United States Patent

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[54] **FUEL INJECTION SYSTEM AND APPARATUS FOR USE THEREIN**
10 Claims, 11 Drawing Figs.

[52] **U.S. Cl.** **123/139,** 123/32, 123/140
[51] **Int. Cl.** **F02d 11/06**
[50] **Field of Search** .... 123/32 (E-1), 32, 139, 139.11, 139.11 (A), 140, 140.3

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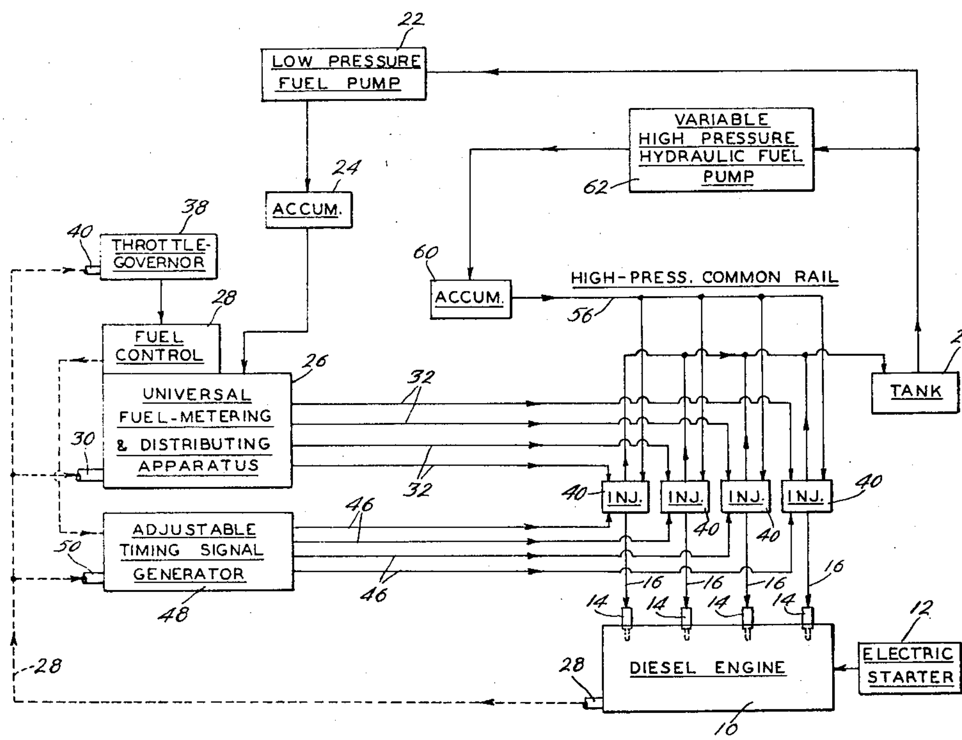
ABSTRACT: A "universal" fuel injection system adaptable for use with any of a variety of types of diesel engines, in which the timing and duration of the fuel injection intervals, as well as the quantity of fuel injected, can readily be selected or adjusted to suit the requirements of any of said engines. A separate fuel injector for each cylinder of the engine is supplied with discrete metered quantities of fuel and a piston discharges the fuel through a nozzle in response to high pressure from a common rail, upon actuation by an electrical timing signal. The timing signal is controllable, as is the source of the metered fuel, thereby to permit independent selection and adjustment of timing and fuel quantity, and variation of the common rail pressure produces an inverse variation in the duration of each injection discharge. Injection accuracy and efficiency are enhanced, and secondary injection avoided, by use of a spill-collecting accumulator connected to the fuel chamber in each injector to receive the spill at the end of the injection stroke and return the spill to the chamber before the next injection operation.



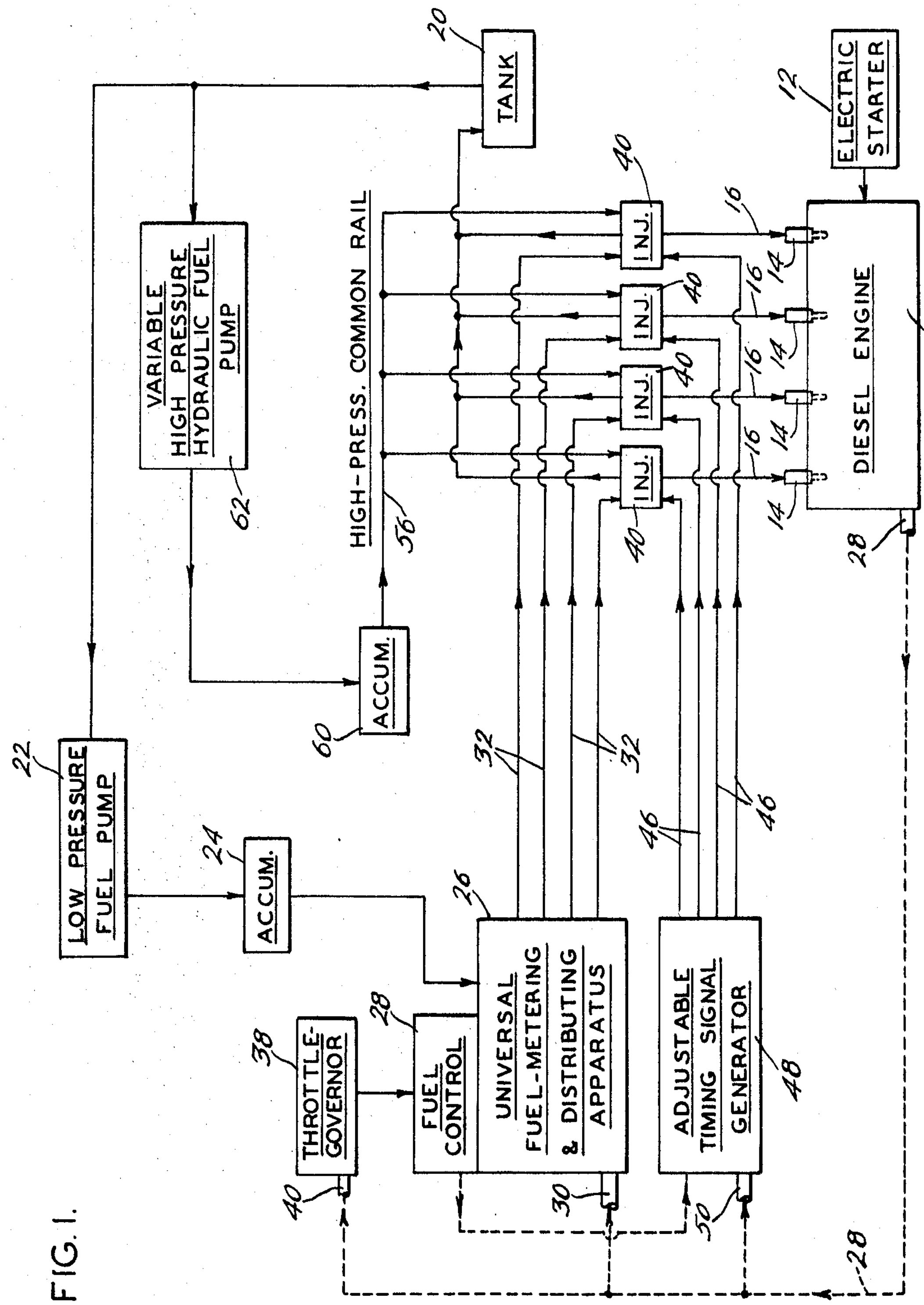


FIG. 1.

