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[54] **INJECTION NOZZLE FOR DIRECT INJECTION ENGINE**

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[51] **Int. Cl.** **F04b 7/04**

[58] **Field of Search** 239/533, 583, 584, 239/585; 123/139

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[57] **ABSTRACT**

An improved needle valve spring apparatus for a fuel injection assembly of the type wherein pressured fuel from a supply conduit is pumped at each cycle to a needle valve which opens to allow the pumped fuel to enter the combustion cylinder. The spring chamber that supplies spring force to the needle valve member to normally keep it closed, and that heretofore contained only a coil spring, is filled with pressured fuel that acts as a spring. The spring chamber is sealed against the outflow of fuel therefrom, and a passage with a check valve therein connects the pressurized fuel supply line to the spring chamber to fill the spring chamber with pressurized fuel when the engine is started.

5 Claims, 3 Drawing Figures

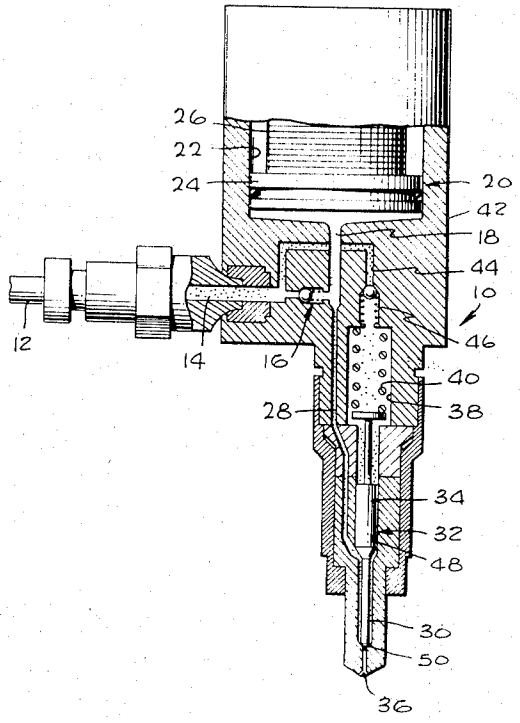


Fig. 2

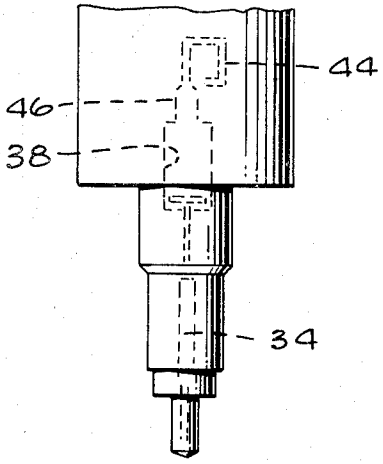


Fig. 1

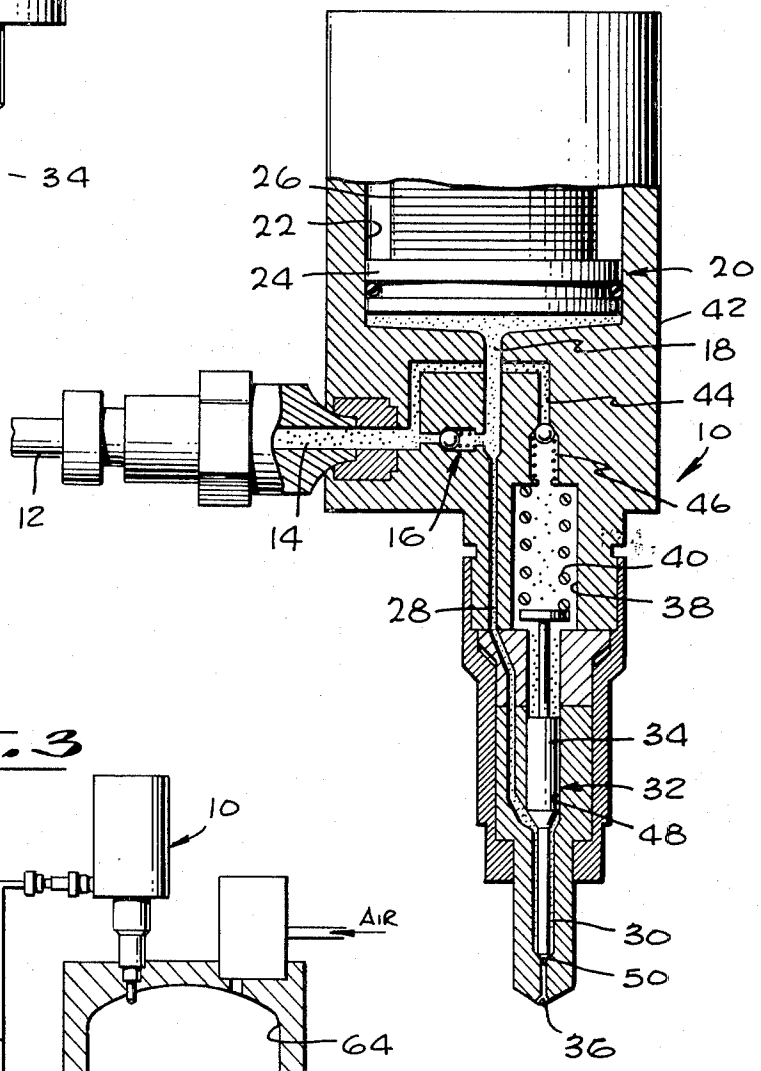
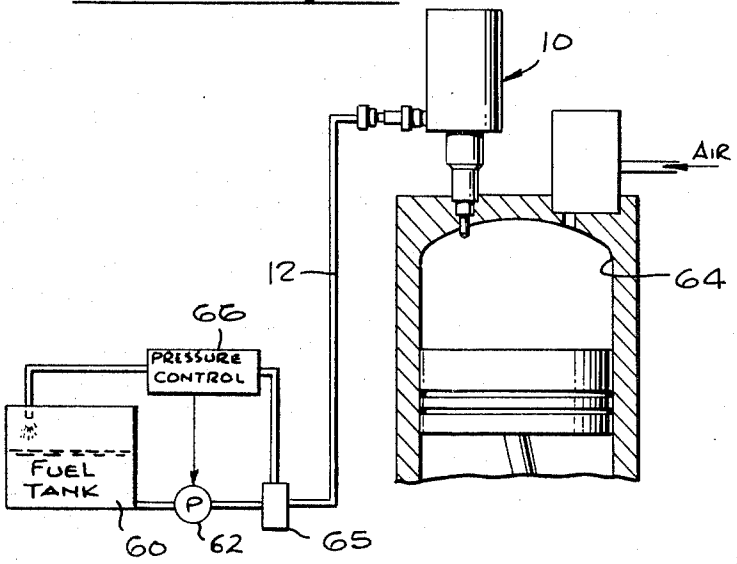


Fig. 3



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INJECTION NOZZLE FOR DIRECT INJECTION ENGINE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to engines of the type wherein fuel is injected directly into a combustion chamber in a closely controlled manner, such engines often being referred to as direct injection engines.

2. Description of the Prior Art:

Direct injection engines employ apparatus that injects fuel in a closely controlled manner into the combustion chamber or cylinder of the engine. The injected fuel then may be burned by spark ignition or compression ignition. One type of engine utilizes a fuel pump that transfers fuel from a storage tank and feeds it at a low pressure such as 5 pounds per square inch (psi) to the injection apparatus. The