United States Patent [19]

Wolfe

[11] 3,810,453

[45] May 14, 1974

[54] FUEL INJECTION SYSTEM

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[22] Filed: **Oct. 18, 1971**

[21] Appl. No.: **190,142**

[52] **U.S. Cl.** .... **123/139 R,** 123/139 AT

[51] **Int. Cl.** **F02m 47/02**

[58] **Field of Search**.... 123/139 R, 139 DP, 139 AS, 123/139 AT

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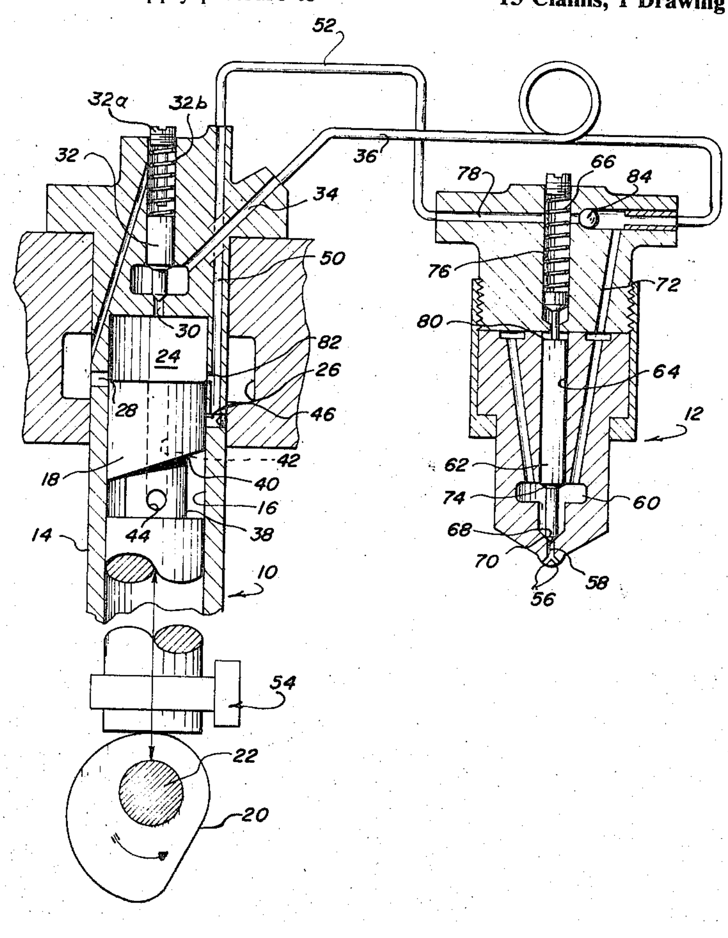
[57] **ABSTRACT**

A fuel injection system for achieving a more complete and efficient combustion of the injected fuel and avoiding the problems associated with low residual line pressure in the system, such as cycling and cavitation erosion. Fuel is pumped in cyclic pressure pulses from a pump to an injection nozzle controlled by a spring loaded. pressure responsive valve which is moved to an open fuel discharging position when the pressure of fuel within a discharge chamber overcomes the biasing force of the valve spring. A second chamber in the nozzle is located to apply pressure to the opposite side of the valve to augment the spring force urging the valve to its closed position. During the initial portion of each pressure pulse generated by the fuel pump, the entire pulse is conducted at full pump pressure to the discharge chamber, thereby opening the valve and discharging fuel from the nozzle to the firing chamber of the engine. At an adjustably selected point in the pressure generating portion of each pump cycle, the second chamber in the nozzle is connected to the pump chamber so that the two chambers at opposite sides of the valve are in fluid communication with the pump. At the instant the second chamber is connected to the pump, a positive pressure wave travels to the second chamber from the pump, thus temporarily dropping the pump output pressure until the system can become equalized. This sudden dropping of the pump pressure, in effect, transmits a negative pressure wave from the pump to the discharge chamber. Arrival of the positive pressure wave at the second chamber develops a pressure acting against the valve in a direction augmenting the spring force of the valve. The valve will move to its closed position when the sum of the spring force and pressure force exerted in the second chamber exceeds the opposing pressure force exerted on the valve by the pressure in the discharge chamber. In order to close the valve while the pressure in the discharge chamber is still at, or close to the full pump pressure, the fluid path between the pump and discharge chamber is of a greater length than the fluid path from the pump to the second chamber.