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FIG. 2.

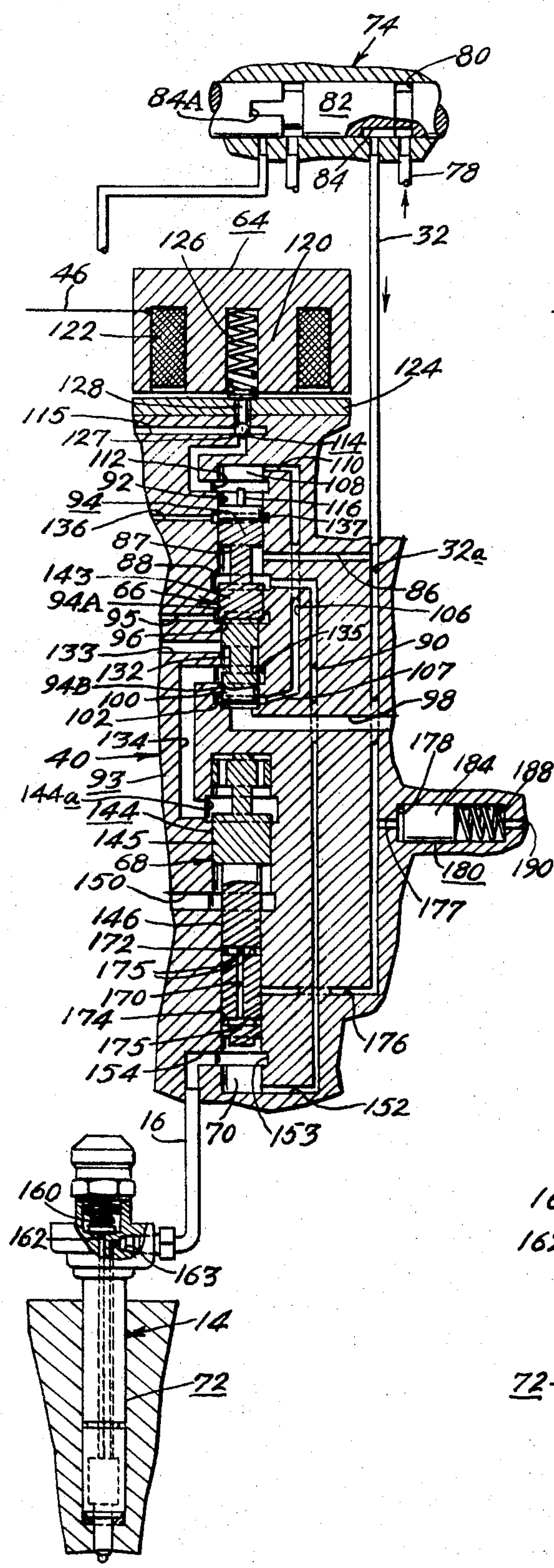

FIG. 3.

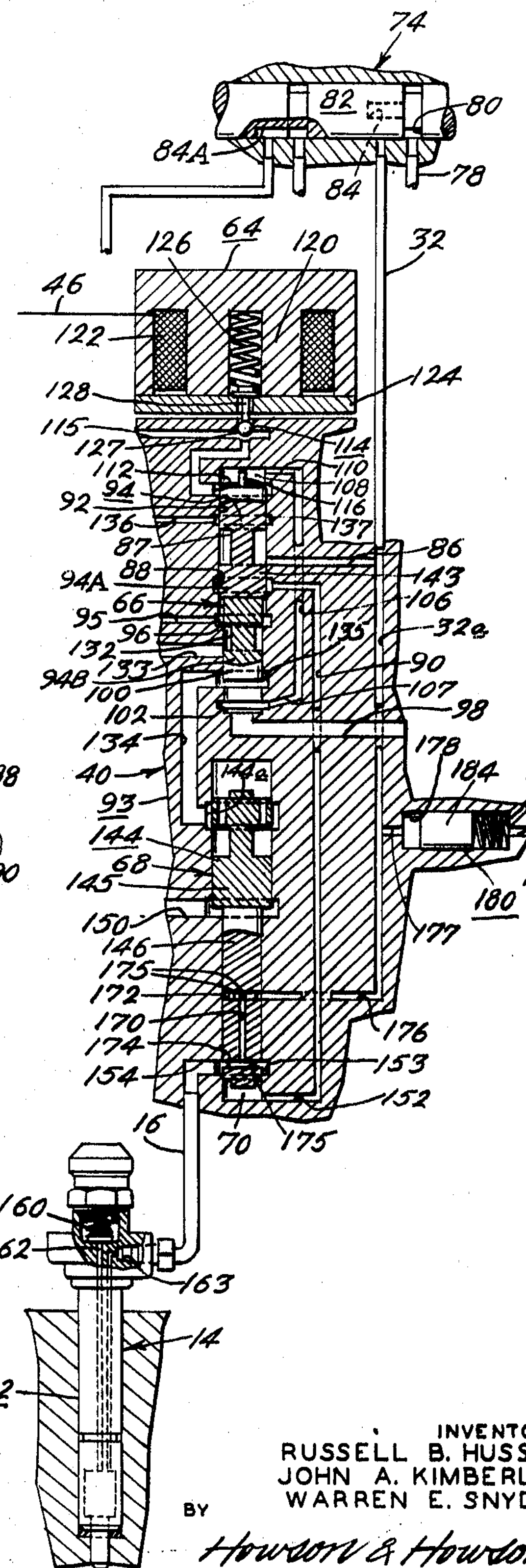

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FIG. 4.

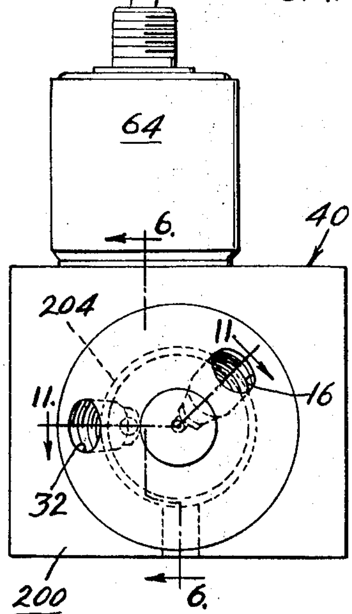

FIG. 5.

