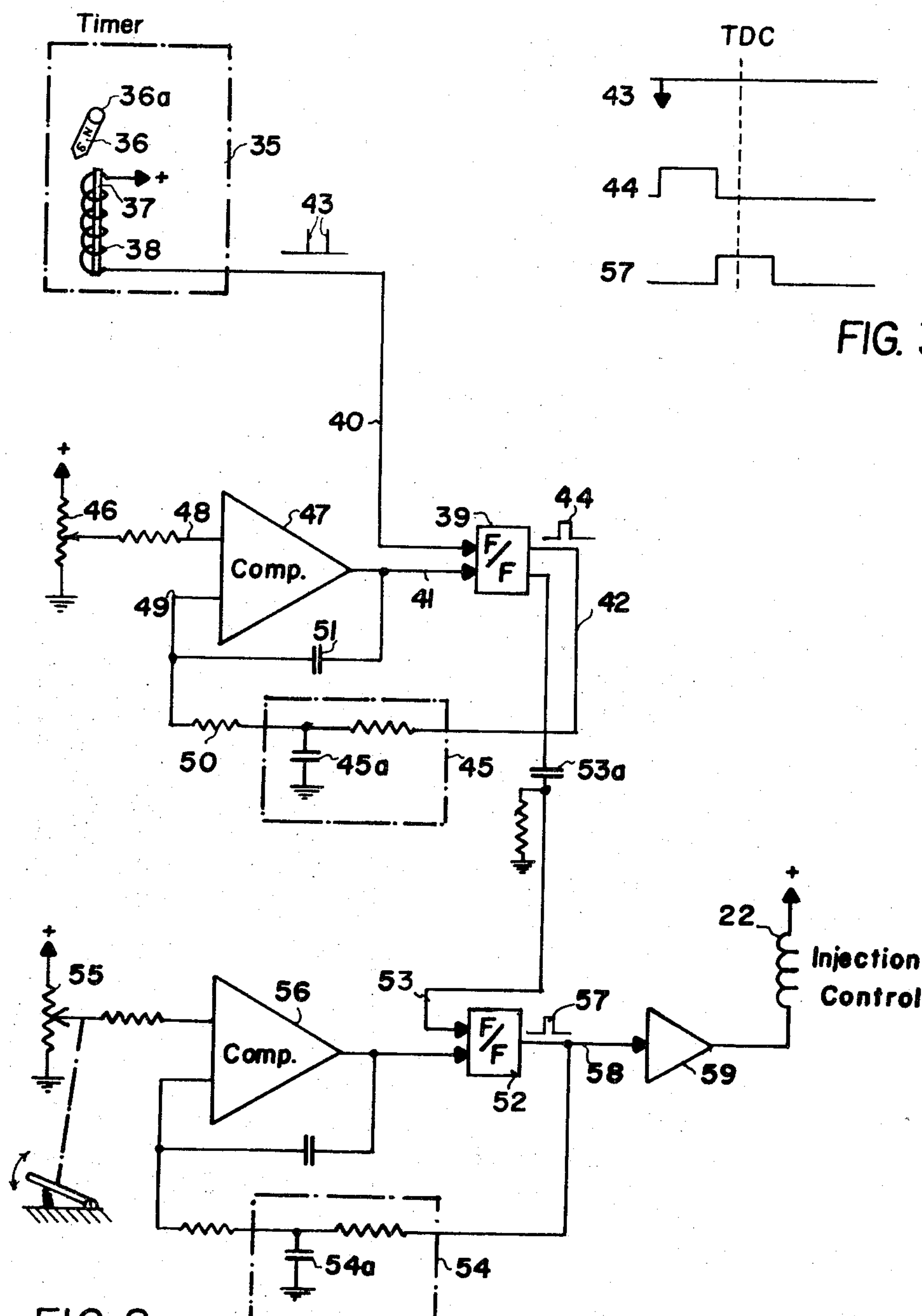

Timer
36a
36
35
37
38
43
40
46
48
47
Comp.
39
F/F
44
41
42
49
51
50
45a
45
53a
22
Injection Control
55
56
Comp.
53
F/F
57
58
59
52
54a
54
TDC
43
44
57

