

⑫ **NEW EUROPEAN PATENT SPECIFICATION**

④⑤ Date of publication of the new patent specification: **21.06.89**

⑤① Int. Cl.⁴: **F 02 M 59/36, F 02 M 59/20**

②① Application number: **80400086.7**

②② Date of filing: **21.01.80**

⑥④ **Fuel injector with electronically operated control.**

③⑩ Priority: **25.01.79 US 6948**
25.01.79 US 6949

④③ Date of publication of application:
06.08.80 Bulletin 80/16

④⑤ Publication of the grant of the patent:
21.09.83 Bulletin 83/38

④⑤ Mention of the opposition decision:
21.06.89 Bulletin 89/25

⑧④ Designated Contracting States:
AT DE FR GB IT SE

⑤⑧ References cited:
AT-B- 195 685
DE-A-2 854 921
DE-B-2 131 841
DE-C- 231 352
DE-C- 459 676
DE-C-1 919 969
US-A-2 843 043
US-A-3 951 117
US-A-4 129 253
US-A-4 134 549

⑦③ Proprietor: **ALLIED-SIGNAL INC.** (a Delaware corporation)
Columbia Road and Park Avenue P.O. Box 2245R
Morristown New Jersey 07960 (US)

⑦② Inventor: **Sisson, Albert E.**
27248 Hystone
Farmington Hills, Michigan (US)
Inventor: **Lewis, Donald J.**
5806 Falmouth Road
Troy, Michigan (US)
Inventor: **Walter, Richard P.**
17025 Crescent
Southfield, Michigan (US)
Inventor: **Erwin, Louis R.**
18547, Westbrook
Livonia, Michigan (US)
Inventor: **Kelso, Charles R.**
30080 Astor Dr.
Farmington, Michigan (US)

⑦④ Representative: **Lejet, Christian**
Division Technique Service Brevets BENDIX
Europe 126, rue de Stalingrad
F-93700 Drancy (FR)

EP 0 014 142 B2

Description

The invention relates to a fuel injector and to a method of electronically operating a fuel injector.

Fuel injection systems are known which employ hydraulic adjustment means to alter the timing of the injection phase of the cycle of operation of a set of injectors mechanically driven from the crankshaft of an internal combustion engine, and the hydraulic means may be responsive to the speed of the engine and/or the load imposed hereon. While the prior art systems functioned satisfactorily in most instances, several operational deficiencies were noted. For example, the hydraulic adjustment means functioned effectively over a relatively narrow range of speeds, and responded rather slowly to changes in the operating parameters of the engine. Also, problems were encountered in sealing the hydraulic adjustment means, for a rotor-distributor pump was utilized to deliver hydraulic fluid to each of the fuel injectors in the set employed within the fuel injection system. In order to provide a hydraulic adjustment means responsive to both speed and/or the load factor such as suggested in US Patent 3,951,117 granted April 20, 1976 to Julius Perr, an intricate, multicomponent assembly is required, thus leading to high production costs, difficulty in installation and maintenance, and reduced reliability in performance.

US—A—3,951,117, and 4,134,549 to Julius Perr, disclose a fuel supply system including hydraulic means for automatically adjusting the timing of fuel injection to optimize engine performance. The system comprises an injection pump including a body having a charge chamber and a timing chamber formed therein. The charge chamber is connected to receive fuel from a first variable pressure fuel supply, and the timing chamber is connected to receive fuel from a second variable pressure fuel supply, while being influenced by pressure modifying devices. The body further includes a passage that leads through a distributor which delivers the fuel sequentially to each injector within a set of injectors.

A timing piston is reciprocally mounted in the body of the injection pump in Perr between the charge and timing chambers, and a plunger is reciprocally mounted in the body for exerting pressure on the fuel in the timing chamber. The fuel in the timing chamber forms a hydraulic link between the plunger and the timing piston, and the length of the link may be varied by controlling the quantity of fuel metered into the timing chamber. The quantity of fuel is a function of the pressure of the fuel supplied thereto, the pressure, in turn, being responsive to certain engine parameters, such as speed load. Movement of the plunger in an injection stroke results in movement of the hydraulic link and the timing piston, thereby forcing fuel into the selected combustion chamber. The fuel in the timing chamber is spilled, or vented, at the end of each injection stroke into spill port and spill passage.

Another fuel supply system of analogous design

is disclosed in DE—A—19 19 969, in which a hydraulic link is created between a primary and a secondary plunger piston by sealing off a timing chamber defined therebetween and supplied with fuel, said sealing being controlled by an electronically operated valve means and initiating the injection phase during which fuel is discharged from another, metering chamber; this injection phase terminates automatically when the displacement of both pistons causes the timing chamber to communicate with a vent passage, thus relieving fuel pressure in said chamber and allowing the primary piston to travel further without moving the secondary piston any longer. During the subsequent return stroke of both pistons, fuel is supplied again to the metering chamber through a suction conduit, the quantity of supplied fuel being metered under the control of another electronically operated valve means. Thus at least two valve means are required to perform a full control of the injection cycle.

Starting from this state of art, it is an object of the present invention to provide a fuel injector wherein all steps of the injection cycle are controlled by one and the same control element and may be easily and rapidly altered in dependence upon any of one or more parameters of engine operation.

To this end, the invention proposes a fuel injector for an internal combustion engine comprising a body having an axially extending bore, a primary pumping plunger and a secondary plunger positioned within said bore for axial movement therein in response to the movement of said primary pumping plunger, a nozzle situated at the end of said bore remote from said primary pumping plunger, a timing chamber defined in said bore between said primary plunger and said secondary plunger, a metering chamber defined in said bore between said secondary plunger and said nozzle, passages in said body of said injector for receiving pressurized fuel and transmitting said fuel into said timing chamber and said metering chamber, and an electronically operated control element situated intermediate said passages and said timing chamber and adapted to be selectively energized to regulate the timing of the discharge of fuel from the metering chamber through the nozzle and consequently the quantity of fuel discharged through the nozzle during an injection phase, said control element controlling the admission of fuel into said timing chamber for creating when it is in a closed position a hydraulic link between said primary pumping plunger and said secondary plunger and for creating when in an opened position an equilibrium pressure condition in said timing chamber which permits independent movement of said primary pumping plunger relative to said secondary plunger during the remaining portion of the operation of the injector, the fuel injector according to the invention being characterized in that the same control element is further used to regulate the quantity of fuel stored in the metering chamber subsequent to an injection phase, said quantity of fuel being

made proportional to the duration during which said control element is held in a closed position after the start of the return stroke of both plungers subsequent to said injection phase.

In a preferred embodiment of the invention, the secondary plunger has an annulus defined near its midsection, said annulus leading into a cross-hole which communicates with a short axial passage which itself communicates with elongated axially extending passages that open into said metering chamber, a check valve and a spring to normally bias said check valve against its seat to prevent communication between said annulus and said metering chamber, said check valve being unseated only during the metering phase of the cycle of operation to allow fuel at supply pressure from the passages in the injector body to enter the annulus and proceed downwardly into the metering chamber through said axially extending passages.