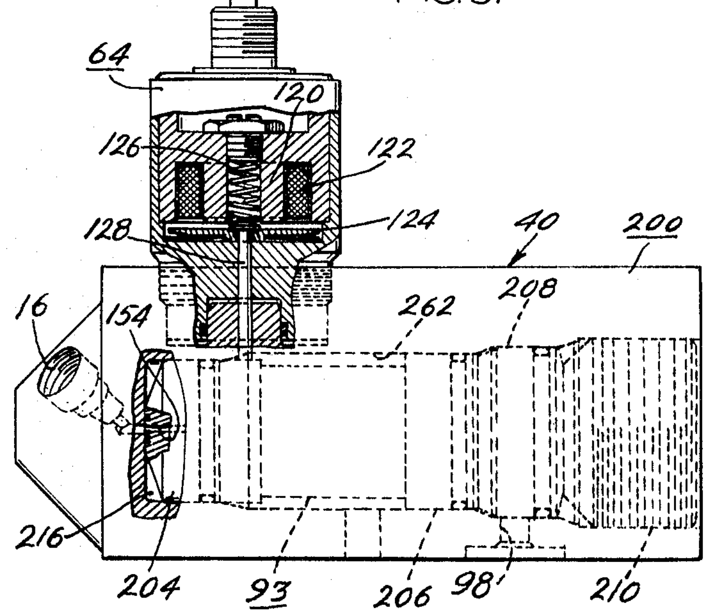

FIG. 6.

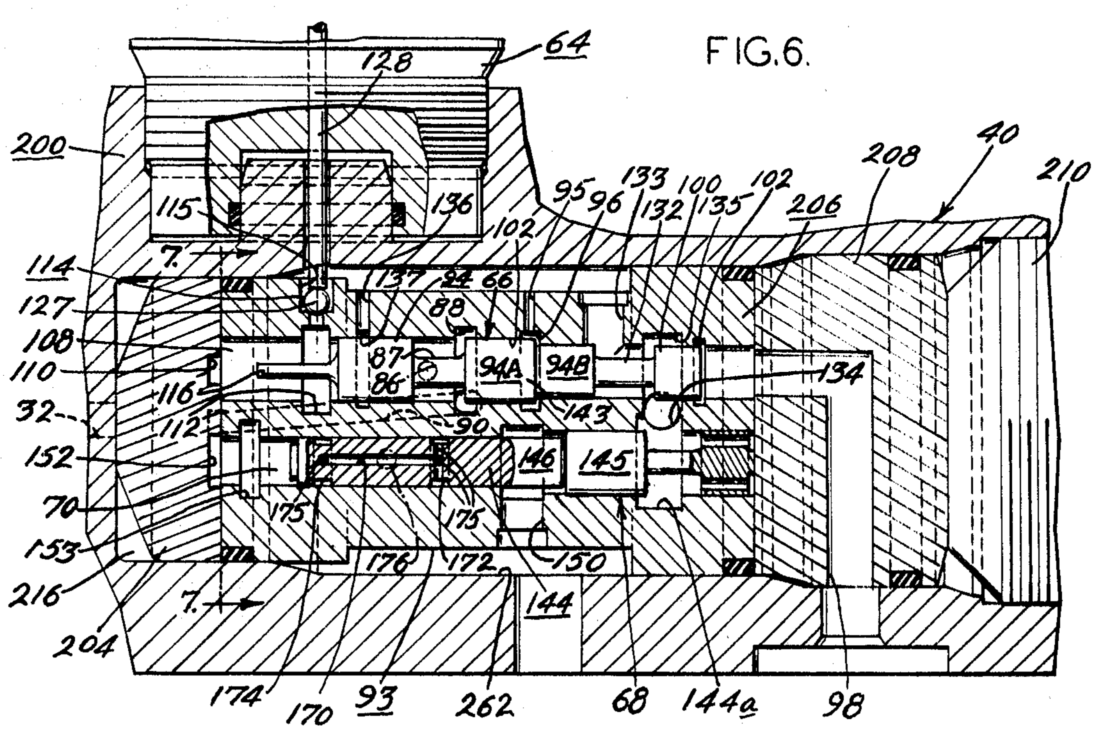

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FIG. 7.

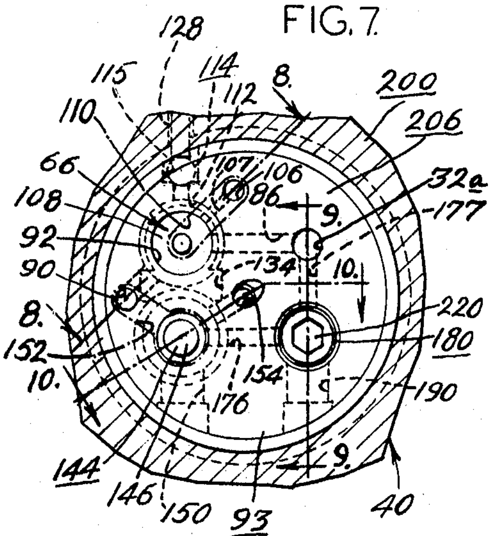


FIG. 8.

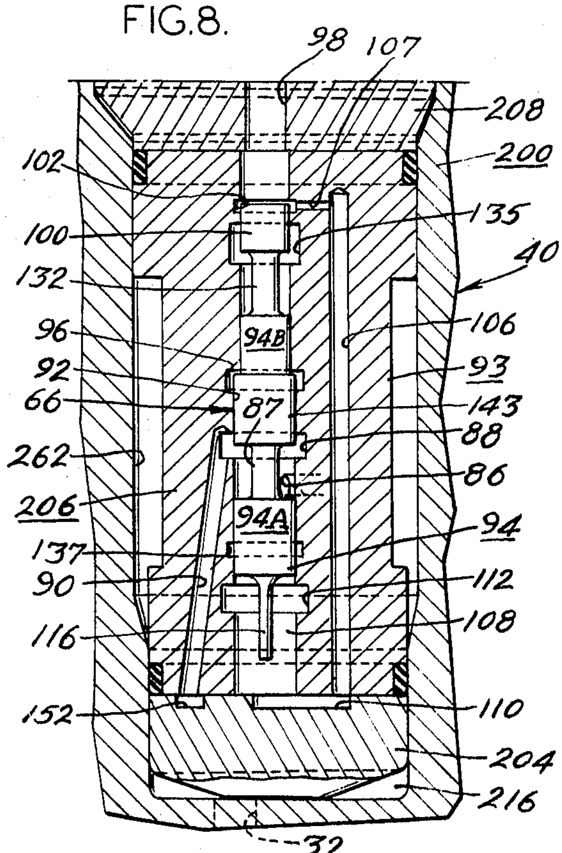


FIG. 9.

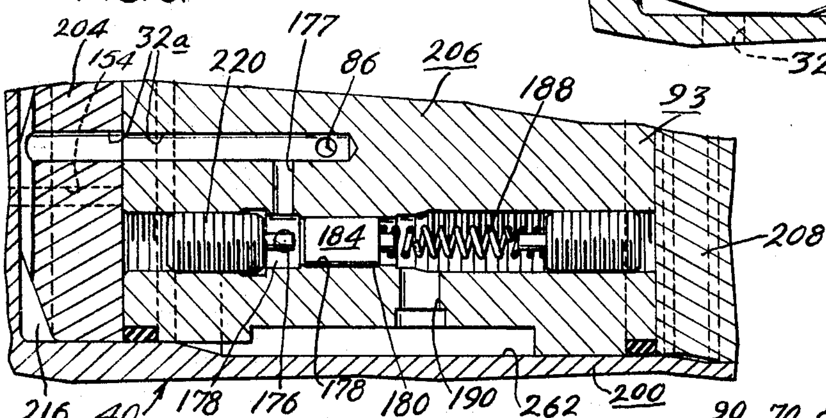


FIG. 10.