FIG. 2

FIG. 3

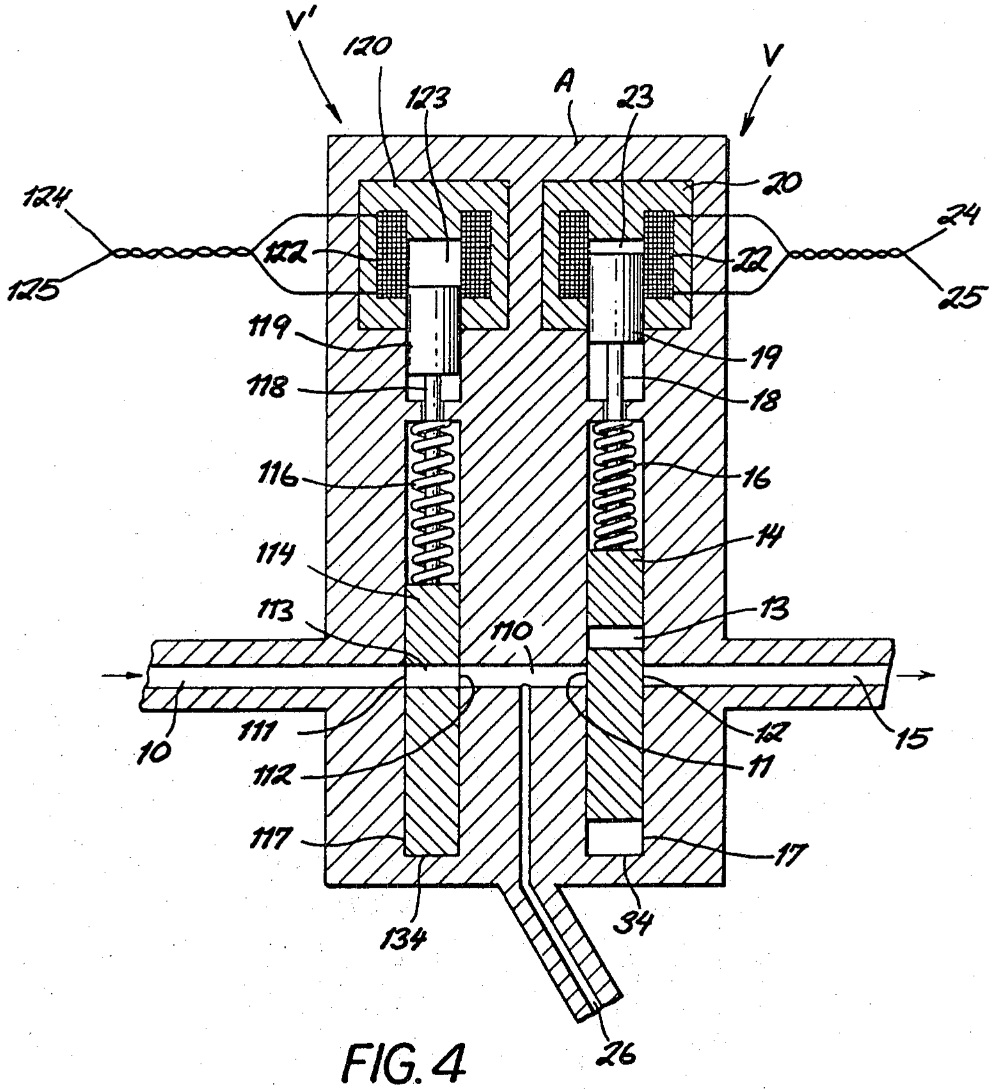

V'
120
123
A
23
V
20
124
24
122
22
125
25
119
19
118
18
116
16
114
14
113
13
110
10
111
12
15
112
11
117
17
134
34
26

FIG. 4

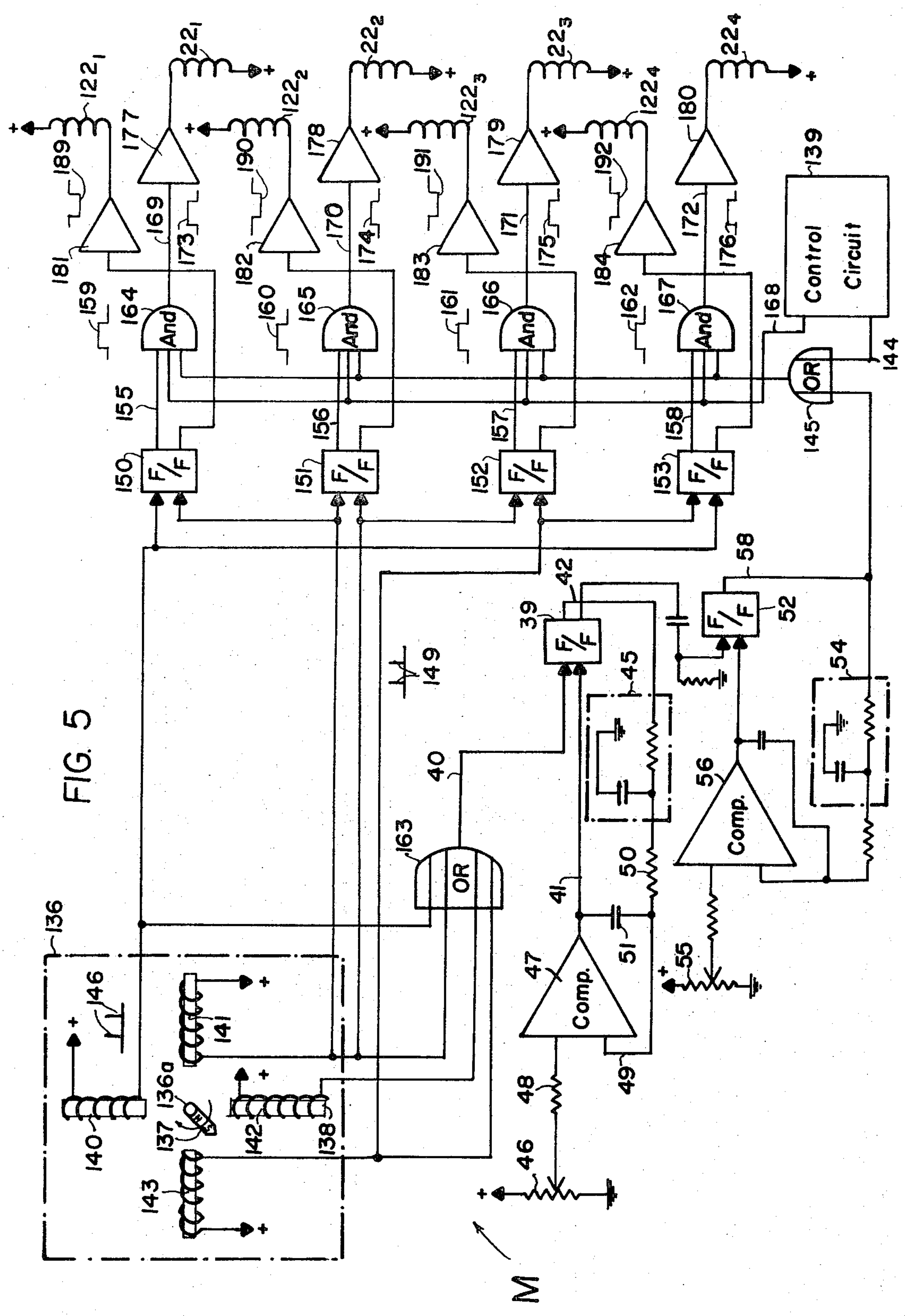


FIG. 5

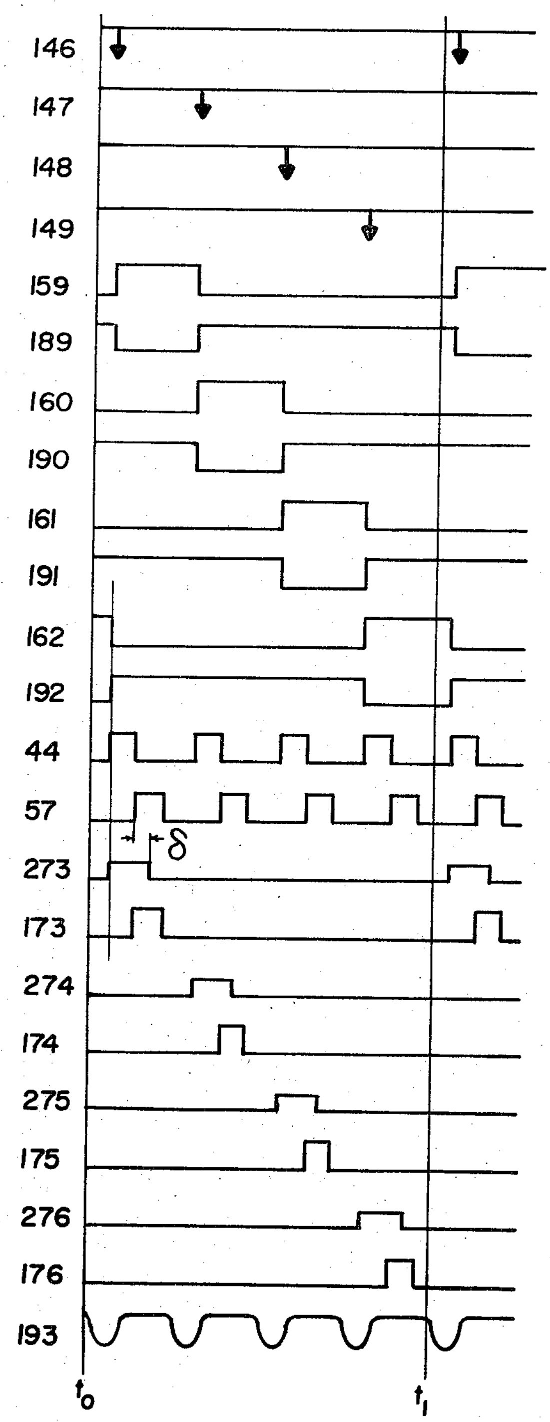

146
147
148
149
