Feb. 19, 1935. E. T. VINCENT 1,991,586

ENGINE

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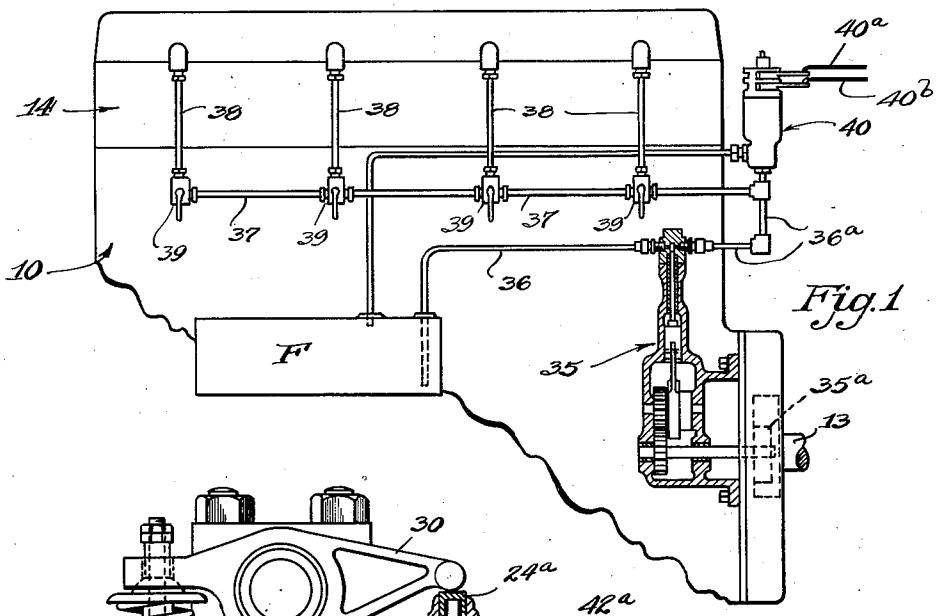


Fig. 1

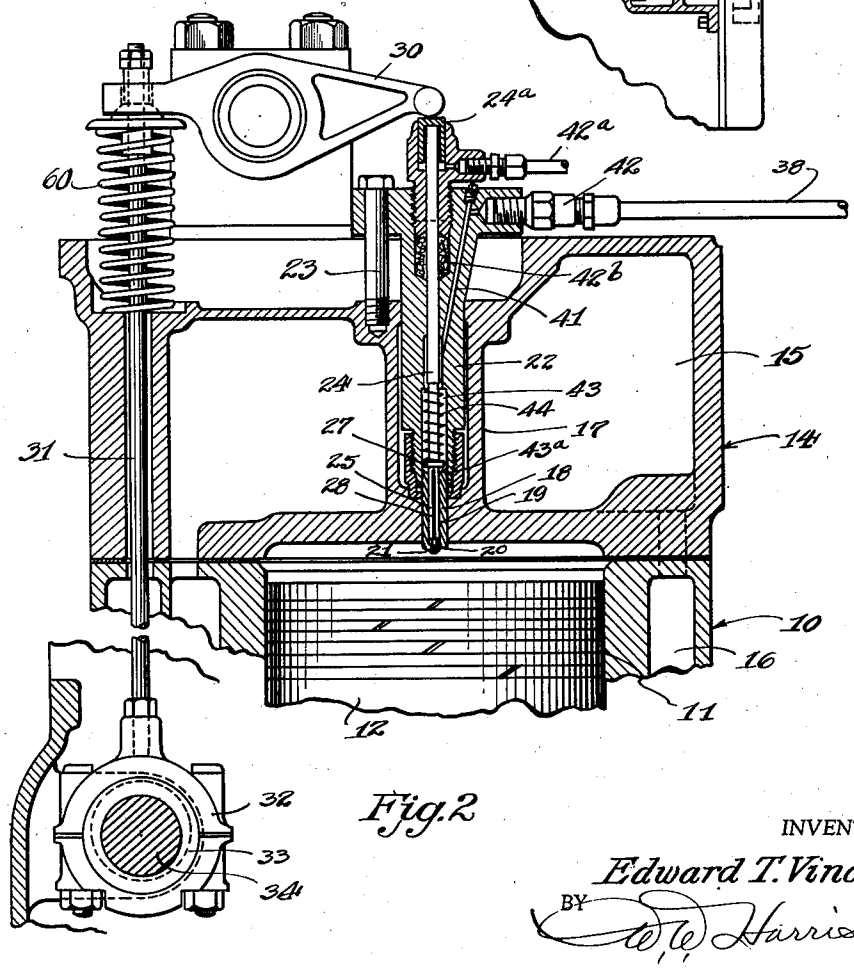


Fig. 2

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Feb. 19, 1935. E. T. VINCENT 1,991,586

ENGINE

Filed Dec. 21, 1933 3 Sheets-Sheet 2

Fig. 5.

