United States Patent [19]
Kimberley

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[45] Aug. 14, 1973

[54] APPARATUS FOR CONTROLLING RATE OF FUEL INJECTION

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[73] Assignee: **AMBAC Industries, Inc.**, Springfield, Mass.

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[21] Appl. No.: **247,333**

[52] **U.S. Cl.** ... **123/139 R**, 123/139 AM, 123/32 G, 123/140 R
[51] **Int. Cl.** **F02d 11/06**
[58] **Field of Search** .... 123/139 R, 139 AM, 123/140, 32; 417/400, 321

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Primary Examiner—Laurence M. Goodridge
Assistant Examiner—Cort Flint
Attorney—Dexter N. Shaw et al.

[57] ABSTRACT

Means for control of the rate of fuel injection in a diesel engine injection system characterized by a separate fuel injector for each engine cylinder. Each injector is supplied with discrete metered quantities of fuel which are discharged therefrom upon actuation of the injector by an injector piston which is driven by a high pressure fluid to pump the fuel through an associated injection nozzle. The rate of injection is controlled by varying the rate of flow of the high pressure fluid into the piston chamber. In the preferred embodiment, the piston comprises an elongated cylindrical member having a concentric bore open at one end and having ports opening into said bore through which the high pressure fluid passes from a communicating annulus. The piston ports are shaped in a predetermined configuration to cooperate with the annulus as the piston travels across the annulus to regulate the rate of flow of fluid into the piston bore and hence the rate of travel of the piston and the rate of injection of the fuel through the injection nozzle. In a modified embodiment, a plurality of piston ports are utilized to produce a pilot injection prior to the main injection. To facilitate the return of the piston following injection, a spill conduit connecting with the end of the piston chamber is provided which is opened in proper timed relationship to the piston movement by the valve controlling the admission of the high pressure fluid to the piston chamber.

13 Claims, 11 Drawing Figures

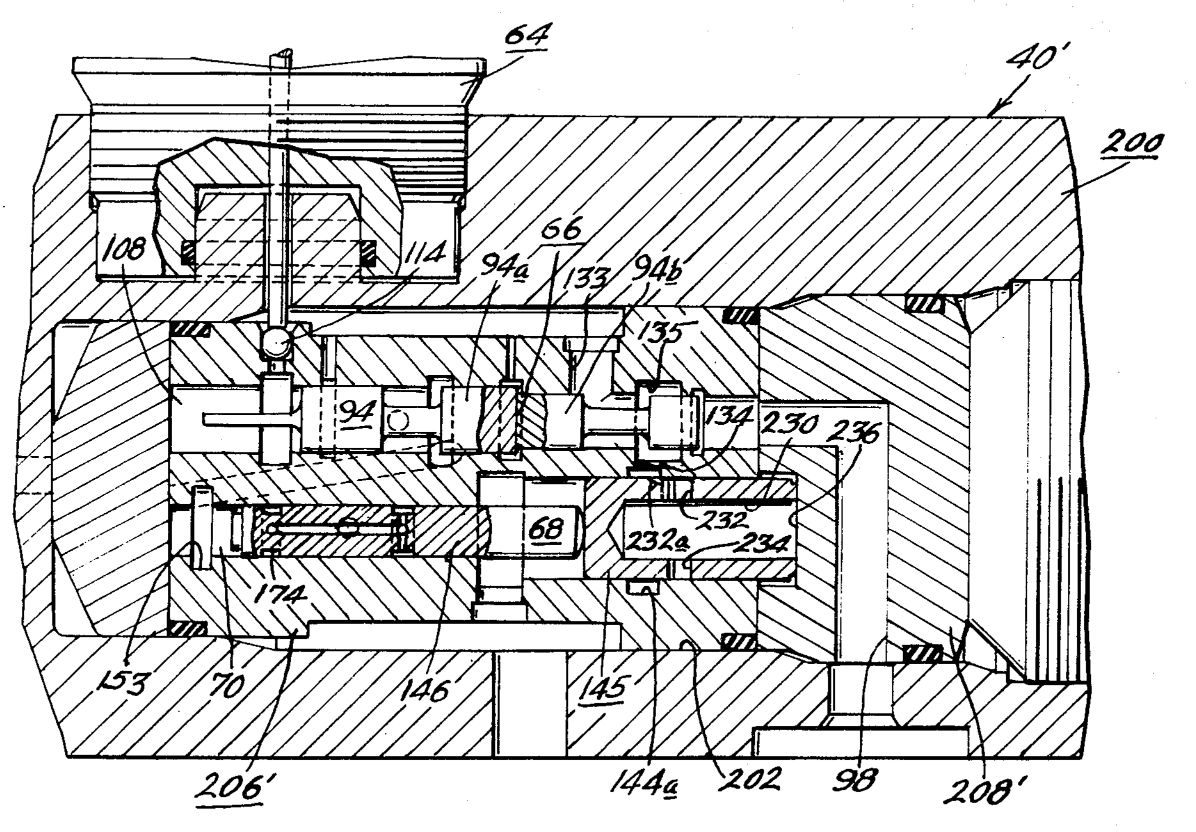
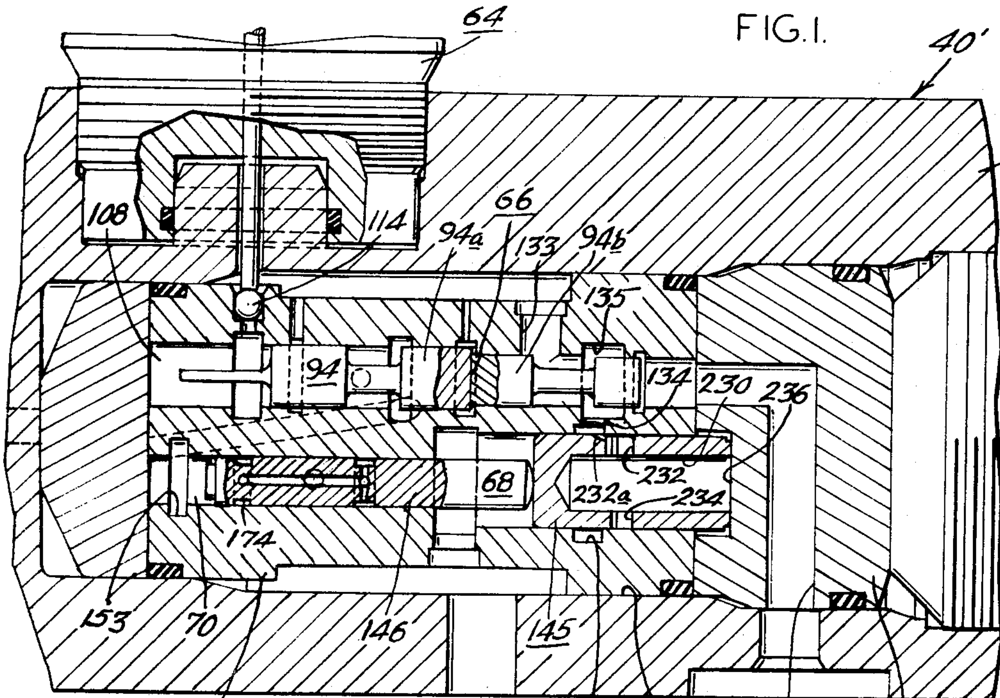