159
189
160
190
161
191
162
192
44
57
δ
273
173
274
174
275
175
276
176
193
t_0
t_1

FIG. 6

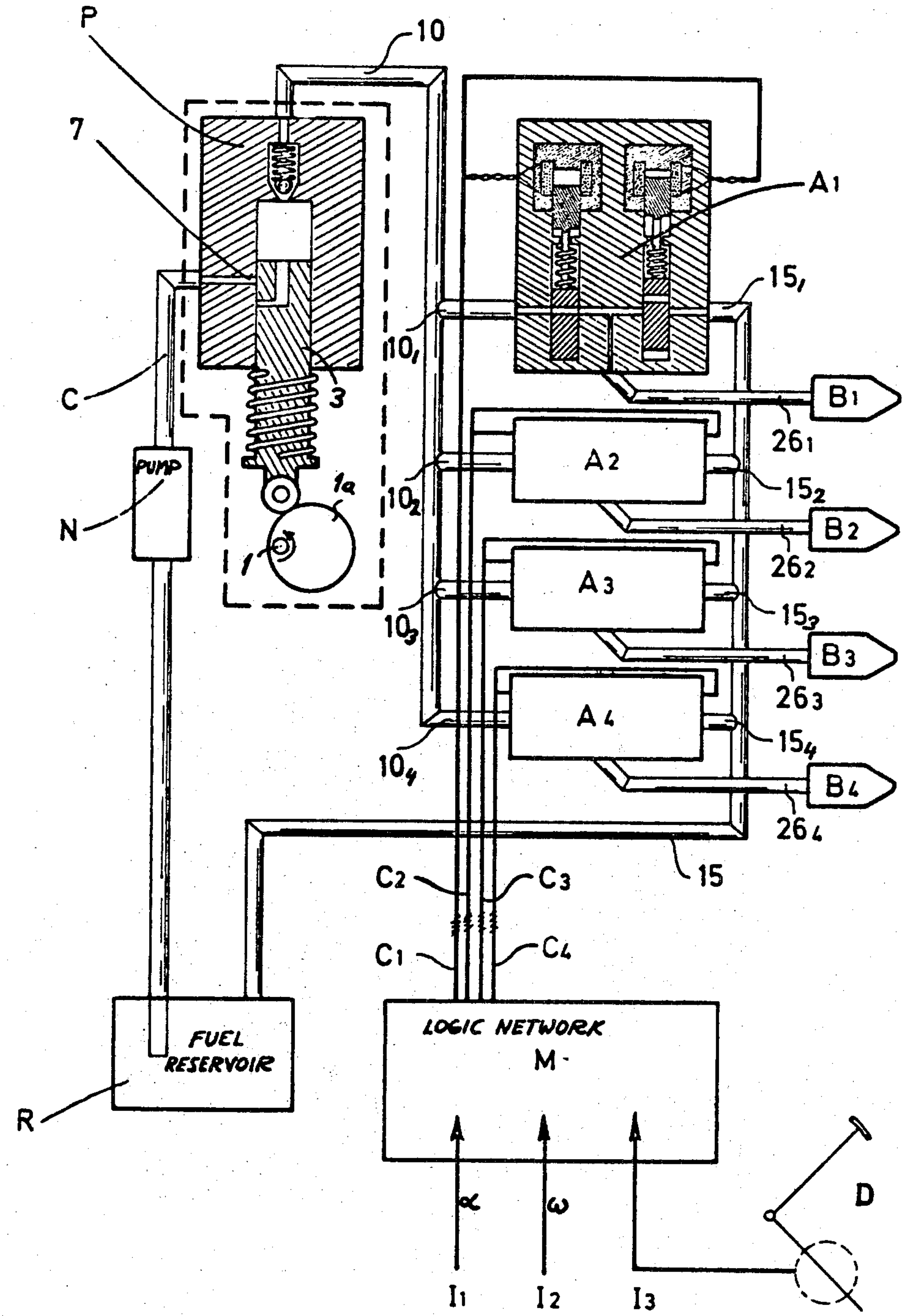

P
10
7
A1
15₁
10₁
C
3
B1
26₁
PUMP
A2
N
1a
10₂
15₂
1
B2
26₂
A3
10₃
15₃
B3
26₃
A4
10₄
15₄
B4
26₄
15
C2
C3
C1
C4
FUEL RESERVOIR
LOGIC NETWORK
M
R
α
ω
D
I1
I2
I3