The invention will now be described with reference to the accompanying drawing wherein:

—Figure 1 is a schematic diagram of a fuel injection system configured in accordance with the principles of the invention;

—Figure 2 is a vertical cross-sectional view, on an enlarged scale, of a fuel injector utilized within the system of Figure 1;

—Figures 3 to 7 schematically show the sequence of operational steps for the fuel injector of Figure 2;

—Figure 8 is a graphical representation of the cam surface utilized to control the movement of certain portions of the injector of the present invention, depicting cam lift relative to degrees of crank angle rotation; and

—Figure 9 is a composite schematic representation of the cycle of operation of an injector in the instant fuel injection system; the upper graph traces the movement of the primary plunger versus the rotational movement of the crankshaft, while the lower chart notes the sequence of events versus the rotational movement of the crankshaft.

Turning now to the drawings, Figure 1 schematically depicts the major components of a fuel injection system employing an electronically operated control valve for regulating the timing and metering functions of each injector within the system. The system includes a fuel injector 10 that is supported by a support block 12 and is controlled to deliver fuel through a nozzle 14 directly into the combustion chamber (not shown) of an internal combustion engine 16. Although only one injector is shown, it should be noted that a set of identical injectors is employed within the fuel injection system, one injector being provided for each cylinder in the engine. The injector 10 is operated in synchronism with the operation of the engine through the reciprocal actuation of a follower 20, the follower 20 being biased upwardly by a heavy duty spring 18.

A cam 22 is secured to the camshaft 24 of the internal combustion engine 16. Cam 22 rotates at a speed which is a function of engine speed, for

the camshaft is driven via meshing gears 23, 25 from the crankshaft 26. The gear ratio of gears 23, 25 may vary from engine to engine depending on various factors, including, inter alia, whether the engine is a two-cycle or four-cycle engine. The crankshaft drives the piston (not shown) within the combustion chambers of the engine 16 in the usual manner. A roller 27 rides along the profile of the cam, and a push rod 28 and rocker arm 30 translate the movement of the roller into the application of axially directed forces upon the follower 20 and the primary piston; the forces act in opposition to main spring 18 and vary in magnitude with the speed of the engine and the profile of the cam. The cam profile is of particular importance to the operation of the injector and will be discussed more fully in the discussion of Figures 8 and 9.

A reservoir 32 serves as a source of supply for the fuel to be dispensed by each injector 10, and fuel is withdrawn from the reservoir by transfer pump 34. Filters 36, 38 remove impurities in the fuel, and distribution conduit 40 introduces the fuel, at supply pressure, to each of the injectors 10. A branch conduit 42 extends between distribution conduit 40 and block 12 and makes fuel, at supply pressure, available for circulation through injector 10. The fuel that is not dispensed into a combustion chamber in the engine is returned to the reservoir 32 via branch return conduit 44 and return conduit 46. A fixed orifice 48 is disposed in return conduit 46 to control rate of return flow into the reservoir. Directional arrows and legends adjacent to the conduits indicate the direction of fuel flow.

The fuel injection system of Figure 1 responds to several parameters of engine performance. In addition to engine speed, which is reflected in the rate of rotation of the cam 22 secured upon camshaft 24, several sensors 50 are operatively associated with engine 16 to determine, inter alia, engine speed, temperature, manifold absolute pressure, load on the engine, altitude, and air-fuel ratio. The sensors 50 generate electrical signals representative of the measured parameters, and deliver the electrical signals to an electronic control unit, or ECU, 52. The electronic control unit then compares the measured parameters with reference values which may be stored within a memory in the unit, takes into account the rotational speed and angular position of cam 22, and generates a signal to be delivered to each injector. The signal, in turn, governs the timing and metering functions of each injector. Leads 54, 56 and a connector 58 interconnect the electronic control unit 52 and the control valve 146 for the representative injector shown in Figure 1.

Figure 2 depicts the components of a representative injector 10. The segment at the left hand side of Figure 2 fits atop the segment at the right hand side of Figure 2.

Referring to the upper end of the injector 10, a fragment of the rocker arm 30 is visible bearing against the enlarged upper end of follower 20, and main spring 18 rests on support block 12 and

urges the follower 20 upwardly. A primary pumping plunger 62 is joined to the lower end of follower 20, the follower 20 and primary pumping plunger 62 moving as a unitary member. A cylindrical guide 64 insures the axial movement of follower 20, while a seal guide 66 provides a seal and insures the axial movement of primary pumping plunger 62. It is to be understood that block 12 and guides 64, 66 may be formed as an integral unit. A slot 68 in the follower 20 cooperates with stop 60 to prevent the follower 20 and spring 18 from becoming disassembled from the remainder of the injector prior to association with the rocker arm 30 and to limit the downward travel of follower 20.

An internally threaded jacket 70 is screwed into engagement with the mounting block 12, and the interior of the jacket surrounds the distinct segments that comprise the body of the fuel injector 10. Each segment of the body is generally cylindrical in shape, is generally executed in metal, has a central bore and has passages drilled, or otherwise formed therethrough, in alignment with the central bore and the passages of the adjacent segment. Thus, in Figure 2, fuel injector 10 includes an elongated sleeve 72, a disc-like segment 74, and a spring cage 76 that communicates with nozzle 14. A seal 78 seals the juncture between the block 12 and the threaded jacket 70. Supply passages 80, 82, of which there are two pairs of each, only one each of which are shown, extend through the various segments, and an annular cavity 84 is defined beneath the seal guide 66 and the upper end of the axial passages. The lowermost ends of passages 80, 82 extend radially inwardly to terminate in annulus 83. The passages 80, 82 (a total of four passages arranged around piston 62) also extend radially inwardly to terminate in annulus 85, spaced above annulus 83 in the sleeve of the injector.

A cylindrical recess 86 is located in the lower end of the primary pumping plunger 62, and a stud 88 is located within the recess to form a spring retaining member. A secondary plunger 90 is axially movable within the central bore of the sleeve 72, and a valve seat insert 92, with a recess 94 in its upper surface, is situated at the upper end of the secondary plunger. A spring 96 extends between stud 88 and the insert 92 and constantly maintains a downwardly directed biasing force upon the secondary plunger. A variable volume timing chamber 98 is defined between the lower end of plunger 62 and the upper end of secondary plunger 90. Secondary plunger 90 slides freely within the bore of sleeve 72 and primary plunger 62 travels within the bore 97 of support block 12.

A passage 99 extends axially through the valve seat insert 92 to communicate with cross-hole passage 100 which opens into annulus 102 formed on the surface of secondary plunger 90. A first check valve 104, preferably in the form of a poppet valve, is normally biased by spring 106 against a valve seat 108 formed in passage 100

to control fluid communication between chamber 98 and passage 100. The spring 106 is seated in a guide cavity 110 in the secondary plunger 90.

An annulus 112 is formed in the outer surface of secondary plunger 90 at approximately the mid-section thereof, annulus 112 communicating with a cross-hole passage 114 and an axial passage 116. A second check valve 118 in the secondary plunger is biased against its valve seat 120 by a spring 121 disposed in a cavity 122 formed in the plunger 90. Valve 118 thus controls communication between passage 116 and inverted L-shaped passages 124, 126, of which there are two each, which extend axially through the lower end of the secondary plunger. The passages open into an annulus 125 formed in the exterior surface of plunger 90. A variable volume metering chamber 128 is defined between the lower end of secondary plunger 90 and the disc-like segment 74.