FIG. 1.


64
40'
200
108
114
94a
66
133
94b
135
94
134
230
236
68
232
232a
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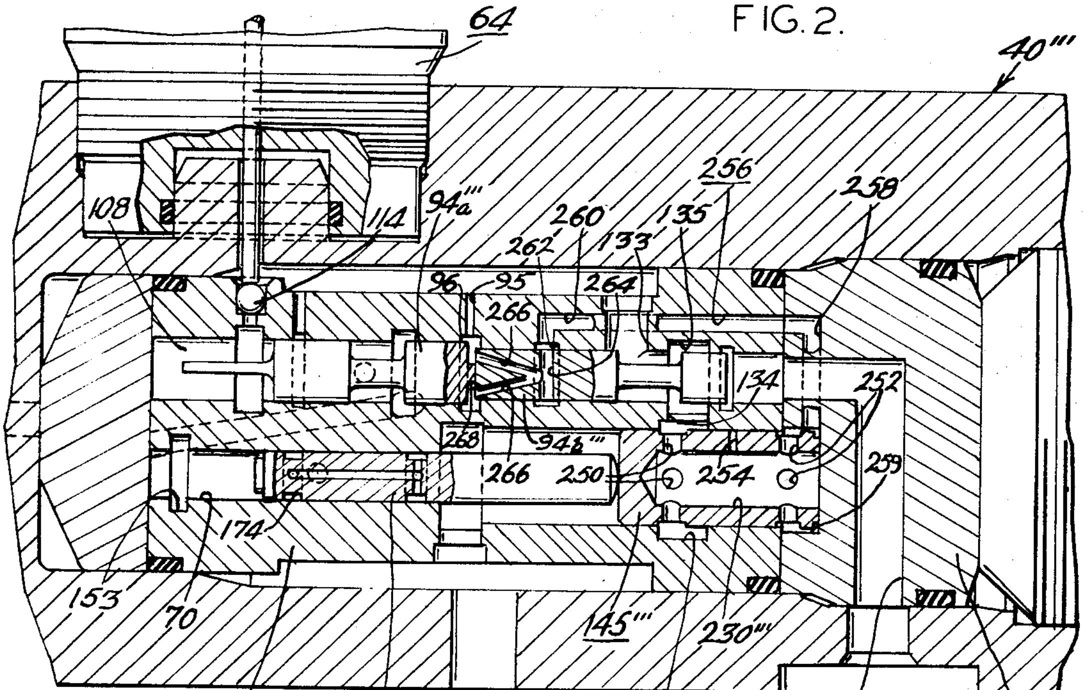
174
153
70
146
145
144a
202
98
208'
206'