FIG. 7

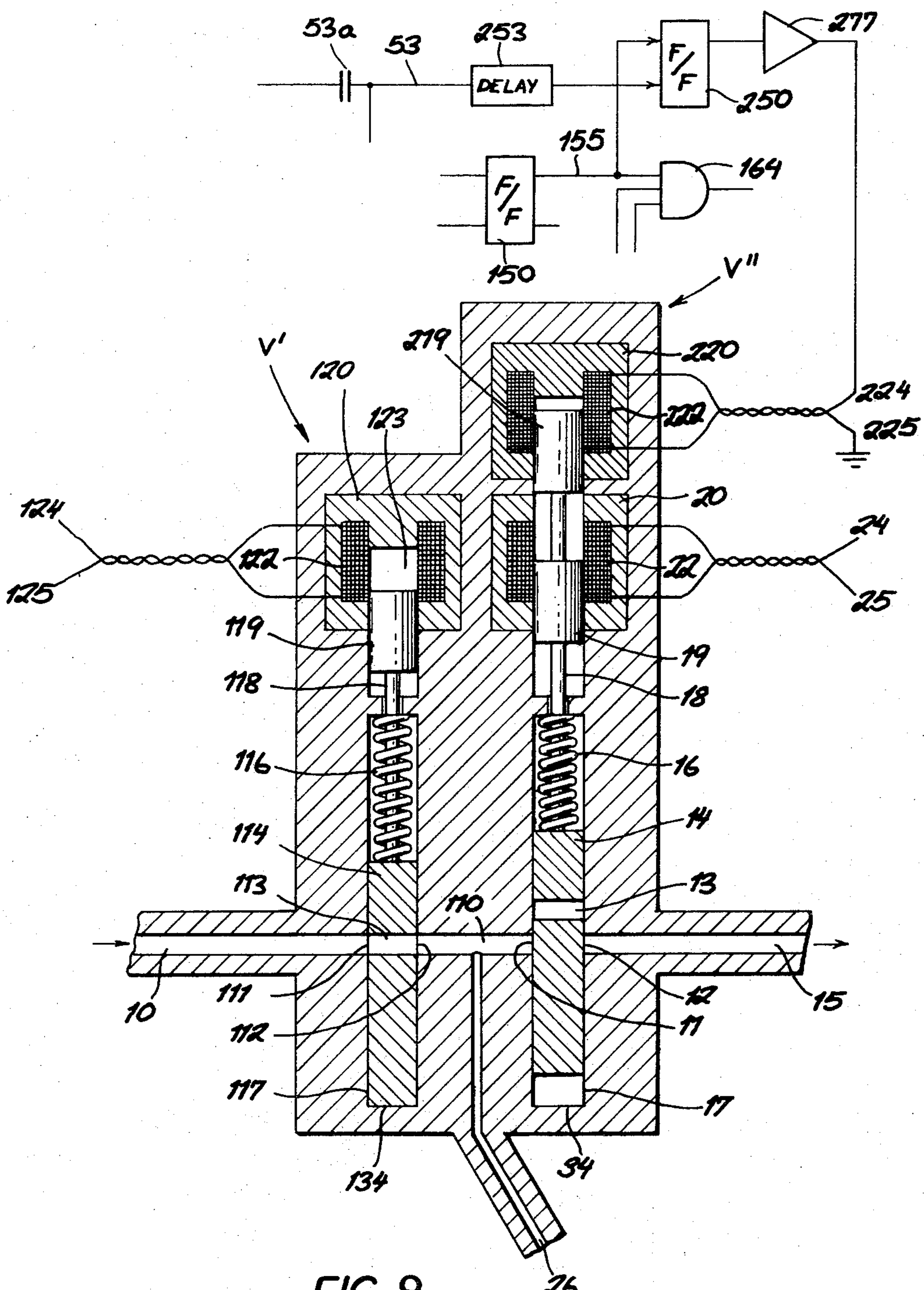

53a
53
253
DELAY
F/F
250
277
155
164
F/F
150
V''
V'
219
220
120
123
222
224
225
124
122
20
24
125
22
25
119
19
118
18
116
16
114
14
113
13
110
10
111
12
15
112
11
117
17
134
34
26