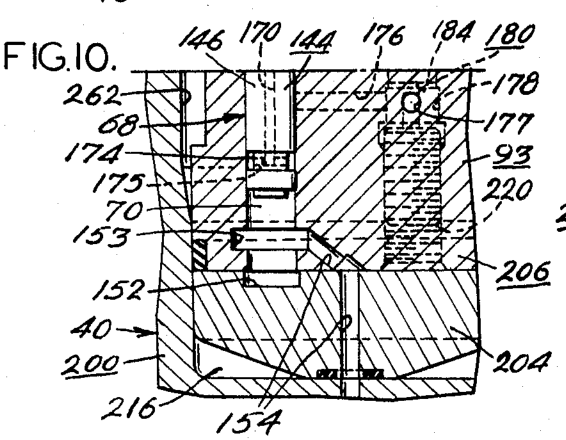
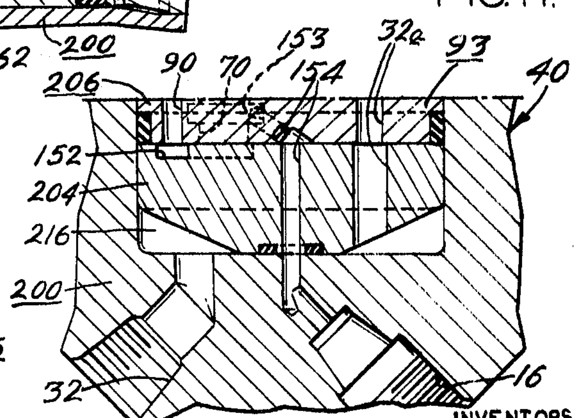


FIG. 11.



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FUEL INJECTION SYSTEM AND APPARATUS FOR USE THEREIN

BACKGROUND OF INVENTION

The invention herein described was made in the course of or under a Contract DAAE07-67-C-4023(T) with the Department of the Army.

This invention relates to fuel injection systems and to apparatus for use therein.

Diesel fuel injection systems are known in the prior art for injecting fuel into engine cylinders in proper timed relation to the phase of engine operation, and with a duration and quantity of injection appropriate for the particular engine. However, there is normally one combination of timing, fuel quantity and duration of injection which is optimum for a given engine operating condition, and the fuel injection system is normally designed to provide this particular optimum combination of operating parameters. It is also typical for these parameters to be inherently interrelated in a particular fuel injection system, so that variation of one will produce, or will require, a change in another if optimum engine operation is to be maintained. Accordingly it is usual to custom-design a fuel injection system for a particular engine operating condition, in which case it may not be optimum for a different engine operating condition and not readily modified or adjusted to produce optimum operation of different engine operating conditions. In addition, different engines may require different injection-system parts. As a result, spare parts must therefore be made and carried on hand for different engines, thus increasing the required inventory of spare parts, and tool and making servicing and training of maintenance personnel more difficult.

It is therefore an object of the invention to provide a new and useful injection system, and apparatus suitable for use therein.

Another object is to provide such a system and apparatus which is versatile in that it may be utilized with any of a large variety of substantially different engines without change of parts, or with only minor simple substitution of one or a few parts.

It is also an object to provide such a system and apparatus which will provide optimum, or near optimum, operation of any of a variety of engines with which it is to be used.

A further object is to provide such a system and apparatus which is relatively simple to manufacture, adjust and maintain, and is reliable and accurate in operation.

A further object is to provide a new and useful spill-collector arrangement for use with a fuel injector, which is especially adapted to be used with, and enhances the performance of, the above-mentioned improved fuel injection system, but which is also useful in connection with other forms of fuel injection apparatus.

SUMMARY OF THE INVENTION

These and other objects and features of the invention are realized by the provision of a fuel injection system employing a fuel injector for each of the one or more cylinders of an engine, each of which fuel injectors has a fuel chamber for receiving and momentarily storing intermittently supplied metered quantities of fuel; each metered quantity of fuel is ejected from the fuel chamber and through the injection nozzle by the stroke of an injection piston means, operated by fluid pressure from a high-pressure common rail each time the control means for the injector is actuated by a timing signal synchronized with engine operation. The quantity of fuel injected on each stroke of the piston means is determined by suitable adjustment of the fuel metering means, and proper timing is assured by appropriate selection and adjustment of the timing means producing the actuating signal, which signal is preferably electrical and actuates electromagnetic control means for each injector. The duration of each injection discharge is adjustable by variation of the high-pressure in the common rail, increase in the latter pressure producing shorter durations of injection.

In the preferred form of the invention a servovalve supplied with the common-rail high pressure is actuated in response to the timing signal to control the times at which the piston means is operated to produce injection. Hydraulic snubbing means and spill means are preferably employed to terminate the stroke of the injection piston means and to relieve back pressure in the nozzle and the discharge line leading thereto.

As a further preferred feature, a spill-collecting accumulator is connected to the fuel chamber of each injector to receive, and store under pressure, the spill produced at the end of the stroke of the piston means, and to return the spill fuel to the fuel chamber after the discharge from the injection nozzle is completed. This saves fuel, prevents cavitation effect, and enhances accuracy of the quantity of fuel injected, while at the same time preventing secondary injection. While the spill-collecting accumulator exhibits a special cooperation with the system as a whole, it is also utilizable in connection with other types of fluid injection apparatus. Preferably the spill-collecting accumulator is disconnected from the fuel chamber before each injection stroke by the action of the same servo valve which controls the application of the common-rail high pressure to the piston means.

BRIEF DESCRIPTION OF FIGURES

These and other objects and features of the invention will be more readily understood from the consideration of the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a block diagram of a preferred system in accordance with the invention;

FIGS. **2** and **3** are schematic views of a preferred system embodiment of fuel injector suitable for use in the system of the invention, showing the same fuel injector in two different points in its cycle of operation;

FIG. **4** is an end view of one convenient practical embodiment of the form of the invention shown in FIGS. **2** and **3**;

FIG. **5** is a side elevation view, with parts broken away, of the apparatus of FIG. **4**;

FIG. **6** is a sectional view taken along lines **6–6** of FIG. **4**;

FIG. **7** is a sectional view taken along lines **7–7** of FIG. **6**;

FIG. **8** is a sectional view taken along lines **8–8** of FIG. **7**;

FIGS. **9** and **10** are sectional views taken along lines **9–9** and **10–10** of FIG. **7**; and

FIG. **11** is a sectional view taken along lines **11–11** of FIG. **4**.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Referring now to the embodiment of the invention shown by way of example only in FIG. **1**, a diesel engine **10** having the usual electric starter **12** contains a plurality of engine cylinders, in this example assumed to be four in number, each cylinder being provided with a conventional fuel injection nozzle such as **14**. For the engine to operate properly, it must be supplied with successive intermittent injections of fuel through the nozzles, produced in response to corresponding successive intermittent fuel discharges through the discharge lines **16** supplying the nozzles. The operation of the engine is uniquely determined by these fuel discharges, and if the discharges occur with the proper timings, durations, fuel quantities and, to a less extent, with an appropriate pattern or waveform of injection rate during each discharge, then it will operate in an optimum fashion. The function of the remainder of the fuel injection system of FIG. **1** is to provide such optimum fuel-injection parameters for the engine, and to be capable also of providing substantially optimum operating parameters for other types of engines, including those having different numbers of cylinders, with only minor changes or substitutions in the system.