FIG. 2.


64
40'''
108
114
94a'''
256
258
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135
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134
252
268
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174
153
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145'''
230'''
206'''
146'''
144a
98
208'''

FIG. 3.

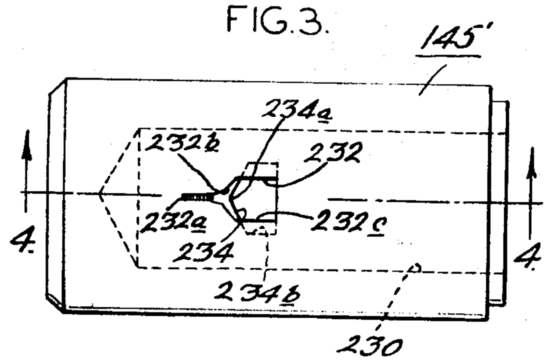


FIG. 7.

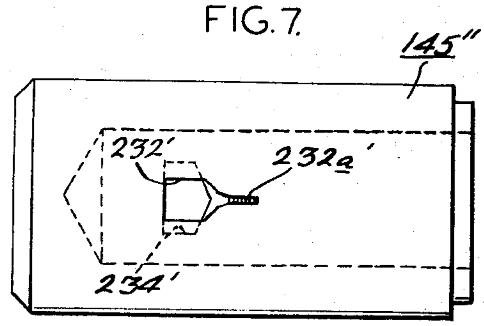
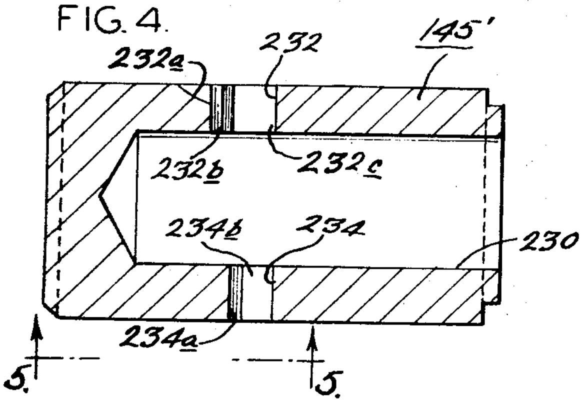


FIG. 4.



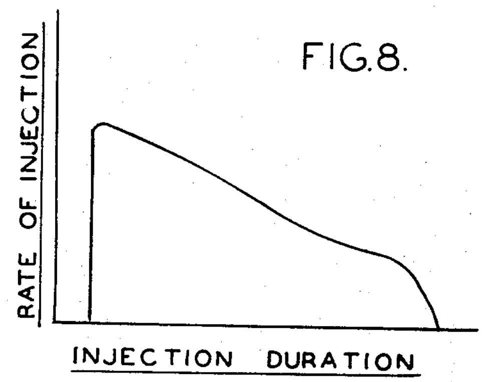


FIG. 5.

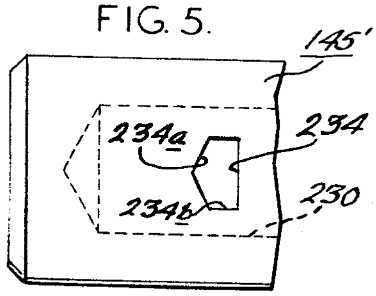


FIG. 9.

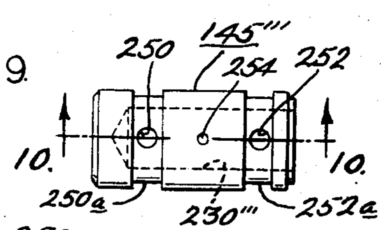
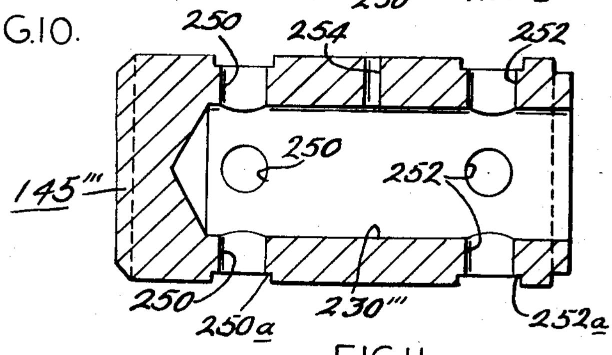


FIG. 10.