FIG. 8

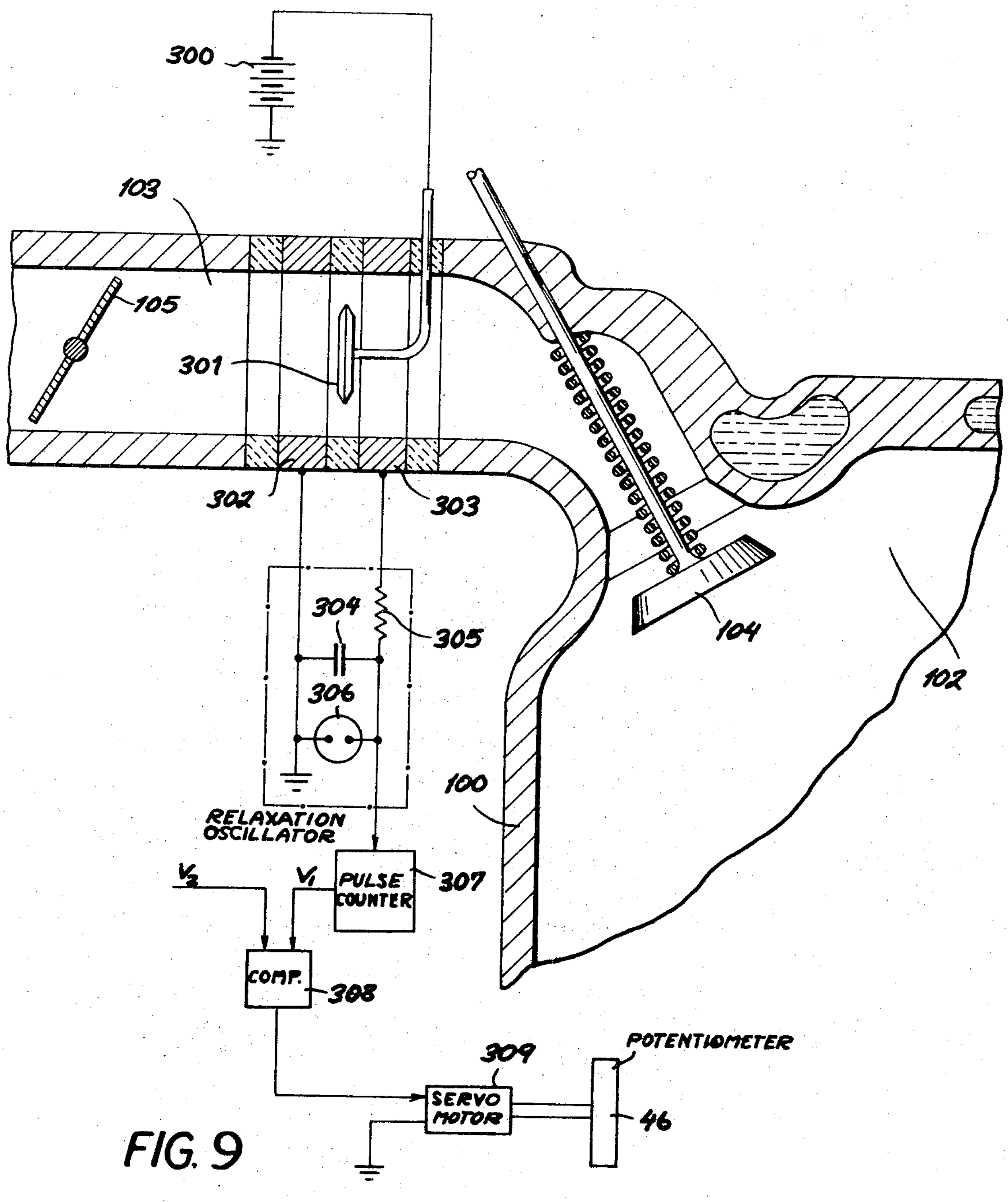

300
103
105
301
302
303
304
305
306
104
102
100
RELAXATION OSCILLATOR
V2
V1
PULSE COUNTER
307
COMP.
308
309
POTENTIOMETER
SERVO MOTOR
46

FIG. 9

ELECTRONICALLY CONTROLLED FUEL-SUPPLY SYSTEM FOR COMPRESSION-IGNITION ENGINE

This is a division of application Ser. No. 36,814, filed May 13, 1970, now Pat. No. 3,742,918.

Our present invention relates to fuel-injection systems for compression-ignition engines deriving their energy from the burning of an inflammable fluid in air.

Conventional injection systems for such engines rely on a fuel pump to meter accurately a given quantity of liquid hydrocarbons to the injectors, usually associating a separate pump with each cylinder. Because of the very small quantities of liquid involved in each combustion cycle, the mechanical complexity and precision required in these metering pumps is high. On account of their inherent inertia, these pumps cannot be quickly adjusted to changing operating conditions in order to adapt their delivery rate to variations in, say, the terrain traveled by an automotive vehicle equipped with such an engine.

Since the operating efficiency, responsiveness to changes in load, and the proportion of unburned fuel in the exhaust gases are all affected by the closing and timing of the fuel injection for each cylinder, our invention aims at providing a closely controllable supply of fuel to the combustion chamber or chambers of an internal-combustion engine.

A more specific object of this invenion is to provide simple and effective means for so controlling this fuel supply in response to certain operating parameters as to minimize pollution of the atmosphere by unburned combustion residue.

These objects are realized, pursuant to our present invention, by the provision of a fuel-supply system for one or more cylinders of an internal-cumbustion engine, e.g. in an automotive vehicle, wherein an engine-driven pump preferably of the reciprocating-piston type delivers fuel under pressure to a distributing channel from which a first conduit extends to an injector or a cylinder served thereby, another extension conduit returning excess fuel to a drain (usually to the reservoir or tank feeding the pump). The first conduit contains a normally closed valve biased by a force less than that exerted upon the valve body by the pump pressure whereby, in response to a pressure buildup within the channel upon a blocking of the drain during a compression stroke of the pump, this control valve is forced open to admit fuel to the cylinder (or to an antechamber periodically communicating therewith) for a period depending upon various operating parameters which control a bypass valve in the second conduit to close and open the fuel-return path. The temporary closure of this bypass valve, therefore, determines the injection interval which may extend over all or part of that compression stroke.

According to a more specific feature of our invention, applicable to a multicylinder engine, the distributing channel has a plurality of branches each with its own supply and return conduit, each branch further containing a shut-off valve ahead of these conduits for isolating them from the corresponding conduits in the other branch or branches during their mutually staggered operating phases. Each compression stroke of the pump finds only one of these shut-off valves open to feed the corresponding injector in the rhythm of a gating signal controlling the associated bypass valve.

The timing of the injection interval with reference to a compression stroke assigned to the corresponding engine cylinder, i.e. the duration of that interval and/or the time of its inception within the compression phase, is advantageously controlled by a logic network forming part of a computer responsive to the aforementioned operating parameters, such as engine speed and load. This network may include a pair of cascaded pulse generators, such as bistable or monostable elements, whose output pulses can be made to vary in length under the control of an analog voltage representing a respective parameter. The first pulse generator may be periodically started by an invariable timing signal derived from the engine itself, thus in correlation with the engine-driven feed pump; the second pulse generator then produces the gating signal which coincides with the injection interval.

The above and other features of our invention will be described in detail hereinafter with reference to the accompanying drawing in which:

FIG. **1** shows part of a fuel-injection system embodying the invention;

FIG. **2** is a diagram of an injection-control network for the system of FIG. **1**;

FIG. **3** is a set of graphs relating to the network of FIG. **2**;

FIG. **4** is a cross-sectional view of a modified control valve for the system of FIG. **1**;

FIG. **5** is a diagram of a control network similar to that of FIG. **2**, for a four-cylinder engine;

FIG. **6** is a set of graphs similar to FIG. **3**, relating to the system of FIG. **5**;

FIG. **7** is an overall schematic view of the complete fuel system of a four-cylinder engine embodying the invention;

FIG. **8** is a cross-sectional view of another modified control valve; and

FIG. **9** is a schematic representation of a measuring device to be used in the control circuit of FIG. **2** or **5**.

FIG. **1** illustrates the basic components of an injection mechanism in accordance with our invention as applied to a single-cylinder engine. A combustion chamber **102**, formed by a cylinder wall **100** and a piston **101**, is equipped with an injection nozzle B having an orifice **30**. This orifice is normally blocked by the tip **29** of a needle **31** whose shank is continuously urged by a spring **33** against a valve seat **28**. The needle **31**, forming part of an injection-control valve, slides in a body **32** whose upper end is integral with a retainer **33***a* for the spring **33** surrounding an extension **31***a* of the needle. When fuel is supplied under pressure, via a conduit **26**, to the injector B, the action of the fluid upon the beveled tip **29** overcomes the bias of the spring **33** and lifts the needle **31** out of the valve seat **28**, thereby enabling fuel to be sprayed into the combustion space **102** via the orifice **30**. Upon the reduction of the supply pressure, the spring **33** returns the needle into contact with the valve seat, thus cutting off further fuel flow to the cylinder.