A disc 130 fits within a recess 132 at the upper end of segment 74, and the disc is of sufficient area to seal off one end of metering chamber 128 to prevent gases in the cylinders of the engine from blowing back into the injector in the event the nozzle 14 fails to seal. The recess 132 opens downwardly into a plurality of passages 134, 136, sets of which are arranged circumferentially around the central axis of injector 10, passage 136 communicating with nozzle 14. The upper end of a needle valve 144 is secured to a spring retaining member 142, and a spring 138 is disposed between element 74 and member 142 to bias valve 144 downwardly against a valve seat 145 to prevent fuel from being dispensed from the nozzle 14. Only when the pressure in passage 136 significantly exceeds the combined forces of the spring biasing pressure and the supply pressure is the needle valve unseated to permit a fine atomized spray of fuel to be issued from nozzle 14.

Branch conduit 42 introduces fuel, at supply pressures of 3,5 to 14 kg/cm², into support block 12 through conduit 43 and thence into injector 10. An electronically operated control valve 146 is disposed between conduit 42 and conduit 43 to control both the timing and the metering functions for injector 10 as will be more fully explained hereafter. Branch conduit 43, as suggested by the diagonally extending dotted lines, communicates fuel at supply pressure with timing chamber 98 when the control valve 146 is open.

The functioning of the several components of the fuel injector of Figure 2 will best be appreciated by reviewing the sequence of operation shown in Figures 3 to 7. However, in order to better portray the sequence of operational events, license has been taken in depicting the various elements of the injector 10. For example, the segments housed within jacket 70 are shown as a unitary member, the guides 64, 66 and disc 130 have been omitted, the follower 20 and the primary pumping piston 62 have been shown as

a unitary member, etc.

Turning now to Figure 3, which shows a convenient but arbitrarily selected starting point for the cycle of operation, control valve 146 is shown in its normally opened condition to allow fuel at supply pressure in the branch conduit 42 access to supply passage 43 and the timing chamber 98. Actually, an equilibrium pressure condition exists (supply pressure) as the primary plunger 62 has ceased its upward motion and is prepared to start its downward motion due to the action of camshaft 24 and cam 22 on plunger 62 as will be seen from a description of Figures 8 and 9. The timing chamber 98 and metering chamber 128 previously have been filled with fuel as will be seen from a description of Figures 6 and 7. With the control valve 146 open, fuel is free to flow into and out of timing chamber 98. As shown in Figure 3, check valve 104 is biased against its seat by spring 106 and check valve 118 is biased against its seat by spring 121.

The primary pumping plunger 62 and the secondary plunger 90 sealingly engage the central bores 97, 69, respectively, of the injector, and the spring 96 continuously imparts a downward bias upon plunger 90. A precise amount of fuel is present in metering chamber 128 due to a prior metering operation, to be described in conjunction with the description of Figures 6 and 7, and the trapped fuel acts against spring 96. With the control valve 146 opened, timing chamber 98 is in its equilibrium condition, so that when rocker arm 30 forces follower 20 and primary pumping plunger 62 downwardly, at the rate suggested by the arrow beneath plunger 62, fuel is forced out of timing chamber 98 through passages 43, 42. The secondary plunger is unaffected by such movement and remains stationary under the bias of spring 96 and trapped fluid in metering chamber 128. The duration of the period during which valve 146 is maintained in its opened condition relative to a fixed reference is a variable quantity determined by the electronic control unit 52 in response to actual engine conditions and independent of the travel of plunger 62. Thus, the instant at which the valve 146 is closed, and the timing chamber 98 isolated from the supply passage 42, can be adjusted relative to the fixed reference, e.g., the top dead centre (TDC) position of the crankshaft 26, over fairly broad limits.

Figure 4 shows the various components of the fuel injector 10 at the instant that injection starts through nozzle 14 due to the high pressure (several hundred bar) created by the trapped fluid in timing chamber 98 and metering chamber 128. During the downward travel of plunger 62 from the arbitrarily selected starting position of Figure 3, and a very short period of time before the instant of injection shown in Figure 4, the valve 146 is closed as described above. With the valve closed, timing chamber 98 is sealed, and the continued downward movement of plunger 62 causes the downward movement of secondary plunger 90 to rapidly increase the pressure of the fuel trapped in chamber 128. The downward

movement of the secondary plunger 90 pressurizes the fuel in chamber 128 to a level sufficient to unseat needle valve 144 and permits a fine spray of pressurized fuel to be discharged through the pin holes in nozzle 14.

The second check valve 118 remains seated during the injection phase of the cycle of operation due to the fact that the high pressure below check valve 118 created by the pressure in metering chamber 128, as communicated thereto by passages 124, 126, is greater than the supply pressure in passages 80, 82 and cross-hole 114.

Figure 5 shows the various components of the fuel injector immediately after the termination of the injection shown in Figure 4, Figure 5 illustrating the "dumping" or pressure relieving phase of operation. In this phase the control valve 146 is still closed and the primary pumping plunger 62 is approaching its limit of downward travel, as suggested by the small arrow beneath the plunger. In this phase, the annulus 125 is in fluid communication with annulus 83 thereby communicating the high pressure in passages 124, 126, 136 with the supply pressure in passages 80, 82. As the pressure in passages 124, 126, 136 approaches the supply pressure existing in passages 80, 82, the pressure on the needle valve is insufficient to hold valve 144 open and the needle valve 144 is again seated against seat 145. The pressure build-up in passage 136 and metering chamber 128 is rapidly relieved, so that the undesirable dribble of fuel through the nozzle is prevented.

At the same time, the pressure of the fuel in timing chamber 98, which has been intensified by the downward movement of plunger 62, is relieved to permit the primary plunger 62 to complete its downward travel after the termination of injection and precludes excess pressure on the parts of the injector subject to the pressure in timing chamber 98. More specifically, the annulus 102 is in fluid communication with annulus 85 thereby communicating passage 100 below valve 104 with the supply pressure in passages 80, 82. The pressurized fuel in chamber 98, as compared to supply pressure in passage 100, creates a pressure differential across first check valve 104 to unseat check valve 104. Fuel flows from timing chamber 98, through check valve 104, annulus 102, and annulus 85 back into axial passages 80, 82. Check valve 104 has been provided to check the flow of fuel from passage 80 to timing chamber 98, through annuli 85, 102, just prior to the metering phase of operation. If valve 104 did not seat, fuel flow from passage 80 to timing chamber 98 would preclude the metering to be described below.

The direction of flow of pressurized fuel from both the timing chamber 98 and the metering chamber 128 is indicated by directional arrows. After entering the axial passages, the fuel is returned to reservoir 32 via conduits 44, 46 (Figure 1).

Figure 6 shows the various components of the fuel injector after the primary pumping plunger 62

has completed its downward travel and has started its upward travel under the urging of spring 18 to create the "metering" phase of operation. The control valve 146 is retained in its closed condition, and annulus 102 is out of communication with annulus 85, thereby sealing timing chamber 98. The fuel in timing chamber 98 is approximately at supply pressure due to the dumping shown in Figure 5. First check valve 104, which was unseated during the "dumping" phase of the cycle of operation, as shown in Figure 5 is again held against its seat 108 by spring 106 to prevent communication between chamber 98 and passage 100.