injection apparatus typically includes an injection pump that raises fuel pressure to a level such as several thousand psi. From the injection pump, the fuel passes along a channel to the nozzle region of a needle injection valve. The injection valve has a valve member with a collar whose lower side is exposed to the fuel pressure at the nozzle region and whose upper side is exposed to a passage in which the pressure is maintained at or close to atmospheric pressure. When the pressure below the collar of the injection valve rises above a predetermined level such as 3,000 psi, the valve member is lifted against a spring force, and fuel can begin passing through the nozzle into the cylinder. It may be noted that as the valve member lifts, the area below the collar that was occluded by the valve seat is exposed to the fuel pressure, thereby further accelerating lifting of the valve member.

Heretofore, the injection valves have employed a spring chamber that contained only a coil spring. The spring chamber was vented to the fuel tank to prevent the accumulation of fuel that leaked past the stem of the valve member. The coin spring has a high spring rate and was installed with a large preload, and it served to urge the valve member closed until highly pressured fuel at the nozzle could overcome the preloading. Several problems arose in this valve arrangement. One problem was that fuel leaked past the sliding valve member into the spring chamber, and had to be returned to the fuel system. Although the fuel leakage was small, the need for return lines and connections added complications and expense. Another problem was that the coil spring had a relatively high incidence of breakage, and this led to increased maintenance and downtime. Furthermore, the spring was subject to coil surge due to disturbance at the natural spring frequency when the valve member was rapidly opened or closed, which could lead to variations in valve seating load and, in extreme cases, to unscheduled openings of the valve.