13 Claims, 1 Drawing Figure



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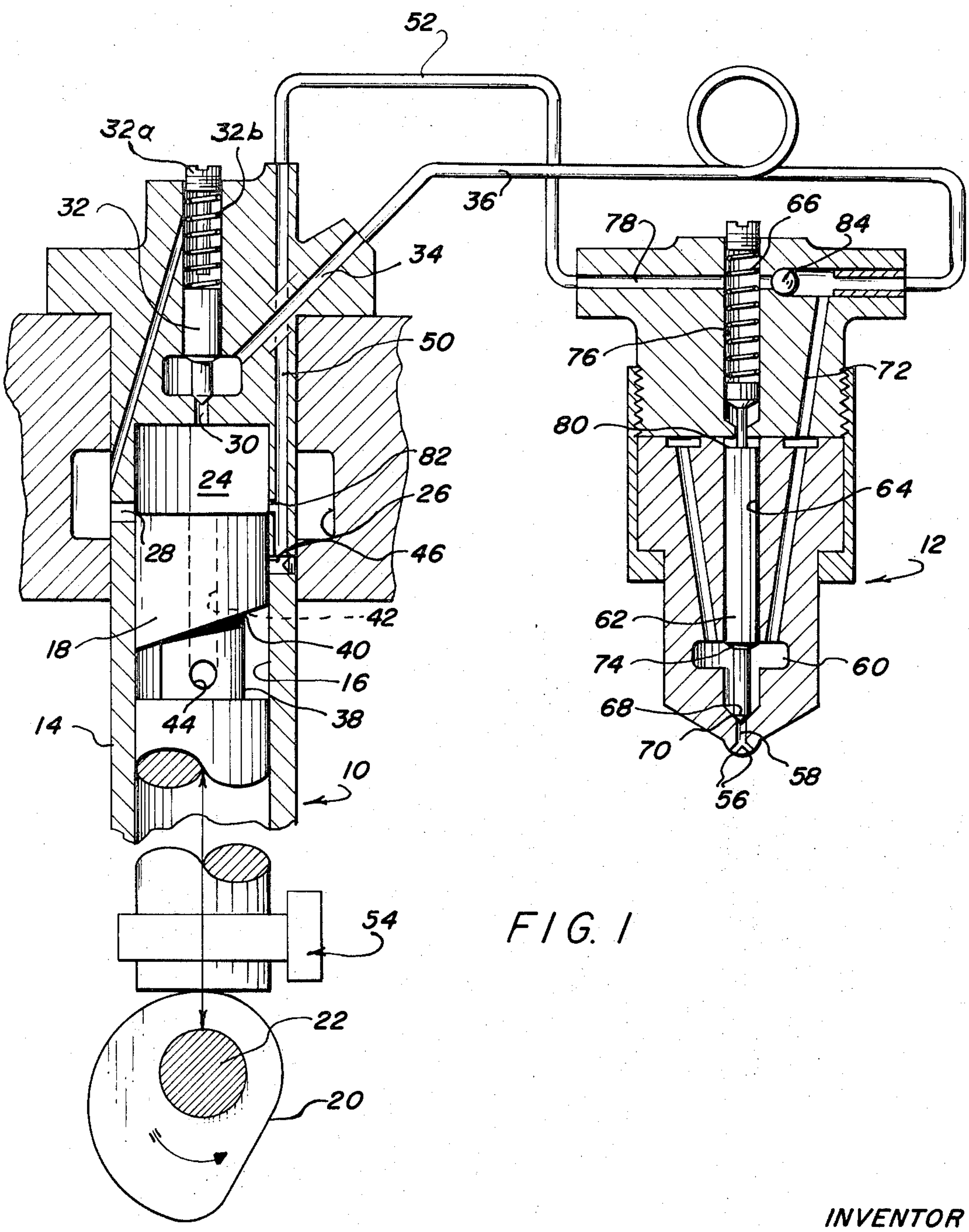