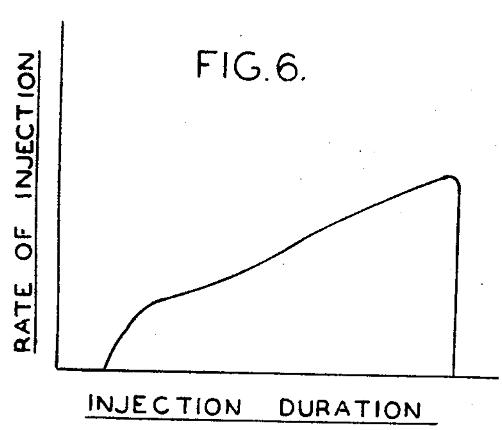
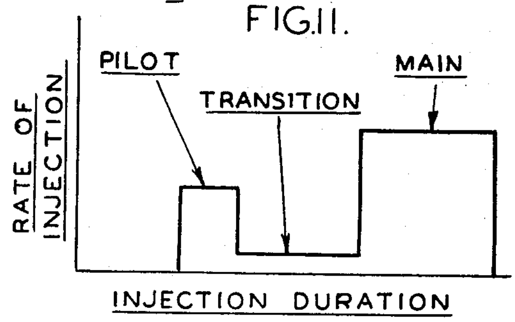


FIG. 11.



APPARATUS FOR CONTROLLING RATE OF FUEL INJECTION

The invention herein described was made in the course of or under a Contract DAAE07-70-C-4647 with the Department of the Army.

The present invention relates generally to diesel engine fuel injection systems and relates more particularly to a means for controlling the rate of fuel injection in a system characterized by a separate injector for each engine cylinder for injecting metered quantities of fuel to an associated nozzle, the injectors being actuated by a high pressure common rail fluid upon communication of a timing signal thereto.

In U.S. Pat. No. 3,587,547 issued on June 28, 1971, which patent is hereby incorporated by reference, a "universal" fuel injection system is disclosed. This system in brief is characterized by a separate fuel injector for each cylinder of the diesel engine, which injector is supplied with discrete metered quantities of fuel which are discharged from the injector through associated fuel injection nozzles. A common rail high pressure fluid is admitted to each injector in response to a timing signal to actuate a piston in the injector, the movement of which discharges the metered fuel through the nozzle into the engine cylinder. The present invention is directed to means for varying the rate of the fuel injection by control of the rate of movement of the injector piston.

The rate of injection of fuel into the engine combustion chamber and particularly the pattern of injection rate variation during the injection interval are important factors which must be considered in designing an engine. Since the injection nozzle spray characteristics are dependent upon the injection pressure, it can be understood that the variations in the rate of injection during the injection interval are of considerable significance. Since the rate of fuel combustion is dependent on the rate of injection of the fuel, for certain combustion chamber designs it may be desirable to initially limit the rate of injection to prevent objectionable engine knocking. A more uniform controlled rate of combustion of the remaining fuel may then be achieved after combustion of the initial injection has raised the combustion chamber temperature to an elevated level.

Since combustion can be controlled by combustion chamber and nozzle design, it is recognized that the rate of injection should be tailored to suit the requirements of the engine. Recent experiments indicate that the control of the rate of injection can be of material benefit in reducing the emissions content of exhaust gases. With the increasing concern with the ecological effects of internal combustion engines, the desirability of an effective means for controlling the injection rate becomes especially significant.

The present invention is particularly adapted for controlling the injection rate in a universal fuel injection system such as that disclosed in the above recited U.S. Pat. No. 3,587,547. In the injector construction shown in the patent, an amplifier piston is actuated by the high pressure common rail fluid to cause a downward pumping stroke of the adjacent spill-control piston. The present invention comprises an elongated cylindrical amplifier piston having a hollow bore open at one end and into which the high pressure common rail fluid passes from an annulus through shaped ports to produce a power stroke of the plunger. To control the rate of the plunger stroke and hence the rate of injection, the amplifier piston ports are shaped in such a manner as to cooperate with the annulus to vary the rate at which the fluid flows into the piston bore as the ports traverse the annulus.