OBJECTS AND SUMMARY OF THE INVENTION

An object of the present invention is to provide a simplified and reliable fuel injection apparatus for an engine.

Another object of the invention is to provide a nozzle spring with extremely high resonant frequency, to permit the valve opening rate to be increased and to permit rapid repetition of valve opening cycles.

Still another object is to provide a direct injection valve assembly which automatically changes injection valve preloading in response to changes in fuel supply pressure.

In accordance with one embodiment of the present invention, an injection assembly is provided which utilizes liquid fuel as a spring to urge the needle valve member closed. The injection apparatus is of the type which includes a fuel supply conduit that carries fuel from the storage tank to an intermediate pressure pump. The intermediate-pressure pump raises the fuel pressure to a level such 50 psi to 2,000 psi and the fuel then flows to an injection pump. The injection pump operates one to several times each cycle to pump fuel through a narrow channel to the nozzle region of a needle injection valve. At the nozzle region of the valve, the fuel, when raised through a further pressure increment by the injection pump, lifts a valve member and passes through the nozzle into the engine cylinder.

Instead of using only a coil spring to preload the valve member towards a closed position, a fluid-tight spring chamber is provided which is filled with pressurized fuel. The fuel in the chamber resists lifting of the valve member, while permitting such lifting when the injection pump delivers fuel under high pressure to the nozzle region of the valve. The spring chamber is connected through a check valve to the pressurized fuel supply so that it quickly fills with pressurized fuel when the engine is started. The check valve prevents outflow of fuel from the chamber, so that the fuel therein can be compressed like a spring. An auxiliary spring of the coil type is provided in the spring chamber to assure seating of the valve member under certain transient conditions, but most of the spring force is applied by the fuel in the chamber.

The fuel-filled spring chamber has the important advantage that any fuel leaking into it past the slideably mounted valve member does not have to be drained back into an unpressurized region of the fuel system. Instead, any fuel leaking into the spring chamber during periods when pressure in the injection pump exceeds pressure in the spring chamber, can leak back along the same path by which it entered, that is, along the slideably mounted valve member. The fluid spring cannot break like a conventional spring, while the auxiliary spring which is employed has a much lower preload and therefore is less likely to break than a conventional spring that supplies the entire spring force. The fluid spring also avoids uncontrolled injections which could otherwise occur by reason of spring surges at high rates of valve opening.

The fuel spring of this invention is especially useful in one type of engine system wherein fuel pressure in the supply line is varied to achieve better control of injection. By using the fluid spring of this invention, the spring loading of the nozzle valve is automatically adjusted by the fuel pressure, thus maintaining a valve seat loading which is always in proportion to the fuel pressure that is being withheld by the valve. Furthermore, in such a system, very high spring preloading is maintained only during the limited period when very high fuel supply pressures are maintained. Accordingly, wear or failure of the injection valve seat which can result from very high loading, is minimized.

The novel features of the invention are set forth with particularity in the appended claims. The invention will be best understood from the following description

when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional side view of injection apparatus constructed in accordance with the invention;

FIG. 2 is an end view of the injection apparatus of FIG. 1; and

FIG. 3 is a highly simplified diagramatic view of an engine having a variable fuel supply pressure, which utilizes the injection apparatus of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS.

FIG. 1 illustrates fuel injection apparatus **10** constructed in accordance with the invention, which includes a fuel supply pipe **12** that carries fuel **14** under a moderately high pressure such as 1,000 psi. The pipe leads through a check valve **16** in the injection assembly to a pump passage **18** which leads to an injection pump **20.** The injection pump **20** includes a pump cylinder **22** that can hold a quantity of the fuel, a pump piston **24** that can move within the cylinder, and an activator **26** such as an electroexpansive element, an electromagnetic element, or a mechanically driven plunger. When the activator **26** moves the piston **24** to inject fuel, fuel passes downwardly through the pump passage **18** and through a channel **28** to the nozzle region **30** of an injection valve **32.** The pressure of fuel at the nozzle region **30** tends to lift a needle valve member **34** so that fuel in the nozzle region **30** can pass out through a nozzle **36** that leads to the combustion cylinder of the engine. Normally, the valve member **34** is biased downwardly to a closed position, and it is only during the relatively short period of each cycle when the injection pump **20** supplies a high pressure such as one exceeding **3000** psi, that the valve member **34** lifts and fuel can be injected through the nozzle **36.**