In the system shown, a tank **20** provides a source of a suitable diesel fuel which is withdrawn from the tank by low-pressure fuel pump **22** and delivered through a conventional accumulator **24** to universal fuel-metering and distributing apparatus 26. By way of example only, the pressure provided by fuel pump 22 may be of the order of 100 p.s.i., and use of the accumulator 24 is optional.

The universal fuel-metering and distributing apparatus 26 may be like that described and claimed in U.S. Pat. application Ser. No. 805,251 of R. B. Hussey and John A. Kimberley, filed Mar. 7, 1969 and of common assignee herewith, which is included herein by reference as an example of one suitable form for apparatus 26. This apparatus is of the positive-displacement shuttle-piston type, wherein each discrete metered quantity of fuel is produced by the travel of a piston through a controlled distance, the stroke of the piston being synchronized with operation of the engine 10 by appropriate mechanical linkage between a shaft 28 driven by the engine and a shaft 30 which controls the timing of the displacement piston of the universal fuel metering and distributing apparatus 26. As described in the above-cited copending application, the preferred form of the universal fuel metering and distributing apparatus 26 is such that discrete metered quantities of fuel can be delivered to any number of cylinders from 1 to 12 in appropriate time-sequence, by appropriate capping or returning to tank of those of the 12 outlet ports of the apparatus 26 which are not required to supply the cylinders of the engine.

Associated with the universal fuel metering and distributing apparatus 26 is a fuel control 28 which, when mechanically varied in position, controls the quantity of metered fuel delivered by apparatus 26. In the case of the apparatus of the above-cited copending application, the fuel control 28 may comprise a control sleeve which is slidable longitudinally of the fuel-metering piston to control the quantity of fuel delivered. In the present example in which four engine cylinders are assumed, there are four outlet lines 32 from the universal fuel-metering and distributing apparatus 26, one for each of the engine cylinders.

In this example, as in that described in the above-cited copending application, the fuel control 28 may be controlled and varied in position by a suitable conventional throttle-governor 38, the drive shaft 40 of which is mechanically linked to the diesel engine shaft 28 by appropriate gearing to enable controllable setting of the speed of the engine at any desired value.

Each of the fuel outlet lines 32 supplies a different one of the four fuel injectors 40, the discharge lines 16 of which supply corresponding different ones of the nozzles 14 of engine 10 with discrete metered quantities of fuel under the high pressures required for injection through the nozzles.

The details of the structure and operation of each of the injectors 40 will be described in detail hereinafter. Broadly, each injector receives its successive discrete quantities of fuel from apparatus 26 and stores each quantity briefly until the injector is actuated, at which time piston means contained in the injector operates to discharge the stored fuel through the corresponding discharge line 16 and nozzle 14, and thence into the corresponding engine cylinder. The time at which each injector is actuated to produce a fuel discharge is controlled and determined by an actuating signal supplied thereto over a corresponding one of the four electrical timing lines 46 from the adjustable timing signal generator 48. Timing signal generator 48 is synchronized with operation of engine 28 by appropriate mechanical linkage to the generator drive shaft 50 so that the output electrical timing signals at lines 46 bear a predetermined phase relation to the phase of operation of engine 10, and differ among themselves in phase according to the differences in phase of operation of the pistons in the four corresponding cylinders of the engine.

A mechanical linkage from the fuel control 28 to the timing signal generator 48 is preferably also provided so as to permit automatic variation of the advance or retard of the signals on lines 46 as a function of the position of the fuel control 28 and hence as a function of the load on engine 10. Timing signal generator 48 may also include an appropriate fly-weight retard-advance mechanism for automatically varying the phase of the output signals on lines 46 as a function of engine speed. Forms of apparatus suitable for providing such operations are known in the art, and in the present embodiment it is preferred to utilize the photoelectric timing signal generator apparatus described and claimed in U.S. Pat. application Ser. No. 781,815 of J. A. Kimberley and R. B. Hussey, filed Dec. 6, 1968 and of common assignee herewith. The latter form of timing signal generator not only provides the above-described automatic phase control as a function of both speed and load, but also provides for use with engines of different numbers of cylinders by using appropriate different ones of the output connections thereof, or in some cases by simple replacement of a minor component of the timing signal generator.

The force for operating the piston means in each of the injectors 40 is provided by fluid pressure from a high-pressure common rail 56. While it is possible to utilize a different fluid for this purpose, in the present embodiment it is convenient to utilize fuel from the tank 20 as the high-pressure fluid, which is delivered to the common rail 56 through a conventional accumulator 60 by means of a variable high-pressure hydraulic fuel pump 62. As an example only, the common rail pressure may be of the order of 4,000 p.s.i. as determined by the required operating pressures of the injection nozzles 14 and the design of the injectors. Suitable high-pressure pumps for providing pressures of these magnitudes, and enabling controlled variation of the magnitudes of the high pressure, are known in the art. While a fixed-pressure pump regulator may be used for this purpose, it is preferred to use the class of pump shown and described in U.S. Pat. No. 2,775,233 of W. O. Bischoff et al., issued Dec. 25, 1956.

In general then, to utilize the fuel injection system of FIG. 1 with a given diesel engine, the common rail system, the universal fuel metering and distributing apparatus 26, and the adjustable timing signal generator 48 are connected as shown in FIG. 1, the timing signal generator 48 being provided with the appropriate number of angle-sensing elements and timing lines for the number of cylinders of the engine and the universal fuel metering and distributing apparatus 26 also being appropriately vented and capped to provide a number of outlets equal to the number of engine cylinders. The adjustable timing signal generator 48 may then be adjusted to provide the desired phase of actuation of the injectors to produce properly-timed fuel injection; the universal fuel metering and distributing apparatus 26 and its associated fuel control 28 may be adjusted so that the appropriate controlled quantity of fuel is injected during each injection operation; and the variable high-pressure hydraulic fuel pump 62 may be adjusted to provide a magnitude of common-rail high pressure such as to produce the desired duration of the injection into each cylinder, the higher the pressure the shorter the duration. As will become clear from a consideration of the following detailed description of the structure and operation of the individual injectors, the timing, fuel quantity and injection duration are thereby substantially independently controllable and selectable, so that optimum conditions of engine operation can be provided for any of a wide variety of engines.

Referring now to the preferred form of fuel injector 40 as shown schematically in FIGS. 2 and 3, the injector comprises electromagnetic valve-actuating means 64 for actuating a servo valve 66, which in turn operates the injection piston means 68 to inject fuel from the fuel chamber 70 into and through the corresponding fuel injection nozzle 14.