The supply of pressurized fuel is effected by means of a positive-displacement pump P, driven from a shaft **1** which is synchronized with the engine crankshaft and may be the usual cam shaft in a single-cylinder engine operating on a four-stroke cycle. A cam **1***a* mounted on the shaft **1** entrains a follower **1***b* attached to a pump piston **3** biased by a return spring **2** into continuous contact with the cam **1***a*.

The piston **3** reciprocates in a pumping chamber within a block **4.** At the bottom of its operating stroke the piston uncovers an inlet **7** to which fuel is fed from a reservoir R (FIG. 7) under the influence of gravity or by a separate low-head pump.

As the piston **3** moves upward, the inlet port **7** is blocked and the fuel trapped in an overlying space **8** is forced, past a check valve **9,** into a distributing channel **10** communicating with the supply conduit **26.** At the top of the stroke a venting bore **6,** machined into the piston, registers with the inlet port **7** and permits the rapid drop of the pressure in the space **8** to the supply level. This results in the closure of the valve **9** with very little reverse flow from channel **10.**

The pumping cycle coincides with a revolution of the shaft **1** and the delivery volume is so dimensioned that during a potential injection period, measured in terms of degress of crankshaft rotation, the fuel delivered by the pump (at a predetermined rate varying with crankshaft speed) equals the maximum quantity consumable in the engine.

Channel **10** also communicates with an orifice **11** of a valve cylinder **17** from which a conduit **15,** under the control of an evaluating network described hereinafter with reference to FIG. **2,** returns excess fuel to the reservoir to regulate the amount of fuel actually injected. This is achieved by means of a bypass valve V which, when open, reduces the pressure in distributing channel **10** to a near-atmospheric level whereupon the restoring spring **33** is no longer opposed by an overriding hydraulic pressure and the injection orifice **30** is blocked by the needle **31.** Closure of this bypass valve during the pumping stroke, therefore, actuates the injector and admits fuel to the combustion space.

A plunger **14** reciprocating in valve cylinder **17** has a transverse passage **13** which in one extreme position of the piston, i.e. at the lower end of its stroke, connects the port **11** with a confronting discharge port **12** at the entrance of conduit **15.** A spring **16** surrounds a narrowed stem **18** of the plunger and abuts a shoulder **16***a* in the wall of the cylinder **17** so as to urge the plunger against the cylinder bottom **34,** thereby maintaining the passage **13** aligned with ports **11** and **12.**

The upper end of the stem **18** carries a cylindrical core **19** of high magnetic permeability forming part of a solenoid whose coil **22** sits in a permeable yoke **20** provided with a cylindrical bore **21** accommodating this core.

When the coil **22** is energized by a signal current on wires **24** and **25,** an upward force is exerted on the core **19** and the plunger **14** is raised, thereby compressing the spring **16** and blocking the return conduit **15.** In this position, the injection system is enabled and will supply fuel to the combustion chamber **102** so long as the pump pressure exceeds the biasing force of spring **33.** De-energization of coil **22** then terminates the fuel-injection phase.

In FIG. **2** we have shown an evaluating network for controlling the energization of coil **22** and, thereby, the timing and duration of the fuel injection.

A magnetic proximity sensor **35,** serving as a timer synchronized with pump P of FIG. **1,** comprises a magnetic coil **38** whose core **37** periodically co-operates with a rotating ferromagnetic armature **36** on a shaft **36***a* driven from the engine crankshaft at a suitable speed, i.e. with a step-down ratio of 2:1 in a four-stroke engine, so as to perform one revolution during each engine cycle. The variable inductance of this circuit induces a sharp pulse **43,** see also FIG. **3,** on an output conductor **40** each time the armature **36** passes close to the coil.

The pulse thus generated is used to set a normally reset flip-flop **39,** thereby generating a rectangular timing signal **44** (as also shown in FIG. **3**) on the set output **42** of this flip-flop. Signal **44** charges a capacitor **45***a* in an integrating network **45** applying a substantially linearly rising voltage to one input **49** of a comparator **47**; the other input **48** of comparator **47** carries a reference voltage generated by a potentiometer **46** which can be adjusted either manually or in response to a variable system parameter as described below with reference to FIG. **9.** The comparator output, appearing on a lead **41,** is sharpened by a resistance **50** and a feedback condenser **51.** The appearance of this signal resets the flip-flop **39,** thereby terminating the timing pulse **44** after a period varying with the potential on lead **48.** Thus, the length of the timing signal **44** is governed by the setting of potentiometer **46** whose controlling parameter, in a preferred embodiment, is substantially proportional to engine speed.

Th trailing edge of the pulse **44,** as derived via a capacitor **53***a* from the reset output **53** of flip-flop **39,** sets another flip-flop **52** to generate a rectangular gating signal **57** (FIG. **3**) on a conductor **58.** The signal **57** enters a power amplifier **59** whose output energizes the coil **22** of the bypass valve V, FIG. **1,** thereby initiating the injection phase of cylinder **102.**

The length of the injection period is governed by the gating pulse **57** whose duration, in turn, is controlled by the output of a comparator **56.** Signal **57** charges a capacitor **54***a* of an integrating network **54** feeding one input of the comparator, its other input receiving a reference voltage from a potentiometer **55** under the control of a driver-operated accelerator pedal D. Like potentiometer **46,** therefore, voltage source **55** establishes a variable threshold potential whose magnitude depends on a significant parameter of the system (here engine load). Gating pulse **57,** whose leading edge may be timed to occur shortly before the piston **101** reaches its upper dead-center position TDC as indicated in FIG. **3,** could terminate before or after the end of the compression stroke. Thus, the start and the end of this gating pulse, and therefore of the injection interval, are determined by the respective settings of potentiomeers **46, 55.**

When the engine to be fitted with our improved injection system contains several cylinders, the system may be expanded by the addition of injectors, by-pass valves and pulse generators individual to each cylinder. The pump need not be duplicated if its capacity is sufficient to maintain the required flow rates and pressures.

When the number of pumps is smaller than the number of cylinders to which fuel is supplied, the individual injectors are, in effect, multipled to a pressurized fuel-supply manifold. In such a system it behooves to isolate each injector from the manifold at all times except during staggered periods set aside for its respective injection phases. FIG. **4** shows, for this purpose, a shut-off valve V′ in tandem with the bypass valve V illustrated in FIG. **1**; the two valves are identical and combined in a common housing A, corresponding elements of valve

V' having been designated by the same reference numerals as those of valve V preceded by a "1" in the position of the hundreds digit.