In one embodiment of the invention, a plurality of axially spaced ports are utilized to produce a pilot injection prior to the main injection. For spaced ports of this type or to facilitate the return of the amplifier piston with any type port, a by-pass drain conduit from the amplifier piston chamber to the injector sump is provided, which drain path is opened in phase with the amplifier piston movement by the servo valve controlling the introduction of the common rail fluid into the amplifier piston chamber.

It is accordingly a first object of the present invention to provide apparatus for controlling the rate of fuel injection in an injector type fuel injection system.

A further object of the invention is to provide an apparatus as described which is of a relatively simple construction which can be readily modified to produce the desired injection rate pattern.

Another object of the invention is to provide an apparatus for controlling the rate of fuel injection as described which is particularly adapted for pilot type injection.

A further object of the invention is to provide means for reducing the undesirable exhaust gas emissions of diesel type internal combustion engines.

Additional objects and advantages of the invention will be more readily apparent from the following detailed description of embodiments thereof when taken together with the accompanying drawings in which:

FIG. 1 is a longitudinal sectional view through an injector assembly similar to that shown in FIG. 6 of U.S. Pat. No. 3,587,547 but modified to embody the present invention for control of the rate of fuel injection;

FIG. 2 is a view similar to FIG. 1 showing a modified form of the invention adapted to produce a pilot injection and including a servo piston actuated by-pass passage to facilitate the return of the amplifier piston;

FIG. 3 is an enlarged view of the amplifier piston utilized in the FIG. 1 embodiment showing the configuration of the high pressure fluid ports;

FIG. 4 is a sectional view taken along line 4—4 of FIG. 3;

FIG. 5 is a partial view taken along line 5—5 of FIG. 4;

FIG. 6 is a graph showing the rate of injection plotted against the injection duration for the injector embodiments of FIGS. 1, 3–5;

FIG. 7 is a view of an amplifier piston similar to that shown in FIG. 3 illustrating a modified form of the fluid ports;

FIG. 8 is a graph showing the rate of injection plotted against the injection as produced by the modified amplifier piston ports shown in FIG. 7;

FIG. 9 is a view showing the isolated amplifier piston of the modified FIG. 2 embodiment of the invention;

FIG. 10 is an enlarged sectional view taken along line 10—10 of FIG. 9; and

FIG. 11 is a graph showing the rate of injection plotted against the injection duration to illustrate the pilot injection pattern produced by the embodiment of FIGS. 2, 9 and 10.

Referring to the drawings, and specifically to FIG. 1 thereof, a fuel injector 40' is illustrated which is essentially the same as that described in the incorporated

U.S. Pat. No. 3,587,547 and illustrated in FIG. 6 thereof. In view of the thorough description of the universal type system and particularly the injector **40** thereof in the incorporated patent, it is not deemed necessary to recite in detail the manner of construction and operation of the system or the injector. Since the structure of the injector of FIG. **1** is nearly identical with that shown in FIG. **6** of the patent except for the amplifier piston and the amplifier piston chamber, the same identifying numbers are utilized to facilitate an understanding of the construction and operation of the injector assembly.

Reviewing briefly the salient features of the device, the injector **40'** includes a housing **200** having a central bore **202** within which is disposed the barrel **206'**. An electromagnetic valve actuating means **64** controls a servo valve **66** which in turn controls the injection piston means **68** to inject fuel from the fuel chamber **70** into and through an associated fuel injection nozzle. The servo valve **66** comprises the piston **94** which includes the abutting piston portions **94*a*** and **94*b*** which are reciprocable within the barrel under the influence of the high common rail pressure entering the injector through inlet **98** which through suitable passages is caused to act on both ends of the piston **94**. The valve actuating means **64** by opening the control valve **114** permits the high pressure fluid directed into chamber **108** at the left hand end of the piston **94** to drain to tank thus permitting the piston to move to its left hand position under the influence of the pressurized fluid bearing against the right hand end thereof. Such movement of the piston **94** permits the high pressure common rail fluid from the inlet **98** to pass into the annulus **135** through passage **134**, and into the amplifier piston annulus **144*a*** to actuate the injector piston means **68**.

The injection piston means **68** includes an amplifier piston **145'** and a smaller spill-control piston **146** in contact therewith. The movement of the amplifier piston **145** toward the spill-control piston **146** under the influence of the high pressure common rail fluid forces the metered fuel in the fuel chamber **70** out of the chamber and through the fuel injection nozzle. The delivery passages for directing the injected fuel from the injector to the nozzle as well as the means for delivering the metered fuel to the fuel chamber **70** are thoroughly described in the incorporated U.S. Pat. 3,587,547.

