FUEL INJECTOR-IGNITOR SYSTEM FOR INTERNAL COMBUSTION ENGINES

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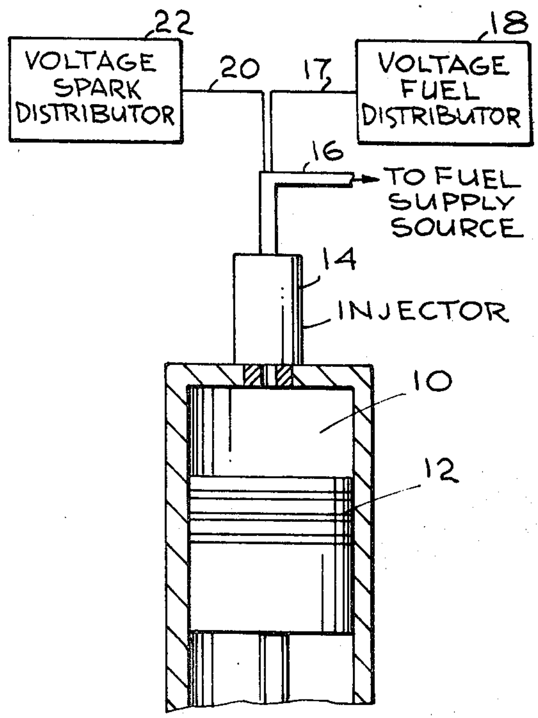
Fig. 1