More particularly, the fuel distributing apparatus 74 of FIG. 2 is a part of the universal fuel metering and distributing apparatus 26 of FIG. 1, through which metered fuel is distributed to fuel supply line 32 at the time represented in FIG. 2. Thus a fuel-metering outlet line 78 is shown through which metered fuel is being supplied from a shuttle piston (not shown) to an annulus 80 on a fuel-distributing shaft 82, the shaft being provided with an axially-extending slot 84 whereby, when the shaft is in the position shown, fuel is delivered by way of slot 84 to fuel outlet line 32 and the fuel injector. A similar arrangement of another annulus, slot and fuel lines is shown at the left of the distributor shaft in FIG. 2, to which another injector may be connected; in the particular phase of engine operation shown, the other slot 84A is rotated out of communication with its corresponding fuel supply line. In the engine phase shown in FIG. 2, the servo valve 66 is in such a position that fuel from line 32 is delivered through a branch line 86, an annular groove 87 in a piston 94, an annulus 88, and another line 90 to the fuel chamber 70 at the bottom of the injector, where it is retained until the injector is actuated to produce discharge through nozzle 14.

Servo valve 66 comprises a cylinder 92 in body 93 containing the reciprocable piston 94 made up of a larger-diameter upper portion 94A and a smaller-diameter lower portion 94B in contact with each other; while piston 94 may be a single piece, preferably the portions 94A and 94B are two pieces which bear against each other throughout operation; a vent line 95 connected to tank and a vent annulus 96 communicating with the region of contact between piston portions 94A, 94B assures this contact at all times.

A high-pressure inlet 98 extending through body 93 to the lower end of cylinder 92 is supplied with fuel under high pressure from the common rail 56 (see FIG. 1), and applies this high pressure to the lower end of lower piston portion 94B. Piston portion 94B is provided with a first enlargement 100 which is of a size to move in sealed sliding relation to the interior of cylinder 92 near the bottom thereof, and a bleed annulus 102 is provided about chamber 92 just above its bottom end. A bleed line 106 is connected at one end to annulus 102 by way of an inlet restrictor 107, the other end of the bleed line communicating with the upper end chamber 108 of cylinder 92 by way of the bleed outlet restrictor 110. A control annulus 112 provides communication from chamber 108 to tank by way of a control valve 114 of the ball type, which is spring-biased to its closed position under the conditions shown in FIG. 2.

It is noted that the area of the upper end of piston 94 which is exposed to the interior of upper end chamber 108 is larger than the area of piston 94 which is exposed to high rail pressure at the lower end of cylinder 92. The piston 94 will remain at rest so long as the forces on its opposite ends are equal, i.e. so long as the product of the pressure in chamber 108 times the area of the upper end of piston 94 is equal to the product of the pressure at the lower end of the cylinder 92 times the exposed area of the lower end of piston 94. For example, if the diameter of the upper exposed end of piston 94 is 0.3 inch and that of lower end of piston 94 is 0.25 inch, while the common-rail pressure is 4,000 p.s.i., the piston will not move up or down when the pressure in the upper end chamber 108 is about 2760 p.s.i. If the pressure in chamber 108 rises above this value, the piston will move downwardly, and conversely if the pressure falls below this value the piston will move upwardly. The pressure in upper end chamber 108 at any time is determined by the flow of fuel into it from bleed line 106 and the flow out of it through control valve 114 when the latter valve is open.

As shown in FIG. 2, the piston 94 is in its lower position and control valve 114 is closed. The pressure in chamber 108 is, for example, 2760 p.s.i. so that the piston is in equilibrium. However, when the control valve 114 is opened by a timing signal applied to valve-actuating means 64 over line 46, fuel in chamber 108 is spilled to tank through line 115 and the pressure in that chamber therefore drops. Piston 94 then responds to the resulting imbalance in pressure by moving upwardly, so that the annulus 102 communicates fully with the high-pressure inlet 98 and fuel flows through bleed line 106 into upper end chamber 108. The flow resistance provided by restrictor 110 is greater than that provided by control valve 114 when it is open, so that the pressure remains low in chamber 108 and the piston continues to rise until the upper piston portion 94A cuts off the control valve annulus 112. The pressure in chamber 108 then rises sufficiently to stop the upward motion of the composite piston, and then continues to rise above the hydraulic balance pressure of 2760 p.s.i. so that the composite piston begins to move downwardly. However, this downward motion soon produces reopening of the control valve annulus 112 at least to a slight extent, which reestablishes outward flow through the control valve 114. When this outward flow exactly matches the inward flow to chamber 108 by way of the restrictor 110, the piston becomes stabilized in its upward position, as shown in FIG. 3.

When the control valve 114 is subsequently closed again, the flow out of the chamber 108 is arrested, flow through the bleed line 106 causes the pressure in chamber 108 to rise, and the piston 94 is driven downwardly. This downward motion continues until the enlargement 100 of piston 94 begins to close off the bleed annulus 102 and thus decreases the flow into chamber 108. Further slight downward motion of the piston 94 causes the pressure in chamber 108 to drop abruptly and, when it reaches 2760 p.s.i., the piston is again at equilibrium in its lower position. If at this point leakage occurs into the bleed line 106 from the lower end of cylinder 92, the piston 94 will move slowly downward until it contacts a mechanical stop at the lower end of cylinder 92. During reciprocating operation, the piston will never contact this mechanical stop due to insufficient time for this leakage to occur. Any leakage from chamber 108 will cause the piston to rise slightly, partially reopen the bleed annulus 102, and supply sufficient flow to compensate for the leakage flow from the chamber 108. Another stop at the opposite end of cylinder 92 is provided by a stop member 116, protruding from the upper end of piston 94, which also is not contacted during normal operation.

Accordingly it will be appreciated that when control valve 114 is closed as in FIG. 2, the servo valve piston 94 will be stabilized in its lower position as shown in FIG. 2, while when the control valve 114 is actuated to its open position the servo valve piston will be raised to its stable upper position shown in FIG. 3. This opening and closing of the control valve 114 is controlled by the electromagnetic valve actuating means 64, which comprises a magnetic core 120 on which is wound a magnetic winding 122 so as to attract a plate 124 of steel or similar magnetic material when a current is passed through winding 122 by way of electrical line 46. Plate 124 is normally spring-biased downwardly by a suitable coil spring 126, and the ball 127 of control valve 114 is then held in its closing position by a pin 128 carried by plate 124. Accordingly, a current supplied through line 46 operates valve-actuating means 64 so as to open control valve 114 and operate servo valve 66 to its upward or open position; upon termination of the current applied over line 46, the spring 126 returns the control valve 114 to its closed position and the servo valve then resumes its closed position.

An annular vent groove 132, positioned on the lower piston portion 94B just above the enlarged portion 100, is connected to tank by line 133 when the piston 94 is in its lower position, and at this time also communicates with the injection-piston supply line 134 by way of the annulus 135, so that the line 134 is also vented to tank when the servo valve is deactuated; as shown in FIG. 3, the connection of line 134 to tank is sealed off by enlargement 100 when the servo valve is actuated. Also, when the servo valve 66 is deactuated, the injection-piston supply line 134 is disconnected from high-pressure inlet line 98, and is connected thereto when the servo valve is actuated. Another tank line 136 communicates with an isolating annulus 137 surrounding the upper part of piston portion 94A, to prevent leakage of fluid under high pressure from upper end chamber 108 to the groove 87.