The injector of FIG. **1** differs from that of FIG. **6** of the aforementioned patent only in the structure of the amplifier piston **145'** and the size of the barrel bore within which the amplifier piston is slidably disposed. In the present invention, the amplifier piston is of a substantially cylindrical elongated configuration and includes a concentric bore **230** extending thereinto from the right hand end thereof. Diametrically opposed ports **232** and **234** in the walls of the amplifier piston are adapted to communicate with the annulus **144*a*** to permit entrance of the high pressure fluid into the bore **230** of the amplifier piston. The pressurized fluid acts against the inner end of the bore **230** to move the piston away from the surface **236** of the end-cap **208'** which the piston engages between pumping strokes. Upon movement of the piston away from the surface **236**, the pressurized fluid acts against the entire cross-sectional area of the piston.

Referring to FIGS. **3–5**, wherein the amplifier piston ports are clearly illustrated, it will be noted that the ports **232** and **234** are of a shape chosen to permit a predetermined increase in the rate of flow of the high pressure fluid into the amplifier piston bore **30** as the piston moves across the annulus **144*a*** to expose the full area of the ports to the annulus. The port **232** in particular is characterized by a narrow slot portion **232*a*** which as shown in FIG. **1** is the only portion of the ports in communication with the annulus **144*a*** at the beginning of the piston stroke. The slot **232*a*** opens at its right hand side into the apex end of a wedge-shaped portion **232*b*** of the port which in turn opens into the parallel walled main port portion **232*c***. Except for the absence of a slot portion, the port **234** is similarly shaped with a wedge-shaped portion **234*a*** and a parallel walled main portion **234*b***.

Upon operation of the injector **40'**, the valve **114** is opened venting the high pressure fluid in chamber **108** and permitting the servo valve **66** to open the annulus **135** to the high pressure common rail fluid in passage **98**. The high pressure fluid flows through the barrel passage **134** from the annulus **135** to the annulus **144*a*** whereupon an initial flow into the amplifier piston bore **230** takes place through the slot **232*a*** to start the amplifier piston and hence the spill-control piston **146** to the left. It will be evident that the fluid flow is greatly throttled by the small size of the slot **232*a*** so that the initial movement of the piston and hence the initial rate of injection is relatively low as indicated in the graph of FIG. **6**. However, as the wedge-shaped portion **232*b*** of the port **232** moves into communication with the annulus **144*a*** the rate of injection increases and continues to increase as the main portion **232*c*** of port **232** and the opposed port **234** move into communication with the annulus **144*a***.

The piston stroke is concluded when the groove **174** of the spill-control piston communicates with the fuel outlet annulus **153** thereby cutting off injection by reducing the pressure in the fuel chamber **70** by means of the passage system thoroughly described in the incorporated U.S. Pat. No. 3,587,547. The valve **114** is then closed and the chamber **108** is pressurized to move the servo valve **94** to the right thereby cutting off the flow of high pressure fluid into the annulus **135**, and venting the annulus **135** to tank by connection **133**. The right hand position of the servo valve **94** also opens the passage **90** to permit metered fuel to flow into the fuel chamber **70**, causing the spill-control piston **146** as well as the amplifier piston **145'** to move to the right. The fluid in the bore **230** displaced by the movement of the amplifier piston **145'** to the right passes through the annulus **144*a***, passage **134**, annulus **135** and connection **133** to tank. The cycle is thus completed and the injector is then ready to receive a further signal to begin the injection cycle anew.

In the modification shown in FIGS. **7** and **8**, the amplifier piston **145''** is identical with that of the described embodiment except that the ports **232'** and **234'** are turned around 180°. In this embodiment, both ports at the beginning of the injection stroke communicate with the annulus **144*a*** so that the rate of injection is at a maximum almost immediately as illustrated in the graph of FIG. **8**. Due to the decrease in effective combined width of the ports as the stroke progresses, the rate of injection decreases in the manner shown in FIG. **8**, tapering off to a very low rate at the end of the injection duration as the slot portion **232*a'*** forms the sole flow path for the fluid just prior to injection cutoff. The injection rate pattern shown in FIG. **8** is thus the opposite of that shown in FIG. 6 and illustrates the type of injection rate variation which can be obtained by the shaping of the piston ports. Other port configurations than those illustrated may be effectively utilized to produce the desired injection rate pattern.

In FIGS. 2, 9–11, a further modified embodiment of the invention is illustrated which is adapted to produce a pilot injection prior to the main injection. As was the case with the FIG. 1 embodiment, the injector shown in FIG. 2 is in structure and operation essentially the same as that of FIG. 6 of U. S. Pat. No. 3,587,547. In view of the summary description of the structure and operation of the injector set forth above with respect to FIG. 1, the structure of FIG. 2 need only be described in those respects in which it differs from that already described.