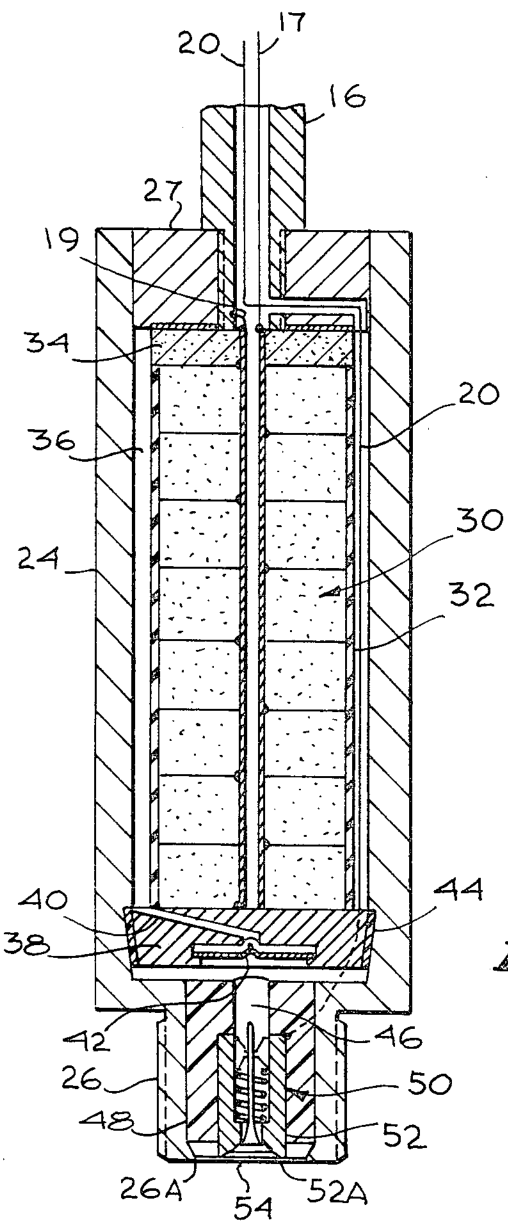


Fig. 2

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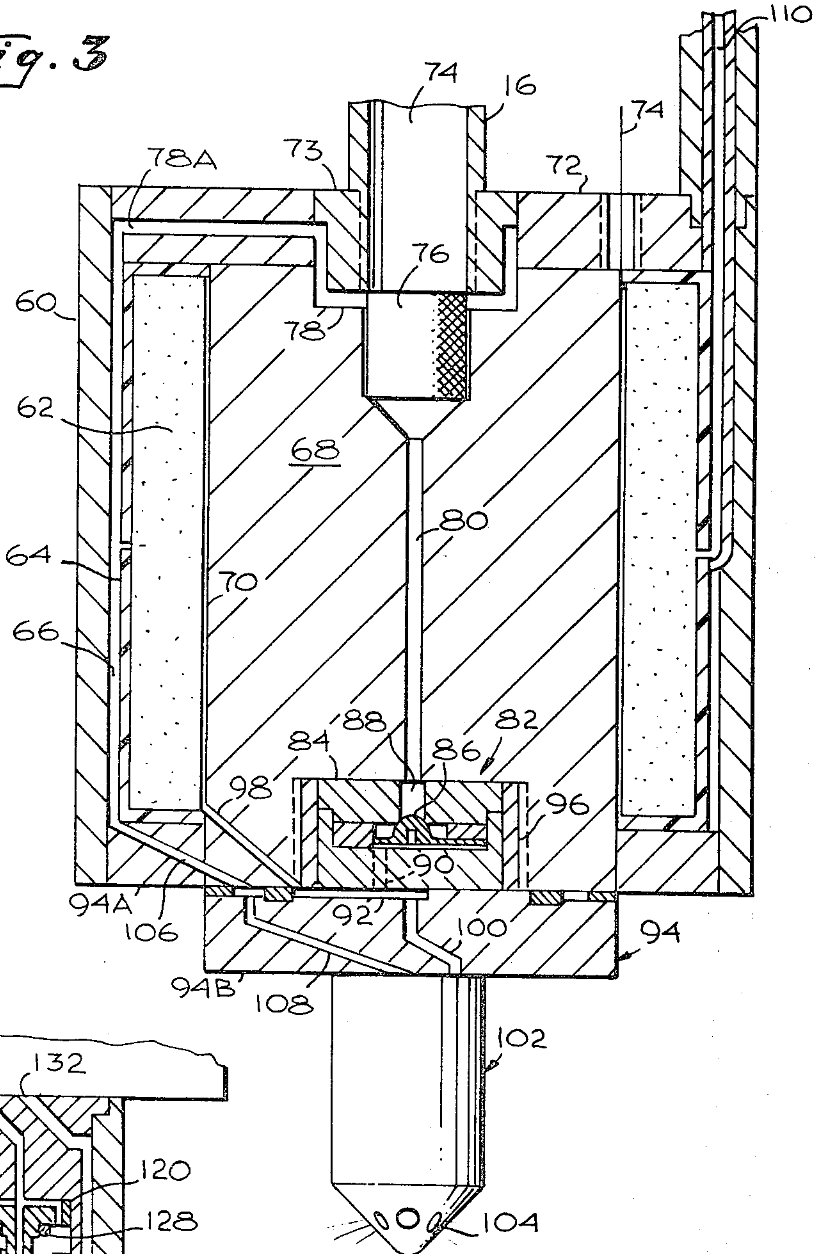
FUEL INJECTOR-IGNITOR SYSTEM FOR INTERNAL COMBUSTION ENGINES

Fig. 3



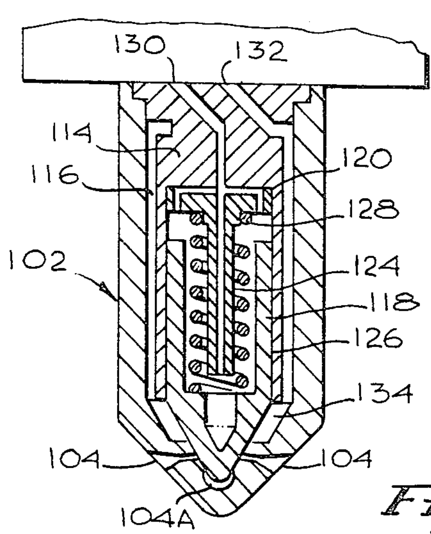


Fig. 4

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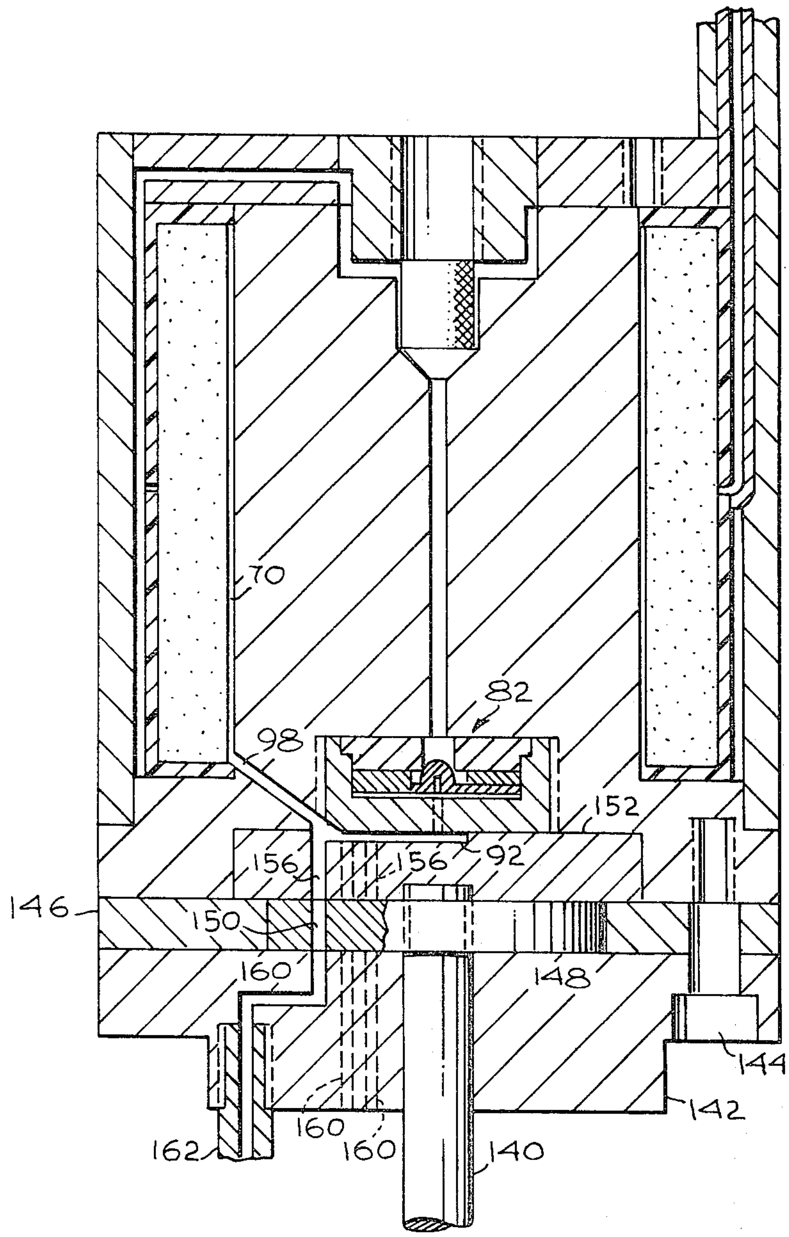