In order to maintain the needle injection valve **34** in a normally closed condition, it is provided with a spring chamber **38.** The spring chamber **38** contains resilient material, including liquid fuel **14** and an auxiliary spring **40,** that supply spring forces tending to close the valve member **34** on its valve seat **50.** These spring forces act upon the full cross-sectional area of valve member **34** and normally exceed the lifting force of pressurized fuel in the nozzle region **30,** that bears against only those lower portions of the valve member that are not masked by the valve seat. In previous injector valves, the spring force was supplied solely by a coil spring in the spring chamber **38.** The spring chamber **38** was often vented to the atmosphere or to a low pressure area, and a drainage pipe led from the spring chamber to the fuel tank, in order to carry away fuel therein that had leaked past the valve member **34.**

In accordance with the present invention, the spring chamber **38** is constructed to be substantially sealed against the outflow of fuel. Accordingly, fuel that leaks from the nozzle region **30** past the valve member **34** and into the spring chamber **38** is allowed to remain under pressure in the spring chamber. Although the auxiliary spring **40** in the spring chamber supplies some force, most of the spring force is supplied by pressurized fuel in the chamber. Thus, the upward force on the valve member **34** resulting from the pressure of fuel at the nozzle region **30** is resisted primarily by the pressure of fuel in the spring chamber **38.** Furthermore, when the valve member **34** does rise during activation of the injection pump **20,** the fuel in the spring chamber **38** is elastically compressed and it supplies most of the force that returns the valve member **34** to its closed position on the valve seat **50.** A passageway **44** is provided in the housing **42** that forms the spring chamber, to couple the fuel supply pipe **12** to the spring chamber **38.** A check valve **46** is provided along the passageway **44,** to allow fuel to move through the passageway only in a direction towards the spring chamber **38** but not in the other direction. The passageway **44** is useful primarily when the engine is started and the spring chamber **38** may not be filled with fuel. As the engine is switched "on" in preparation for starting, pressurized fuel passes through the supply pipe **12** and through check valve **16** to the nozzle region **30.** The pressurized fuel also passes through the passageway **44** and check valve **46** into the spring chamber **38** to rapidly raise the pressure in the chamber, thereby ensuring that a sufficient force is applied to the valve member **34** to prevent fuel discharge until the injection pump is actuated. In conventional injection nozzles, there is only a minute flow of fuel into the chamber **38** where the spring is located, and such flow occurs only through the clearance between the valve member **34** and the bearing hole **48** through which it moves.

A description of typical engine operation utilizing the injector apparatus of the invention will help to show its manner of operation. The engine may pump fuel into the pressurized supply pipe **12** at a pressure such as 1,000 psi. During a majority of the time of each injection cycle, this pressure of 1,000 psi exists in the pump passage **18,** the channel **28,** and the nozzle region **30** of the needle injection valve. A pressure of about 1,000 psi also exists in the spring chamber **38,** thereby developing a force that urges valve member **34** into contact with its seating. The force exerted by pressurized fuel to the top of the valve member **34** is greater than the force exerted at the bottom region, because the valve member portion on the valve seat **50** is not exposed to the pressurized fuel. Thus, the valve member **34** is maintained closed. The auxiliary spring **38** further adds to the valve closing force.

During a small period of each cycle of engine operation, the activator **26** is energized to move the pump piston **24** and force fuel through the pump passage **18** and channel **28** to the nozzle region **30.** When the pressure in the nozzle region **30** rises above a predetermined level such as 3,000 psi, it can overcome the force of pressurized fuel in the spring chamber **38** and the additional force supplied by the preloaded auxiliary spring **40.** The valve member **34** then lifts to allow the pumped fuel to pass through the nozzle **36** into the cylinder. When the injection pump no longer provides a high pressure at the nozzle region **30,** and the pressure thereat falls to a level determined by the ratio of areas of valve member **34** and of the valve seating, such as for example 1,500 psi, the valve member **34** can begin to move down to close the injection valve. The auxiliary spring **40** is provided primarily to assure valve closing at this time, that is, when the lower end portion of the valve member that is normally seated on the valve seat **50** is almost seated but is exposed to fuel at the pressure existing in supply conduit **14.** The same force then may be applied by fuel pressure to the upper and lower ends of the valve member **34,** and the auxiliary spring **38** is required to assure that the valve will close. The pre-