As the primary pumping plunger 62 moves upwardly, as suggested by the arrow atop the head of follower 20, the pressure in timing chamber 98 drops to a pressure level below supply pressure as the volume of chamber 98 increases marginally. The pressure of the fuel beneath secondary plunger 90 in metering chamber 128 is greater than the combined forces of the fuel in chamber 98 and the biasing force of spring 96. The secondary piston 90 thus follows the primary pumping piston 62 in its ascent because of the net, upwardly directed pressure differential. During this early movement of secondary plunger 90, while annuli 125, 83 are in alignment, fuel flows from passages 80, 82, through passages 124, 126, to metering chamber 128.

As the secondary plunger moves upwardly, the lower-most annulus 125 defined on the plunger 90 moves out of alignment with annulus 83, thereby sealing metering chamber 128 from the annulus 83. The intermediate annulus 112, which opens into cross-hole passage 114, stays in alignment with the lower portion of annulus 85. Consequently, supply pressure in passages 42, 80, 82 is impressed on annulus 85, thence into annulus 112, and passage 114, to the upper portion of second check valve 118. This pressure differential across check valve 118 created by the relatively high supply pressure above check valve 118 as compared to the relatively low pressure in metering chamber 128, unseats check valve 118. Thus, fuel flows into metering chamber 128 through check valve 118, through passages 124, 126, as shown by the arrows in Figure 6.

The quantity of fuel that flows into metering chamber 128 is proportional to the volumetric displacement of plunger 90 created by the pressure differential across plunger 90. The plunger 90 can only move in concert with plunger 62 while control valve 146 is closed. In summarizing these relationships, it will be appreciated that the quantity of fuel introduced into the metering chamber 128 is proportionally related to the duration or interval, in crankshaft degrees, during which the control valve 146 is held closed after the start of the upward travel of secondary plunger 90. Obviously, when the valve 146 is held closed by a signal from the electronic control unit 52 for the entire interval in crankshaft degrees allocated for metering, the chamber 128 will be

filled with the maximum amount of fuel. When the valve 146 is held closed by a signal from the electronic control unit for only half of the interval, defined in degrees of crankshaft rotation, then the metering chamber will be half filled. Other proportional relationships are available in accordance with the fraction of the crankshaft rotational interval selected to hold valve 146 closed. This proportionality will become more apparent during the discussion of Figures 8 and 9.

Figure 7 shows the various components of the fuel injector at the termination of the metering phase of the cycle of operations. The metering phase is terminated by terminating the electrical signal from electronic control unit 52 to the control valve 146, which then returns to its normally opened condition. With valve 146 opened, the fuel at supply pressure in passages 42, 43 and the fuel in timing chamber 98 quickly establish an equilibrium condition at approximately supply pressure level. The pressure differential across plunger 90 is removed and secondary plunger 90 is, in effect, disconnected and cannot follow primary pumping plunger 62 as plunger 62 continues its upward movement. With valve 146 opened, the combined forces of the fuel in timing chamber 98 and spring 96 are greater than the force of the fuel, at supply pressure, retained in metering chamber 128. Therefore, plunger 90 is "locked" or retained in fixed position. The instant at which the signal to valve 146 is terminated is determined by engine operating parameters sensed by the electronic control unit relative to the number of degrees of angular rotation of the camshaft 24 as measured by the crankshaft 26 rotation from the above-described fixed reference, as determined by conventional sensors. Primary pumping plunger 62 continues upwardly, following the cam surface, under the urging of spring 18 independently of secondary plunger 90, as suggested by the arrow atop follower 20 in Figure 7. When the primary pumping plunger 62 reaches its uppermost position, as shown in Figure 3, then the cycle of operation for the fuel injection can be repeated in the manner shown progressively in Figures 3 to 7.

Referring to Figures 8 and 9, Figure 8 illustrates, in graphic form, the profile, or lift, of the cam surface of cam 22 (Fig. 1) relative to the number of degrees of crankshaft rotation, and Figure 9 illustrates, in graphic form, the vertical motion of primary pumping plunger 62 relative to the same number of degrees of crankshaft rotation and the relationship thereto of the single electronic control unit pulse which initiates injection and terminates metering. Both figures, Figure 9 particularly, correlate the various phases of injector operation described in conjunction with the description of Figures 3 to 7 with degrees of crankshaft rotation. From Figures 8 and 9, a very graphic illustration of the proportionality of the metering phase may be seen. Thus the termination of the electronic control unit pulse to control valve 146 will be seen to be linearly related to the number of degrees of crankshaft rotation after a

preselected reference point (for example, top dead center).

Specifically describing Figure 8, there is illustrated the lift of the cam, or cam profile surface plotted against the number of degrees of crankshaft rotation, and includes various points (A, B, C, D) along the curve. The curve approaches point A, which is the lowest point of the curve, and will be seen to correspond to the arbitrarily selected starting position described in conjunction with the description of Figure 3. The curve progresses through the injection phase, between points B and C; the dumping phase, between points C and D; and the metering phase, between points D and E. Point E corresponds to the end of the metering phase and a point F corresponds for the next sequence to point A for the previous sequence.

Figure 9 is a composite graphic representation of the operation of one injector 10 in the set of injectors employed in the instant fuel injection system. The upper graph plots the movement, or stroke, of primary pumping plunger 62 along the vertical axis against the degrees of rotational movement of the crankshaft 26; the rotational movement being measured by sensors that provide a signal representative of crankshaft rotation in degrees. The trace of the plunger 62 shows that the plunger instantaneously peaks, then moves downwardly until it reaches a nadir position, and then linearly returns upwardly to the peak position. For a two cycle engine, a complete cycle occurs within 360° of rotational movement of the crankshaft; for a four cycle engine, a complete cycle occurs within 720° of rotational movement of the crankshaft.

The lower graph in Figure 9 plots the opening and closing of control valve 146 by the electronic control unit, and other events, against the degrees of rotational movement of the crankshaft 26. The leading edge of the signal to control valve 146 causes the valve to change state from its normally opened state to its closed state, and the trailing edge of the signal causes the valve to change state again and return to its normally opened position. It will be noted that a single pulse from the electronic control unit initiates the injection phase and terminates the metering phase, while the internal configuration of the injector (annuli, check valves, etc.) terminates the injection phase and initiates the metering phase.

The upper and lower graphs of Figure 9 may be correlated by following the progression of steps indicated by reference characters A, B, C, D, E and F. It is to be understood that the duration of the period A to D, in degrees, is determined by the sum of injection timing variation and injection duration plus the duration of the damping operation. It is believed that the determination of the duration of the period A to D is well within the scope of one skilled in the art. The plunger 62 assumes its peak upward position under the bias of main spring 18 at the start of the cycle of operation (Fig. 3). This is point A on the curve and, with the control valve 146 still in its normally

opened state, as seen at the bottom of Figure 9, the plunger 62 starts downwardly under the force of rocker arm 30 pressing against follower 20.