Fig. 5

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FUEL INJECTOR-IGNITOR SYSTEM FOR INTERNAL COMBUSTION ENGINES

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11 Claims. (Cl. 123—32)

ABSTRACT OF THE DISCLOSURE

A pump made of piezoelectric material is provided suitable for use as a fuel injector and which has structural provisions to additionally function as a spark plug, if required.

This is a division of application Ser. No. 484,404, filed Sept. 1, 1965, by Glendon M. Benson, for "Fuel Injector-Ignitor System for Internal Combustion Engines."

This invention relates to fuel injection and ignition systems for internal combustion engines, and more particularly to improvements therein.

It is well known that when an internal combustion engine is provided with a fuel injection system rather than the standard carburetor, its performance and economy are improved considerably, while potential smog-producing emissions are reduced drastically. One of the factors which has prevented the large-scale use of fuel injectors on engines is the cost, not only of the basic apparatus but also of the subsequent maintenance. The fuel injectors are usually complicated and require precision machining and tuning.

An object of this invention is the provision of a fuel injection system which is simple to construct and requires minimum maintenance.

Another object of this invention is the provision of a relatively inexpensive fuel injection system.

Still another object of this invention is the provision of a fuel injection system which can also include fuel ignition.

Yet another object of this invention is the provision of a rugged and substantially maintenance-free fuel injector.

Still another object of this invention is the provision of a fuel injection system that has an infinitely variable fuel displacement per stroke, infinitely variable timing, rate of injection, and injection pressure which are varied independently and are precisely controlled by simple electrical power supplies.

Yet another object of this invention is the provision of a fuel injection system that has a significantly greater range of injector displacement per stroke that can be precisely and rapidly controlled over the complete range of engine operation than can a mechanically driven system.

Still another object of this invention is the provision of a fuel injection system that has a multiple injection capability in that a variable number of fuel injections per engine cycle can be precisely and continuously controlled to achieve multi-fuel capability for a wide variety of engines.

Yet another object of this invention is that it provides the same desirable injector-pump characteristics as that produced in the conventional helically-grooved plunger ported cylinder fuel injection pump.

These and other objects of the invention may be achieved by using a piezoelectric ceramic material as a solid state active pumping element which can convert electrical energy directly into fluid pressure energy controllably, precisely, and efficiently. Effectively the injector comprises a piezoelectric pump which is extremely simple

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to control over extremely wide ranges and which includes structure such that it may be also used to provide a spark necessary to ignite the injected fuel. The invention provides for a fluid reservoir into which fluid is brought through a unilateral check valve and from which fluid is ejected through an exit valve which is preset to the conditions at which it is desired to eject fluid. The piezoelectric material is operated to pressurize the fluid in the fluid reservoir, to control the volume of fluid displaced, and to replace any fluid which is ejected through the exit valve.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIGURE 1 is a schematic view showing an embodiment of this invention in position over the cylinder of an internal combustion engine;

FIGURE 2 is a cross-sectional view of a fuel injector which is an embodiment of this invention;

FIGURE 3 is a cross-sectional view of another arrangement for a fuel injector, which is an embodiment of this invention;

FIGURE 4 shows a cross-section of an ejector valve, which is used in FIGURE 3; and

FIGURE 5 is a cross-sectional view of a fuel injector modified to operate as a distributor pump in accordance with this invention.