FIG. 1

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FUEL INJECTION SYSTEM

BACKGROUND OF THE INVENTION

In most presently used fuel injection systems, control of the discharge of fuel from the injection nozzle is accomplished by means of a spring loaded valve which is unseated when the fuel pressure in the valve discharge chamber is high enough to open the valve against the biasing action of the valve spring. The relatively high pressures employed are such that during the injecting cycle, the forces exerted on the valve by the fuel pressure substantially exceed the biasing force developed by the valve spring. Thus, at the end of the injection cycle, the fuel pressure must decrease substantially before the spring can drive the valve to its closed position. This results in a period at the end of each injection cycle where fuel is being expelled from the nozzle at decreasing pressures, which in turn results in poor atomization of the fuel within the firing chamber, which in turn leads to incomplete and inefficient combustion of the fuel. In addition to the obvious loss of efficiency of engine operation, this action produces both smoke and unconsumed fuel droplets in the exhaust emission of the engine. Furthermore, the time available for the closing of the valve is very short and thus a fast lowering of the pressure at the end of the injection is essential. To accomplish this, pressure relief at the pump end must be fast which leads to high amplitude negative pressure waves traversing the high pressure system at the end of the injection with a tendency to cavity formation and subsequent irregular injection and cavitation erosion in the system.

It is a primary object of the present invention to provide a fuel injection system in which each injection cycle is sharply terminated with the injection pressure at or substantially at its full normal pressure, to thereby avoid cavity formation and irregular injection and achieve maximum efficiency and completeness of fuel combustion.

SUMMARY OF THE INVENTION

In one form of the invention, a fuel pump having a reciprocatory piston driven by the engine is employed to pump fuel in cyclic pulses to an injection nozzle. The nozzle is provided with a spring loaded valve having one shoulder exposed to the pressure existing within the fuel discharge chamber from which fuel is expelled, when the valve is open, through conventional nozzle orifices. The fuel discharge chamber communicates directly with the fuel pump output chamber. A second chamber is formed in the nozzle with the opposite end of the valve exposed to pressure in the second chamber. Thus, any pressure existing within the second chamber augments the biasing force of the valve spring to urge the valve toward its closed position. At a location behind the front face of the reciprocatory pump piston, a reduced diameter section is formed on the piston and is in constant communication with the pump chamber via an internal passage through the piston. When the piston is moved forwardly a preselected distance in its pressure developing stroke, a port in the side of the cylinder in which the piston slides comes into communication with the reduced diameter section of the piston, thus permitting some of the fuel being compressed by the piston to leave the pump chamber via the internal passage through the piston and the reduced diameter section and the port. This latter port is connected by a conduit to the second chamber in the injection nozzle.

During the first portion of the pressure pulse developing stroke of the piston, the port is closed by the side of the piston and hence, the entire first portion of each pressure pulse generated by the piston is conducted from the pump chamber to the fuel discharge chamber in the nozzle. When the piston has moved forwardly a sufficient distance to uncover the port, uncovering of the port transmits a positive pressure pulse from the pump chamber through the port and to the second chamber of the nozzle. The pressure thus developed augments the spring force urging the valve to its closed position and, depending upon the spring setting, may immediately close the valve upon its arrival while full pump pressure still exists in the discharge chamber. Full pump pressure will still exist in the discharge chamber at the time the positive pulse arrives in the second chamber due to the fact that the fluid path from the pump chamber to the discharge chamber is longer than the fluid path from the pump chamber to the second chamber of the injection nozzle.