The servo valve 66 therefore serves two primary functions, namely to control connection between the metered-fuel supply branch line 86 and the line 90 leading to fuel chamber 70, and to control connection between the high-pressure fuel inlet 98 and the injection-piston supply line 134. In the deactuated condition of the servo valve shown in FIG. 2, the annular groove 87 and annulus 88 provide connection between branch line 86 and line 90, so that metered fuel from the distributor-shaft slot 84 is delivered to the fuel chamber 70. At this time high-pressure inlet **98** is sealed-off from injection-piston line **134** by the enlargement **100** on servo valve piston **94**. When the servo valve is actuated to the position shown in FIG. **3**, enlargement **143** seals-off annulus **88** and the fuel-supply branch line **86** is thereby disconnected from line **90**, while the high-pressure inlet **98** and the injection-piston fuel supply line **134** are then connected together around the bottom of the piston **94** and high-pressure fuel is applied to the upper end of the injection piston **144** by way of annulus **144A**.

Piston **144** is preferably made in two separable parts, namely an amplifier piston **145** positioned above and against a spill-control piston **146**. Amplifier piston **145** has a larger diameter than does the spill-control piston **146**, and, when control valve **64** is actuated, is supplied across its complete upper surface with high-pressure fluid from line **134**. The pressure produced in fuel chamber **70** by the lower end of the injection-piston **144** is multiplied by the ratio of the cross-sectional area of the top of the amplifier piston to the cross-sectional area of the spill-control piston. Accordingly, upon actuation of the servo valve **66**, the lower end of injection piston **144** is caused to execute a downward power stroke into the fuel chamber **70** for ejecting fuel therefrom to the injection nozzle **72**. A vent connection **150** to tank is provided in communication with the interface between the amplifier piston and the spill-control piston to prevent snubbing due to trapped air or other fluid.

Fuel chamber **70** is generally cylindrical and is provided with a fuel inlet port **152** in its side adjacent its bottom surface, an outlet annulus **153** surrounding it above its bottom, and a fluid outlet port **154** communicating with the fuel outlet annulus **153**. The fuel-injection nozzle **72** to which the ejected fluid is supplied may be of conventional known form, and is preferably of the type in which the nozzle valve is normally maintained closed by the action of a coil spring **160** acting through a valve stem **162**, until such time as the fluid supplied to its fuel inlet **163** exhibits a pressure sufficiently large to open the nozzle valve ("turn-on" pressure) and permit fluid discharge into the engine cylinder at the lower end of the nozzle. When the pressure of the fuel delivered to the nozzle falls below another pressure value, generally substantially lower than the turn-on pressure, the valve reseats itself and the discharge from the nozzle is terminated. Such nozzles being well known, it will not be necessary to describe them here in detail.

In the deactuated condition of the injector shown in FIG. **2**, the upper end of injection piston **144** is vented to tank by connection **133**, and the metered fuel is added to fuel chamber **70** over line **90** without substantial resistance, causing the piston **144** to be displaced upwardly; flow does not occur into the injection nozzle **72** at this time, because the pressure of the fluid supplied to the fuel chamber **70** is below that required to open the injection valve. After delivery of the metered quantity of fuel to the fuel chamber **70** has been completed, the distributor shaft **82** will have turned to the position shown in FIG. **3** in which the slot **84** no longer communicates with the fuel supply line **32** for the injector shown. The timing arrangement is such that this operation is completed before the actuating electrical signal is applied over line **46** to actuate the servo valve. When the latter actuation occurs, the high fluid pressure thereby caused to be applied to the upper surface of the amplifier piston **145** drives it, and the spill-control piston **146**, downwardly to apply a pressure which may be of the order of 8,000 p.s.i. to the fluid in the fuel chamber **70** and thus causes the desired discharge of fuel from the lower end of the nozzle **72**.

Spill-control piston **146** is provided with an arrangement of passages consisting of a central bore **170** communicating at its opposite ends with a pair of annular grooves **172** and **174**, by way of radial bores such as **175**. The outer edges of the latter grooves are normally sealed off by the cylinder in which the piston **146** moves, until the latter piston has moved downwardly to an extent such that the lower groove **174** communicates with the fuel outlet annulus **153** and, at the same time, the upper groove **172** communicates with a spill line **176** leading to the inlet line **177** to chamber **178** of a spill-collecting accumulator **180**. Spill line **176** is also connected to metered fuel-supply line **32** by line **32***a*.

Accumulator **180** preferably comprises a piston **184** slidable in the chamber **178** and spring-biased by a coil spring **188** so as to maintain a back pressure in the chamber. A tank line **190** provides return to tank for any fluid leaking past piston **184**. When the servo valve **66** is deactuated as shown in FIG. **2**, the relatively low pressure of the metered fuel in line **32** permits the piston to occupy an advanced position for which the portion of chamber **178** occupied by fuel is relatively small. However when, near the end of the injection stroke, the lower groove **174** communicates with fuel-chamber outlet annulus **153** and the upper groove **172** communicates with spill-line **176**, the extremely high fuel pressure in the fuel chamber is suddenly dropped because of the connection of the fuel outlet-annulus to the accumulator chamber **178**, and the fuel injection nozzle therefore closes abruptly. The communication between fuel outlet annulus **153** and the accumulator chamber **178** is maintained, as shown in FIG. **3**, as the lower end of the piston passes the lower edge of the fluid outlet annulus to seal-off the lower end of the fuel chamber, thereby trapping the remaining fuel therein and providing abrupt snubbing action to terminate the injection stroke.

The accumulator chamber **178** is of sufficient size, and the spring **188** thereof sufficiently soft, that the accumulator readily receives and retains both the fluid displaced by the additional downward motion of the injection piston after spilling begins, and the excess fluid stored at high pressure in the discharge line and in the passages of the fuel injection nozzle during the high-pressure injection operation. The spill action therefore not only provides a sharp cutoff of the injection from nozzle **72** at a specific position of the injection piston, but also absorbs back pressures and prevents secondary injection from the nozzle which otherwise tends to occur. In addition it is noted that when the electrical signal is removed from line **46** so that the servo valve is deactuated again, the fluid path thereby established from the accumulator chamber through the fluid supply line **32**, the servo valve **66** and the line **90** to the fuel chamber **70**, permits the collected spill fuel to return to the fuel chamber **70** as the accumulator piston **184** resumes its original position. This not only serves to prevent loss of fuel and unnecessary venting to tank, but also maintains accuracy of the amount of fuel injected and avoids cavitation effects, both of which problems tend to arise if spill is vented directly to tank or atmosphere.

It will therefore be appreciated that precise control is provided of the timing, duration and quantity of fuel injection during each injection interval. Change of timing is effected by change in the timing signals produced by the timing signal generator, quantity is controlled by adjustment of the fuel control associated with the universal fuel metering and distributing apparatus, and duration of injection is controlled by variation of the common rail pressure through control of the variable high-pressure hydraulic fuel pump **62**, greater common rail pressures causing a more rapid motion of the injection piston **68** and thus a shorter interval of injection. In this manner the factors affecting optimum operation of an engine can readily be adjusted to optimum. The system also lends itself to control of the form of variation of the rate of injection during each discharge, by appropriate shaping of the injection piston.