Referring now to FIGURE 1, as represented schematically, the combustion chamber **10** of an internal combustion engine has a reciprocally operated piston **12**. At the top of the combustion chamber is placed an embodiment of this invention comprising an injector **14** which injects fuel into the combustion chamber **10**, The injector **14** is coupled by means of tubing **16** to a fuel supply source, not shown. The injector, in accordance with this invention, is a piezoelectric device which is preferably made of piezoelectric ceramic material, and which requires an electric voltage pulse for its operation. Accordingly, an electrical lead **17** will extend from the injector **14** to a fuel voltage distributor **18** which is substantially identical to a spark voltage distributor in the usual internal combustion engine.

While the injector in accordance with this invention may be employed primarily as an injector for engines such as diesel engines, it may also be employed as an injector for engines using spark plugs. The device itself has a modification on the tip whereby it may also be used as a spark plug. This comprises providing spaced opposite edges for ejector valve and housing walls. This will be described in more detail subsequently. In those instances where use as a spark plug as well as a fuel injector is desired, an additional lead **20** is provided which connects the spark voltage distributor **22** of the engine to the fuel injector.

Referring now to FIGURE 2, there may be seen a cross-sectional view of an embodiment of this invention. This comprises a cylindrical housing **24** having one end **26** narrowing down to a neck portion which is threaded to engage the usual injector or spark plug opening in the top of a combustion chamber. At the other end of the cylindrical housing an end cap **27** is inserted, after the components within the housing have been assembled.

The interior of the housing essentially comprises a large cylindrical opening extending the length of the larger portion of the housing and then narrowing down to a small cylindrical opening within the narrowed down portion of the housing. Within the large cylindrical portion of the housing there is found a stack of piezoelectric discs **30** which are piled one on top of the other, and are axially aligned. The stack is arranged so that alternate abutting faces of the disc constitute plated high voltage electrodes and then plated ground electrodes. The centers of the discs **30** may be hollow to accommodate an electrical lead. The lead **17** which is connected to the fuel voltage distributor may be connected to the alternate high voltage electrodes through the center opening. A lead **19** connects to the remaining ground electrodes and grounds them to the housing walls. The housing is connected to ground through the conducting walls of the engine with which it is used.

The piezoelectric discs are polarized so that in the presence of a voltage applied between their upper and lower surfaces, they elongate axially. The fuel line **16** threadably engages the end cap **27**. The fuel line abuts a porous metal filter **34** which is inserted between the end of the stack of piezoelectric discs and the end cap. A rubber sleeve **32** may be inserted over the stack of discs. The outer diameter of the sleeve **32** and the inner diameter of the housing **24** is such that there is an annular space **36** to which the fuel can flow through the porous metal filter **34**. The porous metal filter is attached to the end cap and the sleeve which holds the discs to the porous metal filter.

There is attached to the lower end of the piezoelectric cylinder stack a movable plunger **38** that moves axially whenever the piezoelectric stack elongates and responds to an applied electrical voltage signal. The plunger has a passageway **40** therethrough that connects the annular space **36** to an inlet check valve **42**. The plunger **38** is supported from the sides of the housing **34** by an elastic ring **44** which is preferably made of polyurethane and not only serves to provide an elastic support for the plunger **38**, but also seals it from the fuel reservoir **46** which is estabilshed within the narrowed down portion of the housing. A cylindrical insulator **48** is inserted in the narrowed down portion of the housing and serves to support a poppet valve structure **50**. This includes the poppet valve housing **52**, the valve stem **54** which is spring biased to be closed. The end of the valve stem is given a flare so that when it is depressed or when the valve opens, it serves as the atomizing orifice. The outer tips **52A** of the poppet valve housing are sharpened and suitably finished so that they oppose the tips **26A** of the housing and can provide a spark therebetween when a suitable voltage is applied thereacross. The lead **20** extends through the pumping space **36** and down to the poppet valve housing **52** to provide the required voltage to produce a spark between the grounded tips **26A** and the tips **52A**. Furthermore, the flare of the valve **54** is made such that it serves to distribute the fuel which is able to pass therethrough.

In the operation of the apparatus fuel, which may be pressurized by the usual fuel pump of the engine, passes through the dense microporous filter **34** (which may be fabricated from sintered metal or ceramic, for example) into the annular chamber formed between the piezoelectric stack **30** and the outer housing **24**. A voltage applied to the piezoelectric stack produces an axial elongation which pushes downward the plunger **38**. This action causes additional fuel to be drawn into the annular chamber. Removing the applied voltage causes axial contraction of the piezoelectric stack and forces fluid through the inlet check valve **42** into the fuel reservoir **46**. When the fuel reservoir is filled, the inlet valve **42** seats thus blocking the entrance of more fuel. Applying voltage to the piezoelectric stack again now forces the plunger **38** downwardly thereby displacing and pressurizing the fuel in the pump reservoir **46**. This fuel pressure is sufficient to open the injector poppet valve **50** and fuel flow through the injector nozzle occurs, producing an atomized spray. Removing the applied voltage from the piezoelectric stack pulls the plunger upward causing a sufficient pressure drop in the fuel to seat the poppet valve and unseat the inlet valve, whereby more fuel may enter.