The injector of FIG. 2, which is generally designated 40''', comprises an amplifier piston 145''' which as illustrated in FIGS. 9 and 10 is similar to the amplifier pistons 145' and 145'' in including a concentric bore 230''' extending thereinto from the right hand end thereof. The amplifier piston 145''' differs, however, in that it includes a plurality of axially spaced ports to produce the pilot injection pattern shown in FIG. 11. Specifically, the amplifier piston includes the pilot injection ports 250 spaced at 90° intervals about the circumference of the piston adjacent the inner end of the bore 230''' which, as shown in FIG. 2, communicate with the annulus 144*a* at the beginning of the injection stroke. A similar set of main injection ports 252 also spaced at 90° intervals about the piston circumference are disposed in axially spaced relation from the pilot ports 250, close to the right hand end of the piston. Spaced axially intermediate the pilot injection ports 250 and the main injection ports 252 is a single smaller transition port 254, the purpose of which is explained herebelow. As particularly evident in FIG. 9, annular grooves 250*a* and 252*a* in the piston 145''' facilitate the communication of the ports 250 and 252 with the annulus 144*a*.

In addition to the recited differences in the amplifier piston, the FIG. 2 embodiment further differs in the inclusion of a by-pass passage means 256 for venting the right hand end of the amplifier piston chamber to tank during the return stroke of the amplifier piston. The means 256 comprises a conduit 258 in the end cap 208''' which communicates with the amplifier piston chamber portion 259 thereof. The conduit 258 communicates with a conduit 260 in the barrel 206''' which in turn opens into annulus 262 through which the servo valve piston 94*b*''' passes. Means are provided in the servo valve piston to vent the conduit 260 to tank when the servo valve is in the right hand position illustrated in FIG. 2. This venting means comprises a transverse passage 264 in the piston portion 94*b*''' which aligns with the annulus 262 in the right hand position of the piston, and diagonal passages 266 intersecting the passage 264 and opening into an annular groove in the servo valve piston formed by a necked down portion 268 of the piston portion 94*a*'''. The groove formed by the necked down portion aligns with vent annulus 96 when the piston is in the right hand position, which annulus by means of passage 95 is vented to the injector tank.

It will be apparent that to accommodate the servo valve means for opening and closing the by-pass conduit means, the injector has been somewhat elongated, but without changing the essential structure or function of the components thereof. Principally, the barrel 206''', spill-control piston 146''' and the servo valve piston portion 94*b*''' are those elements which have been axially elongated for the purpose described.

The embodiment of FIG. 2 functions essentially as that of FIG. 1. Upon opening of the control valve 114 by the valve actuating means 64, the servo piston moves to the left permitting the high pressure common rail fluid to flow into the annulus 135, through passage 134 and into annulus 144*a*. An initial flow of fluid through the pilot injection ports 250 produces an initial relatively rapid movement of the amplifier piston and spill-control piston to the left, producing the pilot injection as shown in FIG. 11. As the pilot injection ports 250 pass out of communication with the annulus 144*a*, the transition port 254 is opened to the annulus and permits only a greatly throttled flow of fluid to pass into the amplifier piston bore 230''', resulting in a very low rate of injection during the transition period between the pilot and main injections. Just before the transition port 254 passes out of communication with the annulus 144*a*, the main injection ports 252 are opened to the annulus and the rapid piston movement resulting from the consequent fluid flow into the amplifier piston produces the main full rate injection as shown in FIG. 11. The invention is cut off when the annulus 174 of the spill-control piston 146''' reaches the annulus 153 in the same manner described in the incorporated U.S. Pat. No. 3,587,547.

The return of the amplifier and spill-control pistons to the right under the influence of the metered fuel admitted to the fuel chamber 70 is normally permitted by the emptying of the amplifier piston bore 230''' through the amplifier piston ports back into the annulus 135 and hence out through the connection 133 to the tank. However, in the pilot injection embodiment of FIG. 2, the spacing of the sizable pilot and main injection ports with only the transition port therebetween prevents the necessarily rapid emptying of the amplifier piston bore. To permit a rapid emptying of the amplifier piston chamber, the by-pass passage means 256 is provided which supplements the usual fluid discharge path. Accordingly, as shown in FIG. 2, when the servo valve is in the right hand position as it would be during the return of the amplifier piston, the conduits 258 and 260 provide a flow path from the right hand end of the amplifier piston chamber through the servo piston passages 264 and 266 into the annulus 96 and through passage 95, to the injector tank. This passage will, of course, be closed when the servo piston moves to the left, since the passage 264 will then no longer align with the annulus 262. Thus, during the pumping stroke of the amplifier piston, the by-pass conduit means 256 will be closed by the movement of the servo piston, but will be opened by the servo piston during the return stroke to permit the rapid emptying of the amplifier piston chamber and hence the rapid return of the amplifier piston.