By way of example only, the remaining FIGS. **4—11** illustrate one manner in which the apparatus shown schematically in FIGS. **2** and **3** may be embodied in actual mechanical equipment, corresponding numerals designating corresponding parts.

As shown for example in FIGS. **4** and **5**, a supporting housing **200** contains a generally-cylindrical bore **202** extending thereinto from one end thereof, bore **202** containing a front end-cap **204**, a barrel **206**, a rear end-cap **208** and a rear retaining plug **210**, one positioned against the other in the order named; appropriate means (not shown) are provided for holding the various elements in the proper rotational position to provide the necessary communication between them. The electromagnetic valve-actuating means **64** is in the form of a generally cylindrical integral unit having an externally threaded portion permitting it to be threaded into housing **200** generally at right angles to barrel **206**, as shown. As shown particularly clearly in FIG. **11**, metered fuel from line **32** is delivered to an annular opening **216** provided by end cap **204**, around which it travels to the internal metered-fuel line **32***a*.

In the embodiment of FIGS. **4—11**, the servo valve and the injection piston means are positioned side by side, rather than one above another as in the schematic views of FIGS. **2** and **3**, but in other respects the construction and operation is substantially identical with that previously described with respect to FIGS. **2** and **3**, and hence need not be repeated. Also, the spill-collector accumulator and its associated elements, shown particularly clearly in FIG. **9**, are also contained within barrel **206**, immediately adjacent and beside the servo valve and injection piston means, and have the same construction and operation as is described with reference to FIGS. **2** and **3**; a stop **220** prevents the piston in the accumulator from advancing so far as to cover the ports communicating with lines **176** and **177**.

While the invention has been described with particular reference to specific embodiments thereof in the interest of complete definiteness, it will be understood that it may be embodied in a variety of forms diverse from those specifically described without departing from the invention.

We claim:

1. A universal fuel injection system suitable for injecting fuel into a diesel engine having one or more cylinders and having a fuel injection nozzle for each of said cylinders, comprising:

a source of liquid fuel;

a source of fluid at high pressure;

separate fuel-injector means for each of said cylinders, each of said fuel injector means comprising a fuel chamber for receiving liquid fuel to be injected into the corresponding cylinder, a fuel inlet for said chamber, a fuel outlet for said chamber for delivering said fuel from said chamber to the corresponding nozzle, a high-pressure fluid inlet connected to said source of fluid, piston means associated with said chamber and operable in response to fluid supplied thereto under high pressure from said fluid inlet to execute an injection stroke inwardly of said chamber and thereby eject said fluid from said chamber through said fuel outlet and said corresponding nozzle, and control means responsive to an actuating signal applied thereto to supply said fluid from said high-pressure fluid inlet to said piston means, said control means when deactuated preventing said supply of fluid to said piston means;

controllable positive-displacement fuel-metering means synchronized with operation of said engine for delivering discrete metered quantities of said fuel to said fuel chamber in each of said fuel-injector means by way of said fuel inlet at times when said control means is deactuated, whereby the quantity of said fuel delivered to said fuel chamber is constant for a given adjustment of said fuel metering means but controlably variable by control of said fuel metering means;

timing means responsive to operation of said engine for producing and applying to each said control means an actuating signal related in time phase to the operating phase of said engine to actuate said control means repetitively in response to said signal, thereby to effect discharge of said fuel through each of said nozzles at the proper phases of operation of said engine; and

whereby the duration, quantity and timing of the discharges of fuel from each nozzle are determined substantially independently of each other by selection of the operating conditions of said fluid-applying means, said fuel-metering means and said timing means.

2. The system of claim **1**, in which said source of fluid is controllable to vary the magnitude of said high pressure, and in which said timing means is controllable to vary the time-phase relation of said actuating signal to said operating engine phase, whereby said duration, quantity and timing of said discharges are all controllably variable to suit the requirements of different engines and engine operating conditions including speed, load, acceleration and deceleration.

3. The system of claim **1**, in which each of said control means comprises electromagnetic means actuatable by an electrical signal, and in which said actuating signal produced by said timing means is an electrical signal.

4. The system of claim **1**, in which said each fuel-injection means comprises a spill-collecting accumulator and means connecting said spill-collecting accumulator to said fuel chamber at the end of each fuel discharge from said fuel outlet and disconnecting it therefrom during the earlier portion of said injection stroke while said fuel is being discharged through said fuel outlet, thereby to collect spill fuel in said accumulator at the end of each fuel discharge from said fuel outlet and to return said spill fuel to said fuel chamber when said control means is deactuated.

5. The system of claim **4** in which said accumulator provides a back pressure small compared with the pressure in said fuel chamber during each of said fuel discharges.

6. The system of claim **4**, in which said means connecting and disconnecting said accumulator comprises valve means operable between open and closed conditions in response to actuation and deactuation of said control means.

7. The system of claim **4**, in which said means for connecting and disconnecting comprises an opening through said piston means positioned to connect said fuel chamber to said accumulator only when said piston means is near the end of said injection stroke.

8. In fuel-injector apparatus comprising a fuel chamber, means for delivering fuel to said chamber, an outlet for said chamber, piston means operable to execute repetitive strokes inwardly of said chamber to eject said fuel from said outlet intermittently at a high pressure, and a pressure-relief passage providing another outlet from said chamber only when said piston means moves beyond a predetermined position in each of said strokes, the improvement which comprises:

fuel accumulator means connected to said other outlet for receiving, and storing under pressure, fuel from said chamber, and means connecting said accumulator means to said fuel chamber only in the intervals between said strokes so as to return said fuel to said chamber from said accumulator during said intervals.

9. Apparatus in accordance with claim **8**, in which said accumulator comprises an accumulator chamber for receiving said fuel and spring-biased piston means for maintaining fuel in said accumulator chamber at a substantial pressure less than said high pressure.

10. Fuel injector apparatus comprising:

a fuel chamber;

a fuel outlet in a sidewall of said chamber;

a fuel inlet for said chamber;

a piston reciprocable in said chamber in response to high-pressure fluid applied to the end thereof exterior of said chamber to produce a discharge of fuel through said fuel outlet;

said piston forming a sliding seal with the sidewalls of said chamber to seal off said outlet and arrest said piston when said piston advances to a predetermined position within said chamber;

said inlet being positioned to enable supply of fluid through it to said chamber when said piston is in said predetermined position;

a fuel supply line and a high-pressure fluid supply line;

valve means operable when actuated to disconnect said fuel supply line from said fuel inlet and to connect said fluid supply line to said exterior end of said piston, and operable when deactuated to connect said fuel supply line to said fuel inlet and to disconnect said fluid supply line from said exterior end of said piston;

electrical means for controllably actuating and deactuating said valve means;

spill-collector accumulator means having a spill-collector chamber for receiving spill fuel;

means connecting said chamber to said fuel supply line; and

a spill passage through said piston having one end posi-

tioned in a side of said piston so as to communicate with said fuel outlet only when said piston has advanced into said chamber to provide said discharge, the other end of said spill passage being positioned to communicate with said spill-collector chamber when said one end communicates with said fuel outlet.