loading of the auxiliary spring is generally less than half the force supplied by the pressurized fuel in the spring chamber. Thus, in an engine where a force of **60** pounds might be required to maintain the nozzle closed until the desired injection pump pressure was present, an auxiliary spring preload such as 15 pounds might be utilized. The other 45 pounds preload would be supplied by the fluid pressure in the chamber.

Fuel injection through the nozzle **36** generally occupies a very small percentage of each cycle of engine operation (even though injection may occur more than once in each cycle in some engines). The maximum injection duration is typically less than 5 percent of the total cycle time. Thus, there is only a brief period during each cycle when there is a higher pressure at the nozzle region **30** than in chamber **38** and therefore only a small amount of fuel will leak past the valve member **34** into the spring chamber at each cycle, to increase its pressure above the nominal 1,000 psi. During the remainder of over 95 percent of each cycle time, any fuel that has been forced into the spring chamber during injection can leak out again past the valve member **34** to the nozzle region **30.** In any case, so long as the pressure at the spring chamber **38** does not rise excessively above the nominal pressure, performance is not noticeably affected.

The spring chamber **38** can be dimensioned to provide any spring rate within a wide range. In conventional needle valves which utilized only a coil spring to supply valve closing force, a typical spring rate was 1,000 lbs. per inch. A spring rate of the same order can be obtained by utilizing a chamber of approximately 0.6 inches diameter and 1.0 inch long filled with diesel oil, which has a bulk modulus of elasticity of approximately 0.2×10^6 psi. While a typical needle injection valve might use a coil spring preloaded to 60 lbs., the auxiliary spring **40** is preloaded to a much lower force such as 10 lbs. Of course, this smaller preloading is employed because most of the preload of the injection valve member is provided by the fuel pressure in the spring chamber.

In one type engine in which the injection apparatus of this invention is useful, the fuel is delivered to the injection pump at a constant pressure regardless of operating conditions. In another engine apparatus shown in simplified form in FIG. **3,** in which the injection apparatus is especially useful, the supply fuel pressure is not constant but instead is purposely varied to permit greater control over engine operation. The engine apparatus is shown as including a fuel tank **60,** and a pump **62** that pumps fuel from the tank along the conduit or pipe **12** to the injection apparatus **10.** The injection apparatus **10** injects fuel into a combustion chamber or cylinder **64** where the fuel is burned with air to drive a piston that turns a crankshaft. A pressure control **66** is also provided which controls operation of the pump **62** or a spill valve **65** to vary the pressure of fuel in the supply pipe **12** within a range such as 200 to 2,000 psi.

One reason for providing the pressure control **66** to vary the fuel supply pressure is to enable a control of the rate of injection of fuel into the cylinder. Another reason is to provide a wider range in the control of amount of fuel injected. The amount of fuel that is injected is generally regulated by varying the stroke of the actuator **26** of the injection pump. However, there is only a limited range in which close control can be maintained over the amount of fuel injected in each cycle. This range is generally termed the turndown ratio, which is the ratio between the maximum amount of fuel that is injected when the actuator **26** provides a maximum stroke and the minimum amount of fuel that can be injected in a manner that enables moderately close control of the amount. For a given injection apparatus, the range of fuel volume that can be controllably injected can be extended by varying the pressure of fuel supplied to the injection apparatus. Thus, if the fuel pressure in the line **12** can be maintained at 200 psi for operation under idling to moderately high loads, and increased to 2,000 psi for operation at moderate to very high loads, then the amount of fuel injected can be more accurately controlled than if only a single pressure such as 1,000 psi were employed for all operating conditions. Of course, engines of this type can be constructed to operate at any of a variety of fuel pressure ranges such as 50 psi to 500 psi or within a narrower range such as 100 psi to 200 psi.