This plunger stroking action is analogous to a large bore, small stroke conventional plunger fuel injection pump having a precisely controlled variable stroke and a fast pressure release action. The fuel injected by the piezoelectric injector is precisely metered, pressurized, and injected at a controlled flow rate and timing with all functions being variable over extremely large ranges. The application of several voltage pulses per engine cycle produces several separate fuel injections which can be used to better control fuel mixing, ignition combustion, and rate of combustion in spark ignition, compression ignition, and stratified charge engines. In addition, the piezoelectric fuel injector can produce a finer, more thoroughly atomized spray by applying a voltage pulse that has an initial rise time equal to the resonant frequency of the piezoelectric stack. This frequency produces ultrasonic vibrations in the fuel injected stream which aids in cleaning the nozzle orifice and in atomizing the fuel. The quantity of fuel injected is regulated by the peak voltage of the pulse and not by the small amplitude ultrasonic vibrations.

A separate voltage pulse is transmitted through the high voltage lead **20** which connects to the high voltage electrode of the spark gap established between the edge **26A** of the housing and the edge **52A** of the valve. This voltage is sufficient to generate a spark discharge across the spark gap igniting the fuel mixture located in the neighborhood of the spark gap. The electrical insulator **48** in the injector neck prevents voltage arc-over during sparking and in addition, acts as a thermal insulator for the fuel injector and pump chamber.

The seal surrounding the pump plunger is an injection molded polyurethane seal having a slightly inwardly tapered seat which is loaded in shear upon the downward movement of the pump plunger. The slightly tapered seat enhances the degree of sealing by providing a small amount of compressive loading. The combination of complete bonding of the seat to the plunger and housing surface and the lack of seal extrusion caused by the polyurethane characteristics and the geometry of the seal together with the small degree of shear strain experienced in the seal design provide a positive leakproof seal, having an exceptionally long maintenance-free service life.

FIGURE 3 is a cross-sectional view of another embodiment of a fuel injector pump in accordance with this invention. A cylindrical housing **60** has placed therein a cylinder **62** made of piezoelectric material. This cylinder extends almost the entire length of the housing. Its outer surface is enclosed in a sleeve **64**, which serves as a precompression sleeve and as an electrical insulator, such as fiberglass. Between the outer surface of this sleeve and the inner surface of the opening of the cavity an outer annular space **66** is provided. The center of the housing is filled with a core **68** which reduces the fluid volume in the annular space. There is an inner annular space **70** between the periphery of the core and the inner surface of the piezoelectric cylinder. This space serves as the pump cavity.

A top cap **72** closes the top end of the housing. It has a central portion **73** with a threaded input opening **74**, to which the fuel line **16** is coupled. The opening **74** couples the fuel line to a passage formed in the central core **68** wherein a filter **76** is placed. The fuel is urged through this filter into two passageways respectively **78**, **80**. The passageway **78** is formed between the top cap **74** and the central core **68** for a portion of the distance to the annular space **66**. Thereafter it passes through a passage **78A** in the top cap which communicates with this annular space.

In the base of the core **68**, there is provided the check valve structure **82**. This includes a housing **84** holding therein the check valve **86** and having formed therein a passageway **88** which connects with the passageway **80**. Another passageway **90**, represented by dotted lines, communicates from the check valve to the passageway **92**. This passageway is formed between the check valve housing **84** and a bottom cap member **94**. The bottom cap member 94 has two parts. One part 94A closes the outer annular cavity 66 and abuts the core 68. The other part 94B abuts the bottom of the core 68 and has provision for fuel passageways therein, as will be described herein. The bottom cap portion 94B also has walls 96 which extend into the core and define a cavity within which the check valve housing 82 is fitted.

The passage 92 in the cap portion 94B communicates with a passage 98 which extends through the core to the annular pump cavity 70. The passage 92 at its other end communicates with a passage 100 in the member 94, which as will be shown in FIGURE 4, communicates with the reservoir portion of the ejector valve 102. The ejector valve is attached to the member 94 and has a plurality of openings 104 in the nose of the bullet-shaped cover thereof.