During the course of the downward movement of plunger 62, the electronic control unit 52 delivers a signal to valve 146, and closes the valve as described in conjunction with the description of Figure 4. Point B on the curve designates the instant at which injection occurs during the timing function due to the closing of the valve 146, while point C indicates when the injection ceases due to the communication of annuli 102, 85 as described in conjunction with the description of Figure 5. The electronic control unit can be adjusted, either manually or automatically, in accordance with actual engine operating parameters, to shift the timing of the leading edge of the signal relative to the downward movement of the plunger 62. Point B will then shift along the curve to reflect such adjustments. The ability to adjust the instant at which valve 146 is closed to start the injection function assists in more completely burning the fuel discharged into each combustion chamber in the engine 16. Thus, the closure of valve 146 starts the injection phase of the cycle of operation as shown in Figure 4.

The compression-injection phase of the cycle of operation lasts for the brief interval B—C, the length of which is determined by the quantity of fuel which has been metered into metering chamber 128. During the period B—C the secondary plunger follows the primary plunger downwardly and forces the fuel out of metering chamber 128 and through nozzle 14. The plungers are coupled through the sealed timing chamber 98 which forms a hydraulic link between the two plungers.

Point C on the curve designates the cessation of the injection phase of the cycle of operation and the period between points C—D represents the overtravel and dumping portion of the cycle. At point C, while the control valve 146 remains closed, the passages 124 and 126 in the secondary plunger 90 are in fluid communication with the annuli 125, 83 to communicate metering chamber 128 and passage 136 with the supply pressure in passages 80, 82 and vent, or dump, the pressurized fuel trapped in the metering chamber 128 and the nozzle 14 back into the low pressure of axial passages 80, 82. The venting of the nozzle enables the needle valve to be re-seated and prevent dribble of fuel through the nozzle into the combustion chamber.

Due to the alignment of annuli 102, 85, the pressure below check valve 104 is reduced to supply pressure (below the pressure in timing chamber 98), and the upper check valve 104 is unseated so that the pressure in the timing chamber 98 is reduced, or dumped, to supply pressure, while the primary plunger is decelerating. The relationships that exist at the instant of dumping the pressurized fuel from chamber 128, the nozzle 14, and chamber 98 are shown in Figure 5.

The downward travel of the primary pumping

plunger 62 continues for the interval C—D, or until the plunger 62 reaches its maximum travel. The overtravel of the plunger 62 beyond the termination of injection (point C) and end of dumping (point D) provides sufficient time to equalize the pressures in the injector at supply pressure and to provide the necessary range of timing and injection. When plunger 62 reaches point D, the nadir of travel, and then starts to travel upwardly under the urging of main spring 18, its return trip to its peak upward position occurs over a major portion of the cycle of operation which corresponds to the metering phase (Figures 6 and 7).

The curve from point D through points E and F is substantially a linear curve having a constant slope. The linear slope is achieved by a unique profile on the cam 22, which slope is important to the proportional operation of the metering phase of operation. Point E represents the instant that the metering function ceases and corresponds to the termination of the signal from the electronic control unit. The termination of the signal to control valve 146 causes the control valve to return to its normally opened condition, which allows the timing chamber 98 to reach an equilibrium condition with the fuel at supply pressure in passage 42. Spring 96 locks secondary plunger 90 in fixed position in metering chamber 128, and plunger 62 can move independently in response to the application of forces by rocker arm 30 and spring 18. This termination is described in conjunction with the description of Figure 7.

The metering function can be terminated at any point along the slope D—F; if the metering function is terminated shortly after the primary plunger starts its return trip, then the interval D—E will be shorter than the interval from E—F. The greater the interval D—E, the greater the volume of fuel admitted into metering chamber 128. It is to be noted that the linearity of the portion of the curve between points D and F permits a direct, proportional relationship between the amount of fuel metered and the number of degrees of camshaft rotation. The interval, in degrees of rotation, between points D and F represents the maximum volume of fuel which can be metered, any lesser amount is a direct function (proportional) to the number of degrees of rotation the control valve remains closed after point D. Thus, if point E occurs one-half the number of degrees between D and F, one-half the quantity of fuel is metered.

It should be noted that the metering function can occur, potentially, over more than half the cycle of operation. This "stretching out" of the metering function increases the opportunity to accurately fill the metering chamber 128 to the desired level. As described above, the slope of the curve D—F through the metering function is linearly proportional to the degrees of angular rotation of the crankshaft 26. Thus, if the metering function is assumed to occur, potentially, over 300° of angular rotation for the crankshaft for a two cycle engine, then the termination of the signal from electronic control unit 52 to control

valve 146 after 150° of angular rotation, would allow the metering chamber 128 to be half-filled. Alternatively, if the termination of the signal from electronic control unit 52 to control valve 146 occurred after 75° of rotation, metering chamber 128 would be a quarter-filled. Obviously, the metering chamber can be filled to an infinite variety of fractional levels.

It will be readily apparent to the skilled artisan that the foregoing embodiment of this fuel injection system is susceptible of numerous changes without departing from the basic inventive concepts. For example, the primary pumping plunger 62 and follower 20 could be formed as a unitary plunger, and the check valves 104, 112, which are preferably shown as poppet valves, could be disc valves, ball valves, etc. The control valve 146, which is shown as a gate valve responsive to electromagnetic forces, could assume diverse other forms. The profile of cam 22 can also be altered to adjust the duration of the metering function and the rate of return of the primary plunger 62. Also, the spring 96 could be joined to the central bore of the injector, and need not have one end seated in a cavity in the primary pumping plunger; the key consideration is the ability of the spring 96 to always exert a downward force on the secondary plunger and, when necessary, at the end of the metering operation, lock plunger 90 in fixed position.

Claims

1. A fuel injector (10) for an internal combustion engine comprising a body having an axially extending bore (97), a primary pumping plunger (62) and a secondary plunger (90) positioned within said bore for axial movement therein in response to the movement of said primary pumping plunger (62), a nozzle (14) situated at the end of said bore (97) remote from said primary pumping plunger (62), a timing chamber (98) defined in said bore between said primary plunger (62) and said secondary plunger (90), a metering chamber (128) defined in said bore between said secondary plunger (90) and said nozzle (14), passages (42, 43, 80, 82) in said body of said injector (10) for receiving pressurized fuel and transmitting said fuel into said timing chamber (98) and said metering chamber (128), and an electronically operated control element (146) situated intermediate said passages (42, 43, 80, 82) and said timing chamber (98) and adapted to be selectively energized to regulate the timing of the discharge of fuel from the metering chamber (128) through the nozzle (14) and consequently the quantity of fuel discharged through the nozzle during an injection phase, said control element (146) controlling the admission of fuel into said timing chamber (98) for creating when it is in a closed position a hydraulic link between said primary pumping plunger (62) and said secondary plunger (90) and for creating when in an opened position an equilibrium pressure condition in said timing chamber (98) which permits independent move-

ment of said primary pumping plunger (62) relative to said secondary plunger (90) during the remaining portion of the operation of the injector, characterized in that the same control element (146) is further used to regulate the quantity of fuel stored in the metering chamber (128) subsequent to an injection phase, said quantity of fuel being made proportional to the duration during which said control element (146) is held in a closed position after the start of the return stroke of both plungers (62, 90) subsequent to said injection phase.