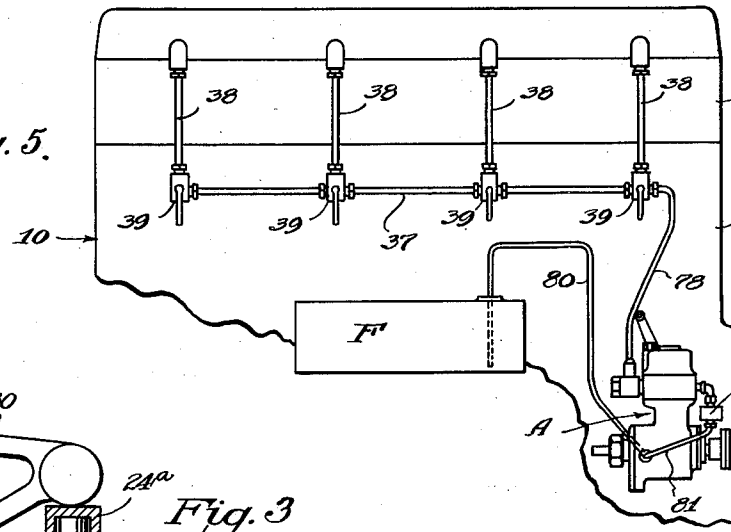


Fig. 3

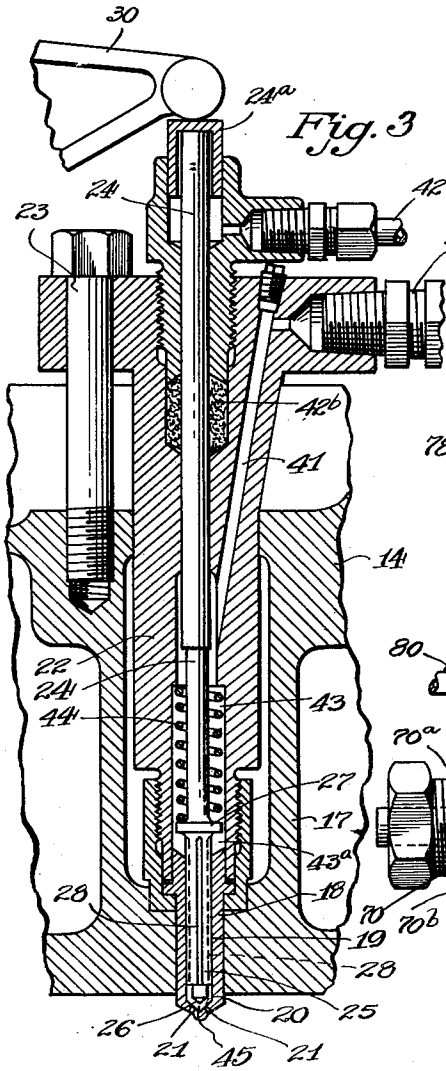
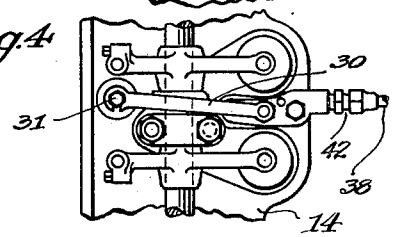


Fig. 4



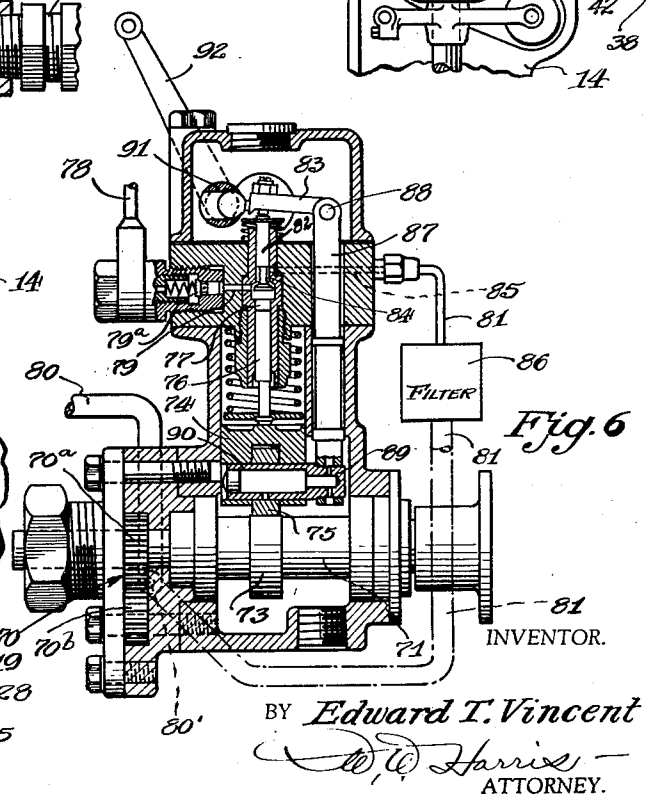


Fig. 6

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Feb. 19, 1935. E. T. VINCENT 1,991,586