A passageway 106 communicates between the annular cavity 66 on the outer periphery of the piezoelectric cylinder and a passageway 108. The passageway 108 extends, as will later be seen from FIGURE 4, to the center of the ejector valve. These passageways vent the valve 102 to fuel feed pressure. The piezoelectric cylinder constituting the active element of the pump shown in FIGURE 3 is polarized so that a potential applied between its inner and outer cylindrical surfaces cause it to expand or contract radially, depending upon the polarity of that potential. The outer surface, constituting the high voltage electrode, is connected to a lead 110 which is connected in the manner of the lead 17 shown in FIGURE 2, to the pump voltage distributor. The inner surface of the piezoelectric cylinder, which is usually coated with a metal film, is connected to ground by a lead 74. The piezoelectric cylinder may also be a circumferentially poled ceramic having segmented electrodes.

Reference is now made to FIGURE 4 which is a cross-sectional view of the ejector valve 102. This includes a tubular housing 112 having the lower end thereof terminating in a point. There are radial openings 104 spaced near the end of the housing 106. The interior of the housing is hollow. It includes a valve holding member 114 which fits within the housing and provides an annular passage space 116 between its outer periphery and the inner periphery of the housing. The member 114, holds at the lower end thereof a valve mechanism 118. This valve mechanism includes a base 120 with a downwardly extending stem 124. A bullet-shaped member 126 is slidably supported and is biased downwardly by a spring 128 which is mounted over the extension 124. The bullet-shaped member 126 under the urging of the spring bias normally closes off the openings 104 at the bottom ends of the housing 102.

The passageway 108, shown in the member 94 in FIGURE 3, communicates with a passageway 130 in the member 114, and extends downwardly through the base 120 and stem 124 into the region between the tubular springs and the bullet-shaped member 126. The passageway 100, shown in FIGURE 3, communicates with a passageway 132, which extends to the annular elongated passageway 116. It will be seen in FIGURE 4 that the passageway 116 extends to an enlarged passageway 134 which is adjacent the end of the bullet-shaped housing 126. Passageways 92, 100, 132, 116 and 134 constitute the fuel reservoir of this structure having an input check valve 86 and an output ejector valve 118.

The operation of the ejector pump structure shown in FIGURE 3 is as follows. Fuel under feed pump pressure passes from the fuel line through the filter 76 through the respective passageways into the annular cavity 66 and down inside the center of the bullet-shaped member 126 thereby commonly pressurizing these to fuel feed pressure. The fuel will also pass through the passageway 80 and pass the check valve 86 down to the cavity 134 adjacent the end of the bullet-shaped member 126. As the piezoelectric cylinder expands, it draws in fuel past the check valve. When the pump chamber is full the equalization of pressure in the pump chamber and fuel feed line causes seating of the inlet check valve 86. As the piezoelectric cylinder contracts, it builds up the pressure of the fuel in the pump chamber 70 which is then transmitted to the cavity 134 and acts against the end of the bullet-shaped member until it forces it upward against the pressure of the spring 128. At that time, the fuel is ejected from the plurality of openings 104 into the cylinder of the internal combustion engine. The fuel is distributed radially within the combustion chamber of the engine thus assuring complete distribution within that chamber, rather than localized distribution.

With the ejection of the fuel from the cavities 134, the back pressure of the bullet-shaped member is reduced whereby it is enabled, as a result of the spring, to promptly seal off the openings 104. In order to prevent bouncing of the valve seat as the valve closes, chamber 104A acts as a hydrodynamic shock absorber that rapidly arrests the valve motion without producing valve bounce. Also, since the back pressure of the fuel in the cavity 134 and in the passageways leading back to the check valve is reduced, the expansion of the piezoelectric cylinder is enabled to draw more fluid past the check valve to enable the injection pump to operate in the manner described again.

FIGURE 5 shows a cross-sectional diagram of an arrangement of a piezoelectric pump, in accordance with this invention, which is employed as a common pump and distributor for distributing fuel to a multi-cylinder engine. It will be seen from FIGURE 5 that the structure is substantially identical with the pump structure shown in FIGURE 4 as far as the piezoelectric pumping portion of the system is concerned. Accordingly, since this portion of the system operates in the same manner as has been described for FIGURE 3, the various structures will be given the same reference numerals. The difference in the structure shown in FIGURE 5 over FIGURE 3 is in the valve structure which in FIGURE 5 is the distributing portion of the pump which constitutes the lower end thereof. Effectively, this distributing portion comprises a rotatable shaft 140, which is rotably driven from the internal combustion engine. The shaft 140 is rotatably supported in an end member 142 which is attached by suitable bolts to the central core. A space 144 whereby such attachment by means of a bolt may be made may be seen on the right side of the drawing. The member 142 is spaced from the central core by a washer-like spacer 146.

The shaft 140 rotates a disc 148 therewith within the central opening of the washer 146. This disc has an opening 150 therein whose purpose will be subsequently described. The space between the washer 146 and rotating disc 148, and the bottom of the check valve structure 82 comprises a spacer member 152 which forms with the bottom of the check valve structure, the passageway 92 which communicates with the passageway 98 to the pump chamber 70. The passageways 92 and 98 also communicate with a passageway 156 which is aligned with the passageway 150 in the rotating disc 148.