At the instant the port is uncovered by the reduced diameter section of the piston, the pressure developed by the piston is suddenly placed in communication with a region of relatively reduced pressure which includes all of that portion of the system between the pump port and second chamber of the injection nozzle. Until pressure in the entire system can be equalized, the pressure ahead of the piston in the pump chamber suddenly drops, thus, in effect sending a negative pressure pulse from the pump chamber to the discharge chamber of the nozzle. Because the fluid path from the pump chamber to nozzle discharge chamber is longer than that from the pump chamber to the second chamber of the nozzle, this negative pulse or reduction of pressure does not arrive at the valve until after the positive pressure wave has arrived in the second chamber. Pressure in the pump chamber, as just stated, drops immediately upon the opening of the port to the reduced diameter section of the piston, as fluid is being dicharged into the newly connected portion of the system. A pressure increase is initiated in the newly connected portion of the system and this portion becomes pressurized. This increase will, of course, arrive at the second nozzle chamber before the change in pressure is felt in the nozzle discharge chamber, hence a situation is created where the pressure in the second chamber, augmenting the spring force, is building up prior to the belated arrival of the negative pressure pulse from the pump chamber. The system is so regulated that the pressure augmented spring force urging the valve to its closed position will overcome the opposing pressure force in the discharge chamber while the pressure in the discharge chamber is at or substantially at the full fuel injection pressure. This action results in a rapid closing of the valve while injection is still continuing at full pressure.

Other objects and features of the invention will become apparent by reference to the following specification and the drawings.

In the Drawings:

FIG. 1 is a schematic diagram, partially in cross-section, of one form of fuel injection system embodying the present invention.

Referring first to FIG. 1, a fuel injection system embodying the invention is shown as including a pump designated generally **10** and an injection nozzle designated generally **12.** Pump **10** includes a casing **14** having an internal bore **16** within which a pump piston **18** is mounted for reciprocatory movement. Piston **18** is driven in reciprocatory movement by conventional means such as a cam **20** mounted on a rotary shaft **22** driven by the engine which is supplied with fuel by the present system. In FIG. **1**, the piston is just beginning its upward or pressure delivering stroke and pump chamber **24** is still in communciation with a constantly filled fuel supply chamber **26** via fuel inlet passage **28.** As piston **18** moves upwardly beyond passage **28**, pressure is developed in the fuel in chamber **24** above the piston and the fuel is discharged under pressure through a main outlet port **30** when the pressure developed in the fuel is sufficient to overcome the biasing action on a spring loaded differential valve **32.** Upon opening of valve **32**, fuel is discharged through a passage **34** in the pump casing to a main outlet conduit **36** connected to injection nozzle **12.**

Piston **18** is formed with a reduced diameter section or groove **38**, the forward wall of which is inclined to the piston axis as at **40.** An axially extending passage **42** and a communicating cross passage **44** place piston chamber **24** in constant communication with groove **38.** As piston **18** is driven upwardly from the position shown in FIG. **1**, groove **38** moves into communication with a second discharge port **46** which communicates via an internal passage **50** through the pump casing with a secondary conduit **52** which is likewise connected to nozzle **12.**

In operation, piston **18** is driven in continuous reciprocatory movement to discharge fuel from the pump in cyclic pressure pulses of finite time duration, each pressure pulse commencing at the moment piston **18** moves upwardly beyond fuel inlet passage **28** and terminating when piston **18** reaches the upward end of its stroke (assuming that groove **38** will not uncover port **28** as will be the case in some systems). During that portion of the upward stroke of the piston between the instant when piston **18** closes port **28** and the point of the stroke of piston **18** at which groove **38** begins to uncover port **46**, the sole outlet of chamber **24** is main outlet port **30.** Thus, considering the discharge of fuel from the pump in terms of a pressure pulse, during the initial portion of each pressure pulse developed by the pump, all of the fuel discharged from the pump passes into conduit **36** at the full pressure developed by the pump (less the relatively small pressure required to unseat valve **32**).