ENGINE

Filed Dec. 21, 1933 3 Sheets-Sheet 3

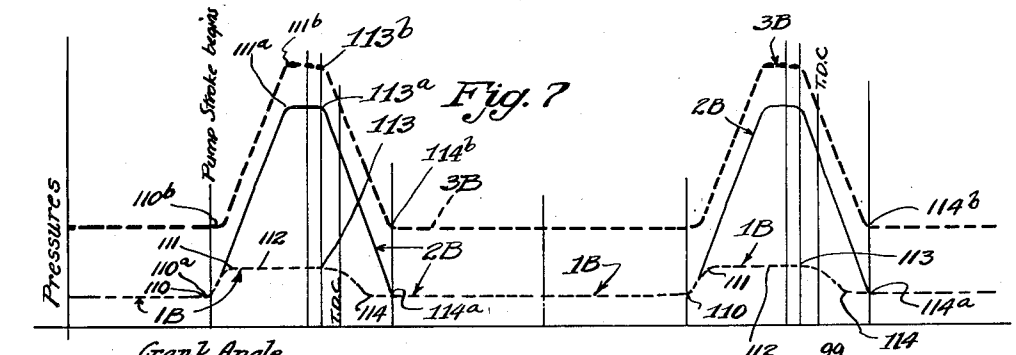


Fig. 7

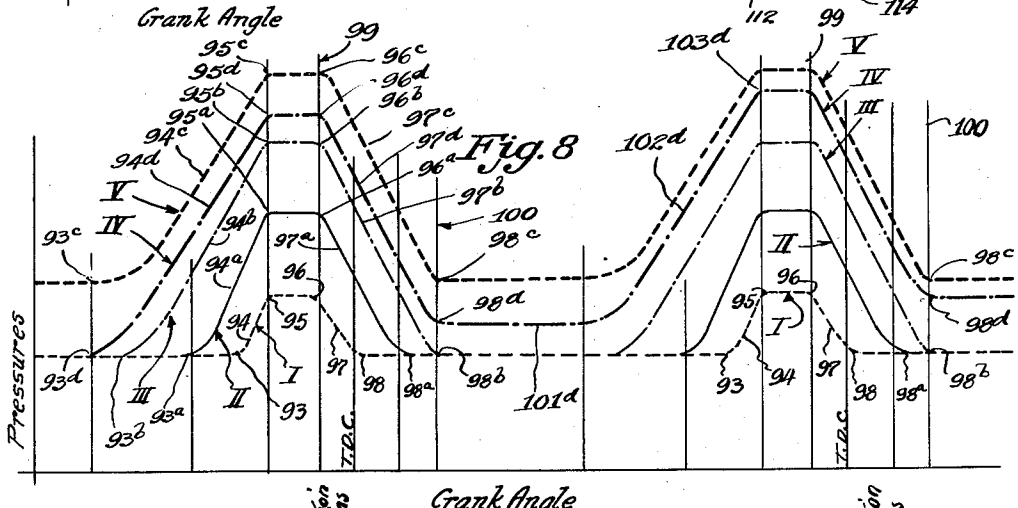


Fig. 8

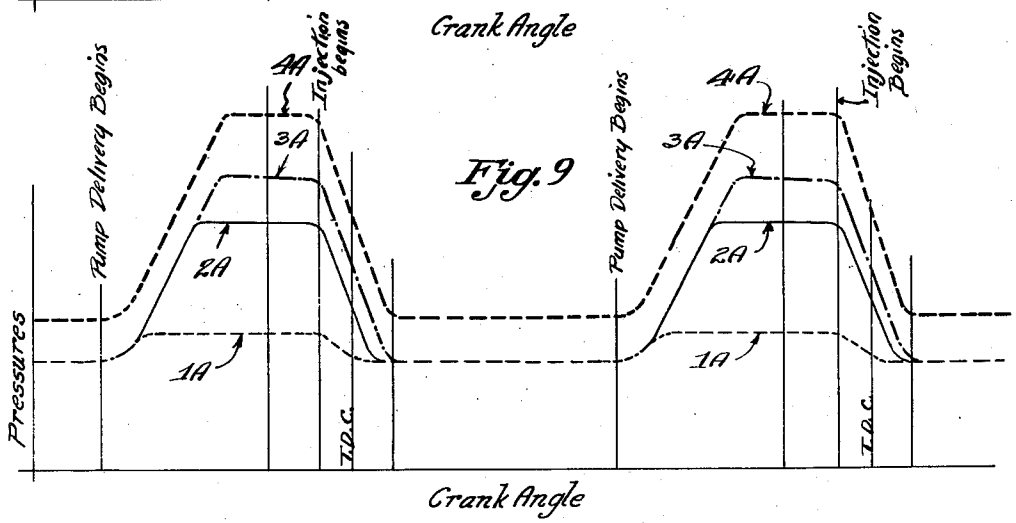


Fig. 9

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Patented Feb. 19, 1935 1,991,586

UNITED STATES PATENT OFFICE

1,991,586

ENGINE

Edward T. Vincent, Detroit, Mich., assignor to Continental Motors Corporation, Detroit, Mich., a corporation of Virginia

Application December 21, 1933, Serial No. 703,440

4 Claims. (Cl. 123—32)

My invention relates to a fuel injection internal combustion engine and more particularly to an engine of the compression ignition type.

Two well known systems of fuel injection for engines of this type are the constant pressure system and the jerk system. The former system gives the most power and economy but more skill is required in maintaining the working parts in proper adjustment and the slightest wear of the timing and control mechanism, the cam in particular, may completely cut out one of the cylinders thereby reducing the engine power and overloading the other cylinders. Even though the wear is not sufficient to cut out the cylinder, the power of the cylinder associated with the worn cam is materially reduced. The latter system is more readily maintained in service but gives less power at a relatively higher fuel consumption. To be more specific it might be noted that the constant pressure fuel injection system is provided with means for mechanically opening and closing the valve for controlling the injection of fuel into the cylinders under a constant pressure, while the jerk system is provided with means for automatically opening and closing the valve, and usually provides an individual fuel pump for each cylinder which measures and delivers a pre-determined amount of fuel. These pumps are relatively expensive besides providing a multiplicity of parts which are subjected to wear.

In both of the aforesaid systems the fuel pump is delivering during the injection period and thus must exert some control upon the injection. In the constant pressure system the fuel pump is usually delivering an excess of fuel, suitable pressure relief valves being employed to control the pressure, but in all cases the success of this type of system is contingent upon a pump delivery which is pumping a definite volume of fuel into the supply line during injection, or at least as much as is injected into the combustion chamber, whereby to maintain a substantially constant pressure in the fuel supply line of said system during injection. In the jerk system, the fuel pump is arranged to operate and is timed with the engine to deliver during injection.