In the engine system of FIG. **3** wherein the fuel supply pressure is varied, it is desirable to vary the preloading of the needle injection valve in accordance with the fuel pressure. For example, the preloading might be increased by ten times when the fuel supply pressure were raised by ten times. A variation in preloading can be accomplished in the case of a conventional needle valve that uses only a coil spring, by tightening the spring or loosening it prior to running the engine at high or low fuel supply pressures. Of course, this requires auxiliary devices for varying the spring preloading. In the needle valve illustrated in FIG. **1,** the preloading depends primarily upon fuel pressure, and therefore it automatically changes as the fuel pressure changes, without the need for separately turning a screw or the like. Furthermore, the increased preloading of the valve member **34** is maintained only for the limited time when the fuel supply pressure is increased. Accordingly, the high preloading is maintained for a minimum period of time and wear on the valve seat **50** is minimized. It should be noted that where high fuel supply pressures are utilized, the high force of the needle valve member **34** on the valve seat **50** can lead to rapid wear of the valve seat, so that minimizing the period of such high preloading can help to reduce maintenance and downtime.

Thus, the invention provides an injection valve which utilizes primarily fuel pressure in a fluid-tight chamber to supply spring forces that keep the needle valve closed except during the forward stroke of the injection pump. A passageway is provided for carrying fuel from the pressurized fuel supply line to the spring chamber to fill it when the engine is started, a check valve being provided along the passageway to prevent loss of fuel from the chamber during valve opening. An auxiliary spring is provided in the spring chamber to aid in keeping the valve member closed, particularly after it has lifted and there is approximately the same area exposed to fuel pressure at opposite ends of the valve member. If the auxiliary spring were preloaded to a level just high enough to prevent the valve from opening during most of each cycle prior to the spring chamber filling with fuel, then it would be possible to eliminate the passageway **44** and check valve **46.** In this case the valve would rely upon fuel leakage past the valve member to fill up the spring chamber with fuel, and excess fuel might be injected until the chamber were filled. It is

possible to fill the spring chamber with another fluid other than the fuel, such as lubricating oil, if the mixing of fuel and such oil is permissible or if a diaphragm is provided to prevent a constant leakage of fuel or oil past the injection valve member.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art and, consequently, it is intended that the claims be interpreted to cover such modifications and equivalents.

What is claimed is:

1. In an internal combustion engine which includes a pressurized fuel supply conduit, an injection nozzle region, an injection pump coupled to the conduit and nozzle region to provide fuel pulses at the nozzle region, and an injection valve member for sliding within a valve housing in a direction to open the nozzle region to the outflow of fuel therefrom when a predetermined high pressure is exceeded at the nozzle region, the improvement comprising:

means defining a fluid chamber which is coupled to said valve member to supply spring forces to said valve member that resist sliding of said valve member in a direction to open said nozzle region, said fluid chamber substantially sealed against the outflow of fluid therefrom so that rapid movement of said valve member in a direction to open the nozzle region compresses fluid in said chamber; and

said fluid chamber being coupled to said nozzle region by clearance between the valve member and the housing portion in which it slides, so that fuel can leak from said nozzle region to said fluid chamber to maintain a fuel pressure in said chamber approximately equal to the average pressure at said nozzle region.

2. The improvement described in claim **1** including:

means defining a passage which couples said pressurized fuel supply conduit to said fluid chamber; and

check valve means positioned along said passage to permit the flow of fuel only in a direction from said conduit to said chamber, whereby to fill said chamber when said engine is prepared for starting.

3. The improvement described in claim **1** including:

an auxiliary spring located in said fluid chamber and preloaded to urge said valve member to close said nozzle region.

4. In an internal combustion engine which includes a fuel supply conduit for carrying fuel under a pressure of at least several atmospheres, a check valve connecting the fuel supply conduit to an injection pump, and a channel for carrying fuel from the injection pump to the nozzle region of an injection valve, the injection valve having a spring chamber that can supply forces which urge a valve member to close the nozzle but the valve member being moveable to open the nozzle to permit outflow of fuel when there is a predetermined high fuel pressure at the nozzle region, the improvement comprising:

check valve means coupling said spring chamber to said pressurized fuel supply conduit for permitting the flow of fuel from said fuel supply conduit to said spring chamber but not in the opposite direction; and

said spring chamber being substantially sealed against the outflow of fuel therefrom.

5. The improvement described in claim **4** including:

a coil spring disposed in said spring chamber to urge said valve member to close said nozzle, said coil spring preloaded to a force less than one-half the total closing force normally required to prevent nozzle opening.

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