In FIG. 4 the branch path from distributing channel **10** to supply conduit **26** leads via ports **111, 112** and the intervening passage **113** of plunger **114**, the port **112** opening into a conduit **110** terminating at the inlet port **11** of the normally closed downstream valve V. Current flowing through solenoid coil **122**, via wires **124** and **125**, blocks this path so as to disconnect the conduit **26** from the common distributing channel **10**. Thus, injection can take place only upon simultaneous closure of valve V and opening of the normally open upstream valve V' by the energization of coil **22** and de-energization of coil **122**.

An injection-control network M designed for a four-cylinder engine is illustrated in FIG. **5**, the corresponding command signals being shown in FIG. **6**.

Starting pulses for this system are derived from a timer **136** differing from timer **38**, FIG. **2**, in that an armature **137** on its shaft **136***a* successively coacts, during each engine cycle consisting of two crankshaft revolutions, with four magnetic pickup coils **140, 141, 142** and **143** whose cores **138** are equispaced around the axis of rotation. The pulse generated by these sensors, shown in FIG. **6**, are designated **146, 147, 148** and **149**, respectively.

A common evaluation network of the type shown in FIG. **2** is used to control all four injectors; this network, operating at four times the pulse rate needed for a single cylinder, is triggered by each starting pulse (signals **146, 147, 148, 149**) through an OR gate **163** working into lead **40**.

Flip-flops **150, 151, 152** and **153** are included in the timing circuits for the four cylinders to actuate the injectors thereof in their firing order. Each starting pulse **146** – **149** is applied to the setting input of the associated flip-flop as well as to the resetting input of the immediately preceding flip-flop so that each flip-flop **150** – **153** remains set for a quarter-turn of shaft **136***a*. Thus, pulse **146** sets the flip-flop **150** and generates a rectangular pulse **159** on the set output **155** thereof, at the same time resetting the flip-flop **153** to terminate a similar pulse **162** on the set output **158** of the latter flip-flop. Similar pulses **160, 161** appear on the set outputs **156, 157** of flip-flops **151** and **152**, each lasting for a quarter-revolution of the shaft **136***a*.

The inversions **189** – **192** of signals **159** – **162**, appearing on the reset outputs of the flip-flops **150, 151, 152** and **153**, are fed to respective power amplifiers **181, 182, 183** and **184** which, in turn, energize the coils 122_1, 122_2, 122_3 and 122_4 associated with the shut-off valves V' (FIG. 4) of the four injectors of the system.

The signals **159** – **162** from the set outputs **155** – **158** of flip-flops **150** – **153** go to respective AND gates **164, 165, 166, 167** which also have other inputs, connected via an OR gate **145** to output lead **58** of flip-flop **52**, and third inputs tied in parallel to an enabling lead **168** originating at a control circuit **139**. Another enabling lead **144** extends from circuit **139** to AND gates **164** – **167** by way of OR gate **145**. Lead **144** may be energizable under the control of a temperature sensor in the cylinder block, during a warmup period, to make the period of conductivity of these AND gates independent of the gating signal **57** on lead **58** when the engine is cold, thereby allowing injection to take place for a full quarter-turn of shaft **136***a* or for some fixed shorter period as determined by, say, a cam on that shaft controlling a switch in circuit **139**. Lead **168** may be de-energized under negative load, as during downhill driving, by switches responsive to a retracted accelerator pedal and an engine speed (as measured by the analog voltage on lead **48**) exceeding a predetermined threshold, a circuit of this type having been described in co-pending application Ser. No. 7,781 filed by two of us, Fernand Murtin and Loic Mercier, on Feb. 2, 1970, now abandoned and replaced by application Ser. No. 235,289 filed 16 March 1972 as a continuation-in-part thereof.

Since, generally, the signal from controller **139** on lead **168** is a steady d-c voltage, the AND gates **164, 165, 166** and **167** become conductive upon the simultaneous presence of a respective signal **159, 160, 161** or **162** on lead **155, 156, 157** or **158** and a gating pulse **57** on lead **58**. The resulting injection signals, shown in FIG. **6**, are relatively staggered trigger pulses **173, 174, 175** and **176**, respectively. These signals traverse amplifiers **177, 178, 179** and **180** to actuate the bypass valves V (FIG. **4**) associated with the four injectors by energizing their solenoid coils 22_1, 22_2, 22_3 and 22_4. The graph **193** shows the four compression strokes of the fuel-supply pump spanning the injection signals within an engine cycle $t_o - t_1$.

A complete injection-control system for a four-cylinder engine of the four-stroke type, embodying the features of FIGS. **1, 4** and **6**, is depicted diagrammatically in FIG. **7**.

The fuel is supplied from reservoir R to the main pump P by an ancillary pump N. The pump P rotates at twice the crankshaft speed to provide a pressure pulse for each of the four injectors B_1, B_2, B_3 and B_4 serving the cylinders. These injectors are connected with respective branches 10_1, 10_2, 10_3, 10_4 of channel **10** through individual supply conduits 26_1, 26_2, 26_3 and 26_4 by way of the corresponding dual control valves A_1, A_2, A_3, A_4 which receive energizing signals for their associated relay coils via electrical leads C_1, C_2, C_3 and C_4 originating in the logic network M of FIG. **5**. Network M receives information in analog form on the angular position α of the crankshaft on a line I_1, on the engine speed ω on a line I_2, and on the position of accelerator pedal D on a line I_3. Line I_2 symbolizes an electrical or mechanical link to the potentiometer **46**, e.g. as described hereinafter with reference to FIG. **9**, whereas line I_2 is the output of sensor **136**. The return or overflow conduits have been designated 15_1, 15_2, 15_3, 15_4, merging in a common drain **15**.

While extremely sharp pulse fronts may be obtained in the electronic components of our control system, it is more difficult to achieve similar precision in the initiation and cutoff of hydraulic fluid flow, largely because of the inertia of the moving components including the fluid and the compressibility of the latter.