However, when pump **18** reaches that point in its pressure developing stroke at which port **46** is exposed to groove **38**, a second outlet is made available to the fuel within chamber **34**, and during the remaining final portion of the pressure pulse, fuel may be discharged from the pump via both conduits **36** and **52**, the sudden opening of port **46** creating a pressure drop in conduit **36** as pressure is built up in conduit **52.**

By inclining the upper or leading edge **40** of groove **38**, the point in the upward stroke of piston **18** at which port **46** is uncovered may be accurately adjusted by rotating the piston to a selected position of rotative adjustment relative to port **46**, as by means of a conventional rack and pinion arrangement, well known in the art and shown schematically at **54.**

Referring now to nozzle **12**, the nozzle is provided with discharge orifices **56** which communicate via a bore **58** with a first internal chamber **60** formed within the nozzle. A reciprocatory valve member **62** is slidably mounted within a bore **64** in nozzle **12** and is resiliently biased by a spring **66** to a closed position in which the valve head **68** is engaged with a valve seat **70** to block communication between chamber **60** and orifices **56.** Chamber **60** is in constant communication with conduit **36** via an inlet passage **72.** A downwardly facing shoulder **74** on valve member **62** is exposed to chamber **60** so that when the pressure of fuel in chamber **60** acting on shoulder **74** is sufficient to overcome the biasing action of spring **66**, valve member **62** is driven upwardly to an open position in which head **68** is lifted clear of valve seat **70** to permit the discharge of fuel from chamber **60** through orifices **56.**

The internal bore **76** within which valve spring **66** is mounted is placed in fluid communication with conduit **52** via passage **78** in nozzle **12.** An upwardly facing surface **80** on valve member **62** is exposed to chamber **76** so that any fluid pressure developed in chamber **76** will act against surface **80** to apply a force urging valve member **62** downwardly toward its closed position.

The system shown in FIG. **1** is especially designed to provide a sharp cut off or termination of each pulse injected into the engine firing chamber from nozzle orifices **56.** Fuel injection systems of the type with which the present invention is concerned operate at very high injection pressures, in some cases as high as 10,000 PSI or more. In the usual form of injection nozzle, closing of the nozzle valve is accomplished solely by the spring loading of the valve which drives the valve back to its seat as the fuel pressure diminishes at the end of the injection cycle. Because the fuel pressure necessary to hold the injection valve open against the biasing action of its spring in a conventional system is normally much lower than the injection pressure, in those systems in which sole reliance is placed upon a spring to close the injection nozzle a substantial pressure drop in the fuel at the nozzle must occur before the spring can successfully drive the valve to its seat. This results in a period at the end of each injection cycle where fuel is discharged at continuously falling pressures which in turn lead to a poorly atomized spray and less efficient or incomplete combustion of fuel in the firing chamber.

A sharp cutoff at the end of the injection cycle is achieved in the system of FIG. **1** by splitting the pressure pulse of fuel during the final portion of the pulse to apply a positive pressure to the upper side of injection valve **62** to augment the valve closing biasing force of spring **66**, while continuing to supply fuel under pressure to chamber **60.**

As described above, as pump piston **18** begins to move up from the bottom ot its reciprocatory stroke, pressure is developed in the charge of fuel in chamber **24** with the resulting increase in pressure in the fuel in conduit **36** passage **72** and chamber **60.** It is convenient to think of the beginning of the pressure pulse thus developed as travelling as a pressure wave from chamber **24** through conduit **36** and passage **72**, the arrival of this wave in chamber **60** developing sufficient pressure in the chamber to lift valve **62**, thereby commencing the discharge of fuel under pressure from chamber **60** through nozzle orifices **56** into the firing chamber. A condition is soon reached in which the advance of piston **18** maintains a pressure in chamber **60**, by continuously replacing the fuel discharged at a controlled rate through the orifices **56.** As described above, this state of affairs continues until piston 18 is driven upwardly to the point at which groove 38 in piston 18 uncovers port 46.