2. A fuel injector according to Claim 1, characterized in that said secondary plunger (90) has an annulus (112) defined near its midsection, said annulus (112) leading into a cross-hole (114) which communicates with a short axial passage (116) which itself communicates with elongated axially extending passages (124, 126) that open into said metering chamber (128), a check valve (118) and a spring (121) to normally bias said check valve (118) against its seat (120) to prevent communication between said annulus (112) and said metering chamber (128), said check valve being unseated only during the metering phase of the cycle of operation to allow fuel at supply pressure from the passages (80, 82) in the injector body to enter the annulus (112) and proceed downwardly into the metering chamber (128) through said axially extending passages (124, 126).

3. A fuel injector according to Claim 2, characterized in that said metering chamber volume is varied linearly during said metering phase of the cycle of operation.

4. A fuel injector according to any of Claims 1—3, characterized in that it comprises spring means (96) situated in said bore (97) for biasing the secondary plunger (90) toward said nozzle (14).

Patentansprüche

1. Kraftstoff-Einspritzventil (10) für eine Brennkraftmaschine, mit einem Gehäuse, das eine axial verlaufende Bohrung (97) aufweist, einem primären Pumpkolben (62) und einem sekundären Kolben (90), der in der Bohrung angeordnet und in Abhängigkeit von der Bewegung des primären Pumpkolbens (62) axial bewegbar ist, einer Düse (14), die an dem vom primären Pumpkolben (62) abgewandten Ende der Bohrung (97) angeordnet ist, einer Zeitgeberkammer (98), die in dem Gehäuse zwischen dem primären Pumpkolben (62) und dem sekundären Kolben (90) gebildet ist, einer Zumeßkammer (128), die in der Bohrung zwischen dem sekundären Kolben (90) und der Düse (14) gebildet ist, im Gehäuse des Einspritzventils (10) gebildeten Kanälen (42, 43, 80, 82), die unter Druck stehenden Kraftstoff empfangen und diesen Kraftstoff an die Zeitgeberkammer (98) und die Zumeßkammer (128) weiterleiten, und einem elektronisch betätigten Steuerelement (146), das zwischen den Kanälen (42, 43, 80, 82) und der Zeitgeberkammer (98) angeordnet und

wahlweise erregbar ist, um die zeitliche Steuerung der Kraftstoffabgabe aus der Zumeßkammer (128) durch die Düse (14) zu regeln und somit die Menge des durch die Düse abgegebenen Kraftstoffs während einer Einspritzphase zu regeln, welches Steuerelement (146) die Kraftstoffzufuhr in die Zeitgeberkammer (98) steuert, um in geschlossener Stellung eine hydraulische Verbindung zwischen dem primären Pumpkolben (62) und dem sekundären Kolben (90) herzustellen und in offener Stellung in der Zeitgeberkammer (98) einen Gleichgewichtszustand herbeizuführen, wodurch eine unabhängige Bewegung des primären Pumpkolbens (62) relativ zu dem sekundären Kolben (90) während der restlichen Betriebszeit des Einspritzventils ermöglicht wird, dadurch gekennzeichnet, daß dieses Steuerelement (146) außerdem zum Regulieren der Menge des in der Zumeßkammer (128) im Anschluß an eine Einspritzphase gespeicherten Kraftstoffs benutzt wird, welche Kraftstoffmenge proportional zu der Zeitdauer gemacht wird, während welcher das Steuerelement (146) nach dem Beginn des Rückhubs beider Kolben (62, 90) im Anschluß an die Einspritzphase in geschlossener Stellung gehalten wird.

2. Kraftstoff-Einspritzventil nach Anspruch 1, dadurch gekennzeichnet, daß der sekundäre Kolben (90) einen Ringraum (112) aufweist, der nahe seinem Mittelabschnitt gebildet ist und in eine Querboreung (114) mündet, die mit einem kurzen axialen Kanal (116) in Verbindung steht, der seinerseits mit den langgestreckten axial verlaufenden Kanälen (124, 126) verbunden ist, die in die Zumeßkammer (128) münden, ferner ein Rückschlagventil (118) und eine Feder (121), die normalerweise das Rückschlagventil (118) auf seinen Sitz (120) drückt, um eine Verbindung zwischen dem Ringraum (112) und der Zumeßkammer (128) zu verhindern, welches Rückschlagventil nur während der Zumeßphase des Arbeitszyklus von seinem Sitz abgehoben wird, damit Kraftstoff unter Zufuhrdruck von den Kanälen (80, 82) in dem Einspritzventilgehäuse in den Ringraum (112) eintreten und nach unten durch die axial verlaufenden Kanäle (124, 126) in die Zumeßkammer (128) fortschreiten kann.

3. Kraftstoff-Einspritzventil nach Anspruch 2, dadurch gekennzeichnet, daß der Rauminhalt der Zumeßkammer während der Zumeßphase des Arbeitsspiels linear verändert wird.

4. Kraftstoff-Einspritzventil nach einem der Ansprüche 1 bis 3, dadurch gekennzeichnet, daß in der Bohrung (97) Federmittel (96) vorgesehen sind, die den sekundären Kolben (90) gegen die Düse (14) hin vorbelasten.

Revendications

1. Un injecteur (10) de carburant pour un moteur à combustion interne, comprenant un corps ayant un alésage (97) s'étendant axialement, un plongeur de pompage primaire (62) et un plongeur secondaire (90) positionné à l'intérieur dudit alésage de façon à pouvoir s'y dépla-

cer axialement en réponse au déplacement dudit plongeur de pompage primaire (62), une buse (14) située à l'extrémité dudit alésage (97) éloignée dudit plongeur de pompage primaire (62), une chambre (98) de fixation du point d'injection formée dans ledit alésage entre ledit plongeur primaire (62) et ledit plongeur secondaire (90), une chambre de dosage (128) formée dans ledit alésage entre ledit plongeur secondaire (90) et ladite buse (14), des passages (42, 43, 80, 82) formés dans ledit corps dudit injecteur (10) pour recevoir du carburant sous pression et transmettre ledit carburant à ladite chambre (98) de fixation du point d'injection et à ladite chambre de dosage (128), et un élément de commande (146) actionné électroniquement situé entre lesdits passages (42, 43, 80, 82) et ladite chambre (98) de fixation du point d'injection et agencé de manière à pouvoir être sélectivement excité pour régler le moment de l'éjection du carburant hors de la chambre de dosage (128) par la buse (14) et par conséquent la quantité de carburant éjectée par la buse au cours de la phase d'injection, ledit élément de commande (146) contrôlant l'admission du carburant dans ladite chambre (98) de fixation du point d'injection pour créer dans sa position de fermeture une liaison hydraulique entre ledit plongeur de pompage primaire (62) et ledit plongeur secondaire (90) et pour créer dans sa position d'ouverture une condition d'équilibre de pression dans ladite chambre (98) de fixation du point d'injection permettant un déplacement indépendant dudit plongeur de pompage primaire (62) par rapport audit plongeur secondaire (90) pendant la partie restante du cycle de fonctionnement de l'injecteur, caractérisé en ce que le même élément de commande (146) est en outre utilisé pour régler la quantité de carburant emmagasinée dans la chambre de dosage (128) consécutivement à la phase d'injection, ladite quantité