The venting channel **6** of the pump piston **3** (FIG. **1**) sharpens the trailing edges of the hydraulic pulses **193** shown in FIG. **6**. A similar sharpening of the actual injection pulses can be achieved by a two-stage energization of the controlling valve, as also disclosed in application Ser. Nos. 7,781 and 235,289 referred to above, i.e. the valve V of FIG. **1** or **4** giving access to the drain **15**. This has been illustrated in FIG. **8** where a modified bypass valve V'' has the core **19** of its solenoid **20, 22** extended at **219** into the yoke **220** of a similar solenoid with electromagnetic coil **222** shown connected, via wires **224** and **225**, to the output of a power amplifier **277** energized from the set output of an ancillary flip-flop **250** individually associated with flip-flop **150.** Flip-flop **250,** whose setting input is tied to the set output **155** of companion flip-flop **150,** has its resetting input connected to the reset output **53** of flip-flop **39** (not shown in FIG. **8**) by way of a delay line **253** whereby amplifier **277** is de-energized shortly after the start of the next gating pulse **57.** The conductive intervals of amplifier **250** and corresponding amplifiers associated with the companion flip-flops of bistable units **151, 152, 153** are shown at **273, 274, 275** and **276** in FIG. **6**; it will be noted that, thanks to a suitable choice of delay time δ introduced by network **253,** they partly overlap the corresponding trigger pulses **173 – 176.**

Pulse **273,** whose leading edge coincides with that of the first pulse **44** shown in FIG. **6,** energizes the coil **222** of the first bypass valve V'' to an extent insufficient to overcome the force of its spring **16** so that the valve will not close until the next gating pulse **57** gives rise to the corresponding trigger pulse **173.** Since only a small current is now required to raise the plunger **14,** closure of the bypass leading to drain **15** is virtually instantaneous. Conversely, the subsequent de-energization of coil **222** does not yet permit the spring **16** to reopen the valve; this action occurs only upon the termination of pulse **173,** again with almost instantaneous effect.

The measurement of the engine speed as a criterion for the operation of the computer network M can be accomplished, advantageously, with the aid of a mass-flow meter of the general type disclosed in U.S. Pat. No. 3,470,741 to Enoch J. Durbin. This has been illustrated in FIG. **9** which shows an air-intake duct or manifold **103** serving one or more cylinders **100**; individual injectors B, not shown in FIG. **9,** are provided for these cylinders as indicated in FIG. **1.**

A high-voltage d-c source **300** has its negative terminal connected to a corona emitter **301** in the form of a sharp-edged conductive disk centrally disposed within duct **103.** A poppet valve **104,** when opened by the cam shaft (not shown) in the usual manner, permits the piston associated with engine cylinder **100** to draw air through the manifold **103** into its combustion chamber **102** at a rate determined by the engine speed and by the position of a throttle or butterfly valve **105** controlled by the driver of the vehicle through the accelerator D (FIGS. **2** and **7**).

The corona originating at electrode **301** ionizes some of the molecules of the air stream traversing the duct **103,** causing them to drift toward two longitudinally spaced, positive (here grounded) annular electrodes **302** and **303** forming part of the manifold wall. The resultant of the transverse drift velocity of these ions, due to the concentric field, and their axial speed component, imparted by the flow of the air stream toward the cylinder, is inclined at a small angle to the plane of disk **301** whereby ring **303** is driven negative with reference to ring **302.**

A condenser **304** and a resistor **305** form an integrating network connected across electrodes **302** and **303**; condenser **304** is bridged by an electronic breakdown device **306,** such as a gas-filled diode, to form therewith a relaxation oscillator generating a sawtooth wave of a frequency depending on the rate of charge of the condenser through resistor **305.** A pulse counter **307** counts the cycles of this sawtooth wave and generates an output voltage v_1, proportional to that count, which is matched in a comparator **308** with a reference voltage v_2 to provide a positive or negative command signal for a servo motor **309** driving the potentiometer **46.** If desired, the output of comparator **308** could be directly fed to a pulse generator replacing the flip-flop **39,** to vary the length of timing pulses **44,** or the voltage v_1 could be applied to lead **48** of comparator **47** in FIGS. **2** and **5.**

If the back pressure in duct **103** is low, i.e. if the engine races with butterfly valve **105** nearly closed, the air will flow rapidly to impart a substantial axial velocity component to the migrating ions, yet their mean transverse speed will also be elevated in view of the low air density. If the value **105** is opened further with the engine speed unchanged, the increased air density reduces the transverse speed component of the ions but the longitudinal flow velocity also decreases with corresponding reduction of the axial speed component. Thus, the angle included between the ion path and a direction perpendicular to the duct axis is practically a function of engine speed alone and substantially independent of throttle position.

It should be understood, however, that the potentiometers **46** and/or **55** could also be controlled by the air pressure prevailing in duct **103** upstream or downstream of throttle valve **105,** or by the difference of these pressures, with the aid of pressure sensors including, for example, a diaphragm in a chamber communicating with the duct through an orifice and acting upon a potentiometer slider as disclosed in the copending application referred to above.

In the case of a gasoline engine or the like, a spark-plug **106** shown in FIG. **9** is conventionally energized at or near the end of each injection interval to ignite the air/fuel mixture; this ignition may be timed, under the control of pulses **173 – 176,** to coincide with the trailing edges of these pulses or to follow them with a certain delay which could also be made variable in response to changes in cylinder temperature or other operating parameters as likewise described in applications Ser. Nos. 7,781 and 235,289.

Our improved system has been found to operate with great precision, enabling the establishment of injection intervals with an accuracy on the order of a fraction of a degree of crankshaft revolution. A fuel-utilization rate of up to 99%, corresponding to an almost total suppression of unburned combustion residue contributing to air pullution, can be achieved, in this way, with virtually total elimination of CO and NH in the exhaust fumes.

We claim:

1. A system for controlling the fuel supply to a compression-ignition engine having a plurality of piston cylinders each provided with a fuel injector, comprising:

a source of fuel for said engine;

a distributing channel having a plurality of branches extending to a drain for excess fuel;

engine-controlled pump means for delivering fuel at high pressure to said channel in a succession of compression strokes;

a pair of electrically controlled valves disposed in tandem in each of said branches, said pair including a normally open first valve and a normally closed second valve;

an extension conduit leading from each branch to a respective fuel injector, said conduit communicating with the corresponding branch at a location downstream of said first valve and upstream of said second valve; and

electronic gating means for periodically opening said first valve and concurrently closing said second valve of each branch in cyclic succession during successive injection intervals for admitting fuel

from said channel to the respective injectors.

2. A system as defined in claim **1** wherein said channel is provided with pressure-controlling valve means upstream of all said branches.

3. A system as defined in claim **1** wherein said first and second valves are provided with a common housing.

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