Although the by-pass conduit means illustrated in FIG. 2 is essential for the pilot injection amplifier piston port configuration, it will be apparent that this by-pass conduit means may also be employed with other types of amplifier port configurations such as those shown in the embodiments described above. An injector equipped with the by-pass conduit means may thus be utilized with any type of amplifier piston port configuration.

Manifestly, changes in details of construction can be effected by those skilled in the art without departing from the spirit and the scope of the invention.

I claim

1. In a fuel injector comprising cylinder-piston means for injecting discrete metered quantities of fuel from a fuel chamber to an injection nozzle, said cylinder-piston means being actuated by a high pressure fluid, the improvement comprising means for controlling the rate of fuel injection, said means comprising an open-ended bore within the piston of said cylinder-piston means, an annulus in the piston chamber of said piston-cylinder means, means for introducing pressurized fluid into said annulus, port means in said piston providing communication between said annulus and said piston bore to permit high pressure fluid to flow into said piston bore to drive said piston toward the fuel chamber, said port means being configured to cooperate with said annulus to provide a predetermined variation in rate of piston movement and hence fuel injection during the injection interval.

2. The invention as claimed in claim **1** wherein said port means comprises at least one port in said piston, said port being disposed so as to travel across said annulus during movement of said piston whereby the area of said port communicating with said annulus varies during the piston stroke.

3. The invention as claimed in claim **1** wherein said piston port means comprises a plurality of axially spaced ports.

4. The invention as claimed in claim **3** including by-pass conduit means for venting said piston chamber to tank, and valve means for closing said by-pass conduit means during the injection stroke of said piston.

5. The invention as claimed in claim **3** wherein said plurality of axially spaced ports comprise a first port adapted to initially communicate with said annulus to produce a pilot injection of fuel, a second port axially spaced therefrom of reduced area, and a third port axially spaced from said second port for producing the main fuel injection stroke of the piston, said second port providing a transition movement of said piston between the pilot and main injection movements of said piston.

6. In a fuel injector comprising a fuel injecting piston means reciprocably disposed for delivering discrete metered quantities of fuel from a fuel chamber at one end thereof to a fuel injection nozzle, said piston being actuated toward said fuel chamber by the introduction of a high pressure fluid into a piston chamber adjacent the end thereof opposite said fuel chamber, valve means for controlling the introduction of metered fuel to the fuel chamber and the introduction of high pressure fluid to the piston chamber in timed sequence in response to engine generated timing signals, the improvement comprising means for controlling the rate of fuel injection, said means comprising an open-ended bore within said piston, an annulus in said piston chamber for receiving the pressurized fluid from said valve means, port means in said piston providing communication between said annulus and said piston bore to permit the pressurized fluid to flow into said piston bore to drive said piston toward said fuel chamber, said port means being configured to cooperate with said annulus to provide a predetermined variation in rate of piston movement and hence fuel injection during the injection interval.

7. The invention as claimed in claim **6** wherein said valve means is adapted to vent said annulus to tank following the completion of the piston injection stroke whereby said fluid within said piston bore may empty through said port means to permit return of said piston prior to a successive injection stroke.

8. The invention as claimed in claim **6** wherein said port means comprises at least one port in said piston, said port being disposed so as to travel across said annulus during movement of said piston whereby the area of said port communicating with said annulus varies during the piston stroke.

9. The invention as claimed in claim **8** wherein said piston port is shaped so as to increase the area of communication thereof with said annulus and hence increase the rate of injection as said piston travels toward said fuel chamber.

10. The invention as claimed in claim **8** wherein said piston port is shaped so as to decrease the area of communication thereof with said annulus and hence decrease the rate of injection as said piston travels toward said fuel chamber.

11. The invention as claimed in claim **6** wherein said piston port means comprises a plurality of axially spaced ports.

12. The invention as claimed in claim **11** including by-pass conduit means for venting said piston chamber to tank, and means for closing said by-pass conduit means during the injection stroke of said piston, said means for closing said by-pass conduit means comprising said valve means.

13. The invention as claimed in claim **11** wherein said plurality of axially spaced ports comprise a first port adapted to initially communicate with said annulus to produce a pilot injection of fuel, a second port axially spaced therefrom of reduced area, and a third port axially spaced from said second port for producing the main fuel injection stroke of the piston, said second port providing a transition movement of said piston between the pilot and main injection movements of said piston.

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