The member 142 has a passageway 160 therein which is enabled to communicate with the passageway 156, when the disc 148 is rotated so that the passageway 150 extends therebetween. It will be appreciated that this can occur only for one position of the rotating disc 148. The passageway 160 is coupled by a high pressure line 162 to one of the cylinders of the engine. There are a plurality of passageways 156 and 150, shown in dotted lines, which respectively extend through the members 152 and 142, and which are aligned with one another and communicate with one another through the passageway 150, at specific angular positions of the rotating disc 148. One of these sets of passageways is provided for each cylinder into which fuel is to be injected. It will be appreciated that all of the passageways 156 communicate with the passageway 92. However, the passageway 150, as the shaft **140** is rotated, serves to permit fuel to pass from the fluid reservoir into the fuel line only for the position at which the passageway **150** will permit communication. The shaft and rotating disc are mechanically driven by the engine through either the distributor quill shaft or cam shaft, for example. Suitable port overlap may be provided by the opening **150** sufficient to accommodate any advance or retard in fuel injection timing relative to crank angle position. The piezoelectric cylinder both pumps and controls the quantity, rate and pressure of the fuel injected. The rotating disc connects this pumping action to the appropriate cylinder through conventional high pressure, injection piping of suitable lengths and cross-section.

There has been described accordingly herein a novel, useful and unique arrangement for fuel injection using piezoelectric pumps.

What is claimed is:

1. A piezoelectric fluid pump comprising walls defining a fluid reservoir, check valve means at one end of said reservoir for enabling one way fluid flow into said reservoir, exit valve means at the other end of said reservoir for enabling fluid exit therefrom, and piezoelectric pump means for pressuring the fluid in said reservoir and for replacing the fluid in said reservoir ejected through said exit valve means, said piezoelectric pump means comprising:

an elongated piezoelectric body, means for applying potential to said body for causing reciprocal axial motion, walls defining an elongated cavity which is longer than said piezoelectric body and within which said piezolectric body is placed, said cavity being dimensioned to provide an annular space between said piezoelectric body and said walls, a cap closing one end of said housing, means for attaching one end of said elongated piezoelectric body to said cap, passage means in said cap extending to said annular space for permitting the introduction of fluid into said annular space, a plunger connected to the other end of said elongated piezoelectric cylinder and being reciprocally movable therewith, said plunger being dimensioned to extend to said cavity walls and to be slidably engageable therewith, and a passageway through said plunger from said annular space, said check valve means being in said passageway.

2. A piezoelectric fluid pump comprising walls defining a fluid reservoir, check valve means at one end of said reservoir for enabling one way fluid flow into said reservoir, exit valve means at the other end of said reservoir for enabling fluid exit therefrom, and piezoelectric pump means for pressuring the fluid in said reservoir and for replacing the fluid in said reservoir ejected through said exit valve means, said piezoelectric pump means comprising:

a hollow cylinder of piezoelectric material, means for applying a potential to said cylinder to cause it to reciprocate radially disposed coaxially within said hollow cylinder, said core being dimensioned to provide an annular space between it and said piezoelectric cylinder wherein said piezoelectric cylinder may extend, said check valve being disposed within said core, means for closing off the ends of said annular space, and a passageway through said core extending from said annular space to said reservoir.

3. A piezoelectric fluid pump comprising walls defining a fluid reservoir, check valve means at one end of said reservoir for enabling one way fluid flow into said reservoir, exit valve means at the other end of said reservoir for enabling fluid exit therefrom, and piezoelectric pump means for pressuring the fluid in said reservoir and for replacing the fluid in said reservoir ejected through said exit valve means, said exit valve means comprising:

a disc, means for rotatably driving said disc, said disc having a single passageway extending axially therethrough, said reservoir having a plurality of separate exit ports positioned to be successively aligned with said single passageway as said disc is rotatably driven, and means for supporting said disc means adjacent said reservoir exit ports.

4. A piezoelectric fluid injecting pump comprising walls defining a fluid reservoir, check valve means at one end of said reservoir for enabling one way fluid flow into said reservoir, exit valve means at the other end of said reservoir for enabling fluid exit therefrom when the pressure of fluid in said reservoir exceeds a predetermined level, and piezoelectric pump means for increasing the pressure of the fluid in said reservoir and for replacing the fluid ejected through said exit valve means said piezoelectric pump means comprising a stack of piezoelectric discs, means for applying potential to said stack of piezoelectric discs to cause axial motion thereof, a cap carried at one end of said stack of discs, said cap having a passageway therethrough for communicating with said fluid reservoir, and means positioning said check valve means in said passageway.