At the instant that groove 38 uncovers port 46, a second pressure wave is transmitted from chamber 24 through passages 42 and 44 in piston 18, groove 38 and into conduit 52 via port 46 and passage 50. This action has the effect of dropping the pressure in chamber 24 because the chamber 24 has, in effect, been suddenly placed in communication with a region of relatively reduced pressure. Thus, as port 46 is uncovered by groove 38, a positive pressure wave starts moving from the pump toward chamber 76 of the injection nozzle via port 46, passage 50 and conduit 52. Simultaneously, a corresponding negative pressure wave begins moving from chamber 24 toward injection chamber 60 via passage 34, conduit 36 and passage 72.

When the positive pressure wave reaches surface 80 of valve 62, pressure will begin to build back up into chamber 24, until all of the portions of the system in communication with chamber 24 come to a common equalized pressure.

The arrival of the positive pressure wave, generated by the uncovering of port 46, at surface 80 applies pressure to this surface which augments the valve closing force exerted by spring 66. However, valve 62 may or may not close immediately upon the arrival of the pressure wave at surface 80, because the opposing pressure in chamber 60 at this instant is still at the original full pump pressure. Chamber 60 is still at full pump pressure because the path of travel from pump chamber 24 to injection chamber 60 via passage 34, conduit 36 and passage 72 is deliberately made longer than the fluid path from chamber 24 to surface 80 via passages 42, 44, groove 38, passage 50 and conduit 52.

Thus, at the instant the positive pressure pulse generated by the uncovering of port 46 arrives at surface 80, the corresponding negative pressure pulse traveling toward chamber 60 via conduit 36 and passage 72 has not yet arrived at chamber 60. The magnitude of the pressure against surface 80 at the time of the arrival of the positive pressure pulse is inherently lower than the pressure in chamber 60 because of the pressure reduction in chamber 24 occasioned, in effect, by the extraction of the positive pressure pulse from chamber 24 by the uncovering of port 46. However, the pressure against surface 80 will increase further as the system moves toward equalization and at some point in time the pressure exerted against surface 80 will reach a point at which this pressure, augmented by the force of spring 66, will act to close valve 62 against the pressure force in chamber 60.

Thus, valve 62 may be closed and injection terminated without any substantial drop in the injection pressure. The point in time at which valve 62 begins to close is the moment at which the combined force of spring 66 and the force developed by the pressure acting on surface 80 exceeds the opposing force exerted on the valve by the pressure in chamber 80. Depending upon the adjusted spring force of spring 66 and the relative length of the fluid paths via conduits 36 and 52, closing of the valve may be accomplished either before the arrival of the negative pressure wave at chamber 60 or in response to the arrival of the negative pulse.

Chamber 76 is dimensioned such that — together with the rest of the system and due to the compressibility of the fluid — it can absorb the fluid displaced by piston 18 after the termination of injection. Pressure is relieved in the system during the return or downward stroke of piston 18 by exposing conduit 52 and passage 50 to the fuel supply pressure or sump via passage 82, uncovered when the piston is at its lower end of stroke. Excess pressure from chamber 76 and conduit 52 can also be vented from conduit 52 across ball check valve 84 into conduit 36 as piston 18 moves downward prior to uncovering port 82. The residual pressure prevailing at the beginning of the consecutive injection in the high pressure system (comprising essentially conduits 36, 72 and chamber 35 and 60) can be adjusted by adjusting the closing pressure of valve 32 by means of plug 32*a* and spring 32*b*. If port 82 is omitted this residual pressure pressure will also prevail in the rest of the system (including essentially chamber 76, passage 78 and conduit 52).