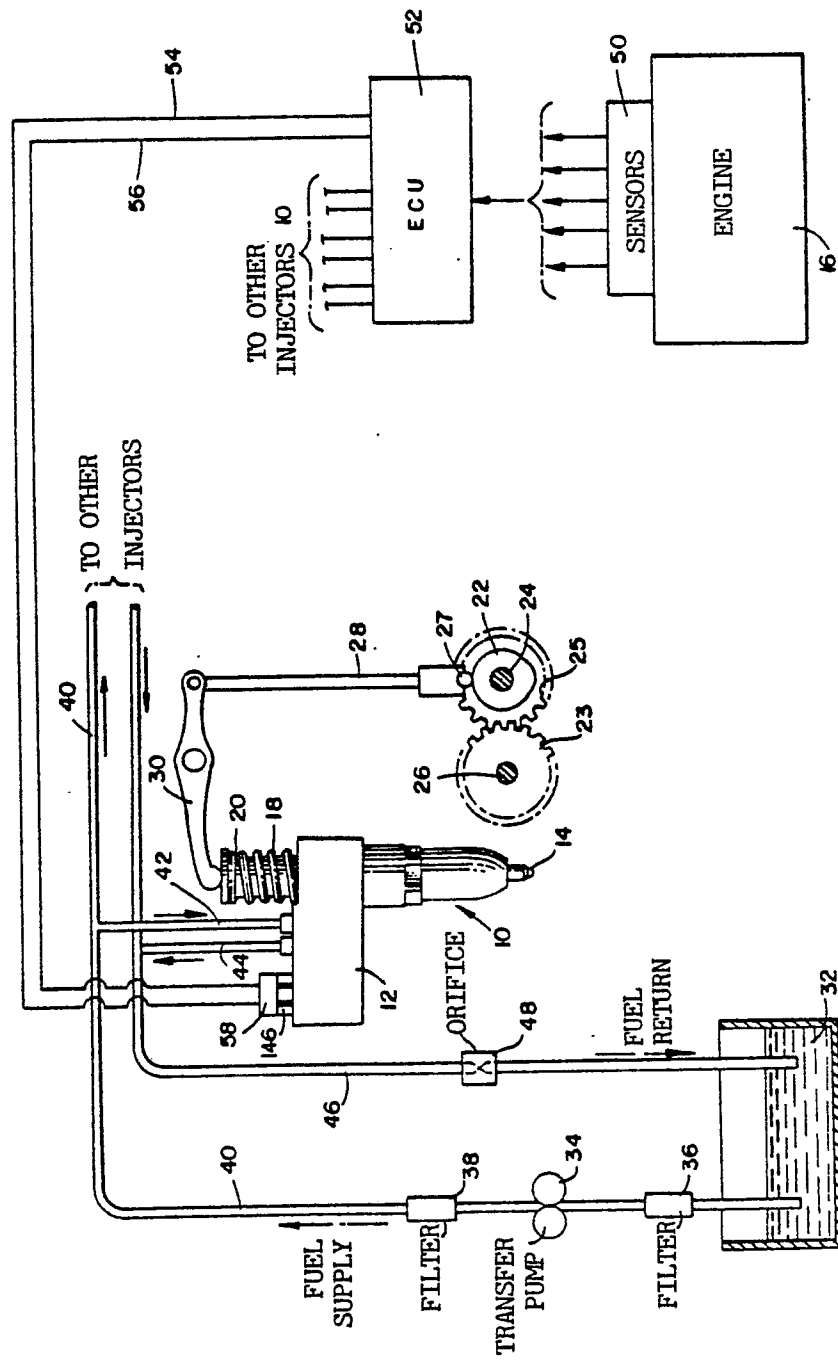
de carburant étant rendue proportionnelle à l'intervalle de temps pendant lequel ledit élément de commande (146) est maintenu en position fermée après le début de la course de retour des deux plongeurs (62, 90) consécutive à ladite phase d'injection.

2. Un injecteur de carburant selon la Revendication 1, caractérisé en ce que ledit plongeur secondaire (90) comporte un espace annulaire (112) formé au voisinage de son milieu, ledit espace annulaire (112) débouchant dans un passage transversal (114) qui communique avec un court passage axial (116), ledit court passage axial (116) communiquant avec des passages allongés (124, 126) s'étendant axialement qui débouchent dans ladite chambre de dosage (128), une soupape de retenue (118) et un ressort (121) pour solliciter normalement ladite soupape de retenue (118) en appui contre son siège (120) afin d'empêcher la communication entre ledit espace annulaire (112) et ladite chambre de dosage (128), ladite soupape de retenue n'étant écartée de son siège que pendant la phase de dosage du cycle de fonctionnement pour permettre au carburant à la pression d'alimentation provenant des passages (80, 82) formés dans le corps de l'injecteur de pénétrer dans l'espace annulaire (112) et de s'écouler vers le bas jusque dans la chambre de dosage (128) par lesdits passages (124, 126) s'étendant axialement.

3. Un injecteur de carburant selon la Revendication 2, caractérisé en ce que le volume de ladite chambre de dosage (128) varie linéairement pendant ladite phase de dosage du cycle de fonctionnement.

4. Un injecteur de carburant selon l'une des Revendications 1 à 3, caractérisé en ce qu'il comprend des moyens élastiques (96) à l'intérieur dudit alésage (97) pour solliciter le plongeur secondaire (90) vers ladite buse (14).

FIG. 1.



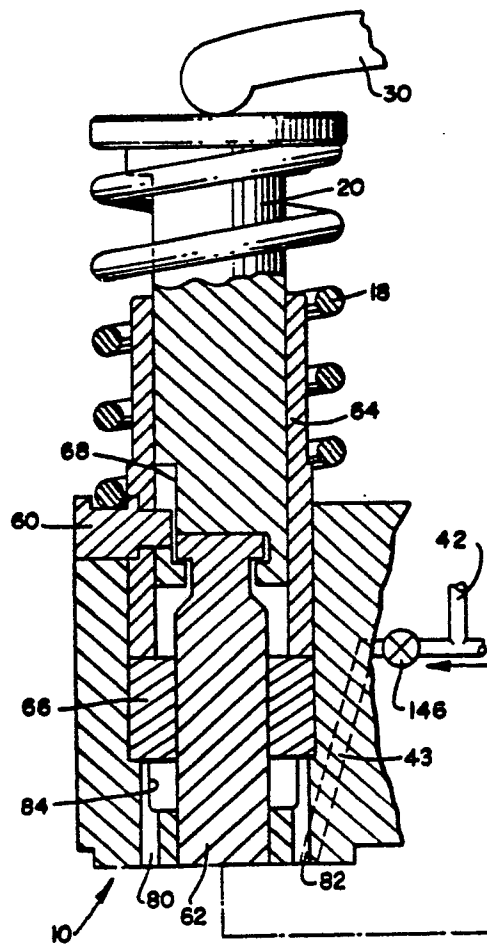


FIG. 2.