5. A piezoelectric fuel injector comprising an elongated piezoelectric body, means for applying potential to said body to cause it to elongate and to contract in response thereto, a housing having walls defining a central opening therein within which said piezoelectric body is placed, said central opening being sized to be longer than said elongated piezoelectric body and to provide a space around said piezoelectric body, means attaching one end of said piezoelectric body to the walls at one end of said central opening, plunger means attached to the other end of said piezoelectric body, said plunger means being dimensioned to extend to the walls defining said central opening to thereby divide said central opening into two cavities, said piezoelectric body being in one of said two cavities, a passage extending through said plunger communicating between said two cavities, check valve means positioned to block said passage for permitting unilateral fluid flow therethrough from said first to said second cavity, exit valve means positioned at the terminal end of said second cavity for permitting the ejection of fluid therefrom when said fluid exceeds a predetermined pressure, and means for introducing fluid into said first cavity whereby it is pumped into said second cavity and then ejected out through said exit valve means.

6. A piezoelectric fuel injector as recited in claim **5** wherein said exit valve means comprises a poppet valve having a valve stem which is flanged to provide a wide fuel distribution.

7. A piezoelectric fluid injector comprising walls defining a cylindrical cavity open at both ends, plunger means positioned near one end of said cylindrical cavity movably engaging the walls thereof for dividing said cavity into a large and small cavity, said plunger means having a passageway therethrough for affording communication between said large and small cavities, cap means closing the other end of said cylindrical cavity, cylindrical piezoelectric means having one end attached to said cap means and the other end attached to said plunger means, means for applying a potential to said piezoelectric means for causing reciprocal axial motion thereof, said piezoelectric means being dimensioned to leave an annular space between its periphery and the walls defining said cylindrical cavity, a passageway extending through said cap to said annular space, check valve means in said small cavity for permitting fluid to flow unidirectionally through said passageway in said plunger means into said small cavity, poppet valve means, means insulatingly supporting said poppet valve means at the open end of said small cavity for permitting fluid discharge from said small cavity only through said poppet valve means, and means for applying fluid to be pumped to said passageway in said cap.

8. A piezoelectric fluid injector comprising a hollow cylinder of piezoelectric material, means for applying potential to said piezoelectric material to cause it to reciprocate radially, a cylindrical core disposed coaxially within said hollow cylinder, said core being dimensioned to provide an inner annular space between it and said piezoelectric cylinder within which said piezoelectric cylinder may extend, means closing off the top and bottom of said inner annular space, walls defiing a fluid reservoir positioned adjacent one end of said core, an inlet check valve mounted in said one end of said core adjacent said fluid reservoir, a first passageway communicating between said check valve and said reservoir, a fluid inlet passageway extending through said core to the check valve, a second passageway extending between said inner annular space and said fluid reservoir, and exit valve means supported in said walls defining a fluid reservoir for ejecting fluid when it exceeds a predetermined pressure.

9. A piezoelectric fluid injector as recited in claim **8** wherein a cylindrical housing encloses said hollow cylinder of piezoelectric material, the inside of said housing being dimensioned to provide for an outer annular space into which said piezoelectric material may move, and a second passageway communicating between said fluid inlet passageway and said outer annular passageway.

10. A piezoelectric fluid injector as recited in claim **8** wherein said exit valve means comprises a hollow bullet-shaped housing having a plurality of radially disposed openings adjacent the nose thereof, a bullet-shaped closing member, means slidably supporting said closing member between a first position wherein it closes off said radially disposed openings and a second position wherein it does not close off said radially disposed openings, spring means for biasing said closing member to its first position, said fluid reservoir extending to the nose of said bullet-shaped closing member whereby fluid under pressure can urge it to its second position, and a third passageway communicating between said outer annular opening and the inner portion of said closing member to apply fluid at atmospheric pressure thereto.

11. The combination with an internal combustion engine having a cylinder with an opening in the head thereof of a piezoelectric fuel injector mounted in said opening said piezoelectric fuel injector including walls defining a fuel reservoir, check valve means at one end of said reservoir for enabling one way fuel flow into said reservoir, exit valve means in said reservoir for ejecting fuel into said cylinder when the pressure of said fuel exceeds a predetermined value, a hollow cylinder of piezoelectric material, potential means operated responsive to said engine for applying voltage pulses to said piezoelectric cylinder to cause it to reciprocate radially synchronously with the operation of the engine, a cylindrical core disposed coaxially within said hollow cylinder, said core being dimensioned to provide an annular space between it and said piezoelectric cylinder wherein said piezoelectric cylinder may extend, said check valve being disposed within said core, means for closing off the ends of said annular space, and a passageway through said core extending from said annular space to said reservoir.

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LAURENCE M. GOODRIDGE, *Primary Examiner.*

U.S. Cl. X.R.

103—1; 123—139