While one embodiment of the invention has been described in detail, it will become apparent to those skilled in the art that the foregoing description is exemplary, rather than limiting, and that the true scope of the invention is that defined in the following claims.

I claim:

1. A fuel injection system comprising an injection nozzle having an inlet passage, an internal chamber, and a discharge orifice, a valve member mounted in said nozzle for movement between an open position wherein said inlet passage is in communication with said discharge orifice and a closed position wherein said valve member blocks communication between said inlet passage and said orifice, biassing means biassing said valve member toward said closed position, said valve member having opposed surfaces thereon respectively exposed to said inlet passage and to said chamber for urging said valve member toward said open position in response to pressure in said inlet passage and for urging said valve member toward said closed position in response to pressure in said chamber, pump means for pumping fuel in cyclically generated pressure pulses, and conduit means for conducting a first portion of each pressure pulse generated by said pump means to said inlet passage to move said valve member to an open position and for conducting a subsequent portion of each pressure pulse generated by said pump means to said inlet passage and said chamber to move said valve member to its closed position.

2. A system as defined in claim 1 wherein the length of the fluid path via said conduit means from said pump means to said inlet passage is greater than that from said pump means to said chamber.

3. A system as defined in claim 1 wherein said pump means comprises a piston reciprocable within a pump chamber, and said conduit means comprises a first conduit connecting said pump chamber to said inlet passage, a second conduit in constant communication with said chamber in said nozzle, and passage means in said pump piston for placing said second conduit in communication with said pump chamber during a selected portion of the cyclic movement of said piston.

4. A system as defined in claim 3 wherein the length of the fluid path from said pump chamber to said valve member via said first conduit and said inlet passage is greater than the length of the fluid path from said pump chamber to said chamber in said nozzle via said second conduit.

5. A system as defined in claim 3 further comprising means for adjustably selecting the range of movement

of said piston over which said second conduit is in communication with said pump chamber.

6. A system as defined in claim **3** having passage means for venting said second conduit cyclically, said passage means being connected with an area of lower pressure during a selected portion of the cyclic movement of said piston.

7. A system as defined in claim **3** further comprising means to store the fuel displaced by said piston after the end of injection, and means to vent said fuel during a selected portion of the cyclic movement of said piston.

8. A system as defined in claim **3** having valve means for venting said first conduit, said valve means determining the pressure remaining in said first conduit after the end of the injection.

9. A system as defined in claim **8**, said valve means being adjustable in respect to the pressure at which said venting is terminated.

10. A system as defined in claim **1** having passage means connecting said inlet passage and said internal chamber, and valve means normally preventing flow through said passage means from said inlet passage to said internal chamber.

11. In a method of operating a fuel injection system wherein discharge of fuel into the firing chamber from an injection nozzle is controlled by a discharge valve normally biassed to a closed position and movable to an open fuel discharge position in response to pressure against one side of said valve, and wherein the opposite side of said valve is exposed to a pressure chamber; the improvement comprising the steps of pumping fuel in cyclic pressure pulses of finite time duration to said valve, conducting the first portion of each pulse to said one side of said valve to open said valve and discharge fuel from said nozzle, splitting the remaining final portion of each pulse into two components, and conducting one of said two components to said opposite side of said valve to augment the closing bias of said valve.

12. The method defined in claim **11** wherein the step of pumping fuel is performed by a cyclically operable positive displacement pump having an outlet chamber in constant communication with said one side of said valve, and the step of splitting the final portion of said pulse comprises the step of placing said outlet chamber in communication with said other side of said valve during the final portion of each pulse generating cycle of said pump.

13. The method defined in claim **12** further comprising the step of conducting fuel from said outlet chamber to said other side of said valve along a flow path which is shorter than the flow path along which fuel is conducted from said chamber to said one side of said valve.

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