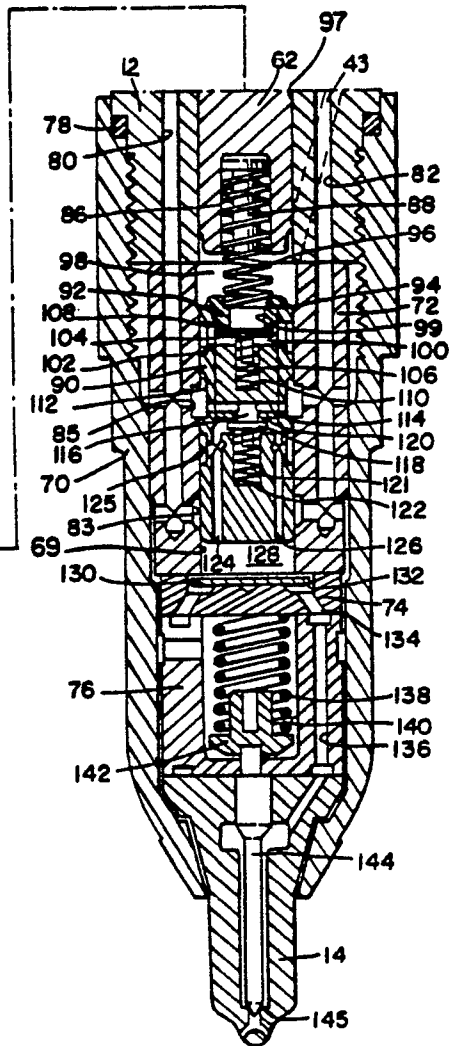


FIG. 3.

STARTING POSITION

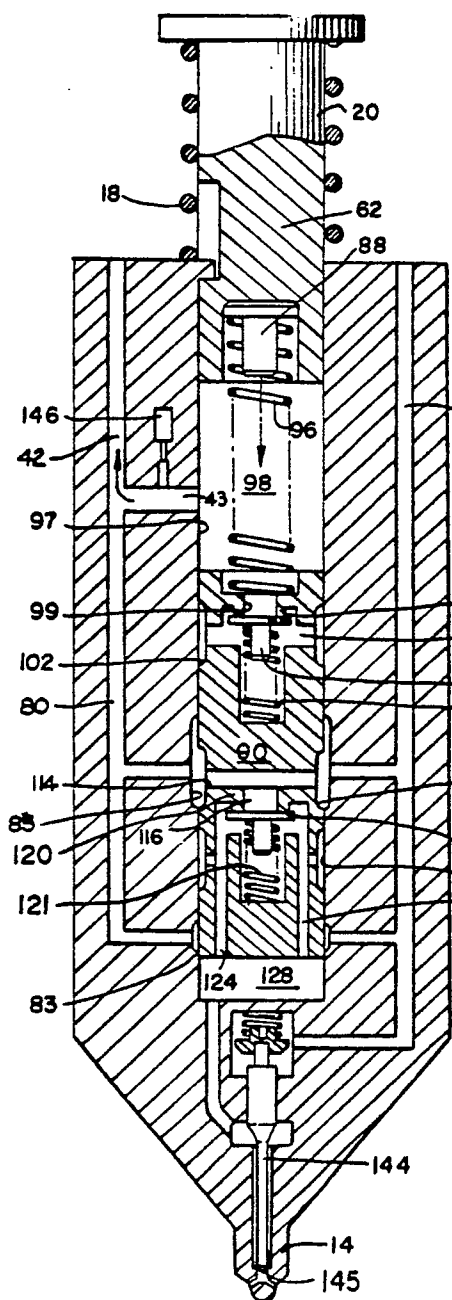


FIG. 4.

INJECTION OPERATION

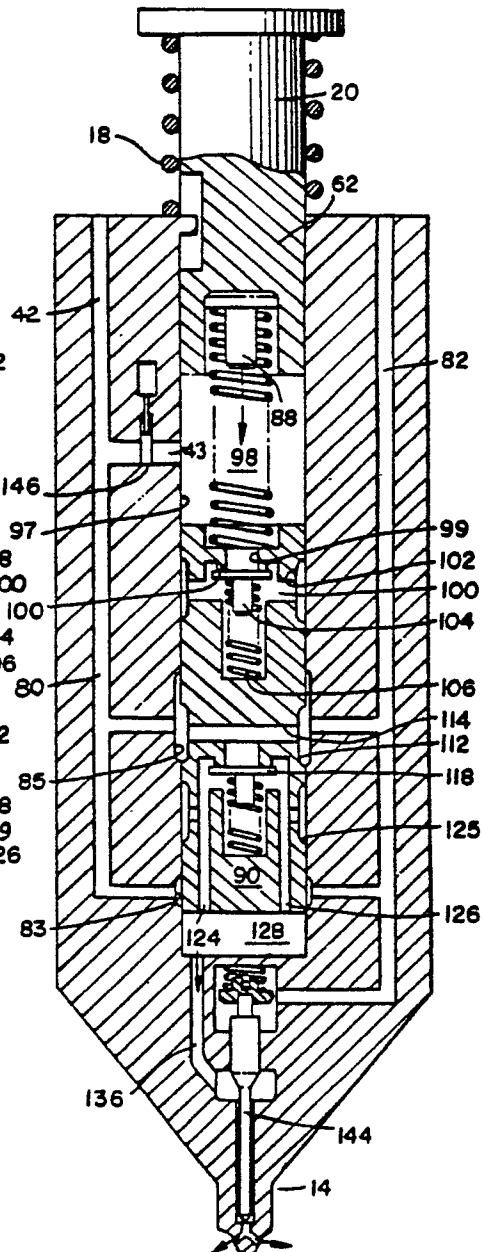


FIG. 5.

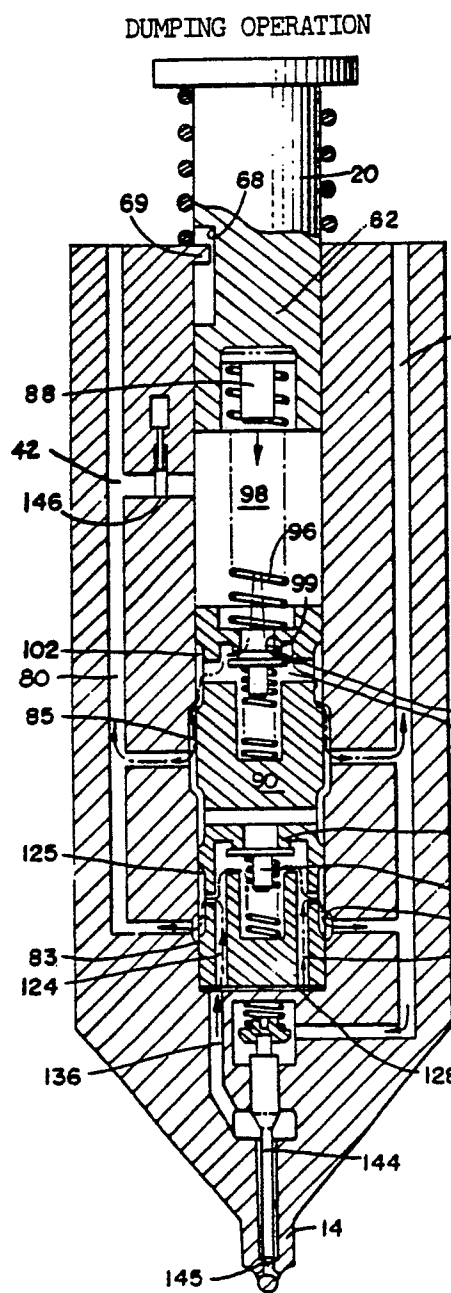


FIG. 6.