It is the object of my invention to provide an engine of the fuel injection type having the advantages of both systems without any of the disadvantages.

More particularly it is the object of my invention to construct a fuel injection system for an engine of the compression ignition type by providing means for controlling the injection of fuel under pressure into the cylinders having the advantages of the constant pressure fuel injection system for mechanically controlling the opening of the valve which controls the injection of the fuel into the cylinders, and having the advantages of the fuel injection system of the jerk type by automatically closing the injection valve for the most part in response to a predetermined fall in fuel pressure in the fuel supply line of said fuel pressure system.

Another object of my invention is to construct a fuel injection system for an engine of the compression ignition type including a mechanically controlled valve opening means controlling the injection of fuel into the engine cylinders under pressure which has been previously built up by a pump means that is operated in timed relation with the engine operation, and with means responsive to a predetermined fall of fuel pressure in the source of fuel supply system resulting from an injection of fuel into the engine while the pump has a zero delivery for automatically closing or controlling closing of said valve when a predetermined charge of fuel has been injected into the cylinder.

A further feature of my invention is to construct an engine of the aforesaid type having a fuel injection system including a reservoir or "rail" in which fuel under pressure is contained for distribution to a plurality of cylinders, said fuel being preferably forced into the reservoir or "rail" by means of a pump unit of one or more cylinders, the actuation of said pump being timed in such a way as to build up a predetermined fuel pressure in the "rail" at the beginning of injection of the fuel into each of the respective cylinders in accordance with the load under which the engine is to be operated but to have substantially zero delivery during the injection period of any cylinder, the elasticity of the fuel under pressure being such as to displace predetermined amounts of fuel from the system in accordance with the resulting fuel pressure drop.

A further object of my invention resides in the provision of an improved fuel pressure supply system especially adapted for use in conjunction with an improved fuel injection apparatus, the latter being more particularly described and claimed in my co-pending application Serial No. 706,414, filed Jan. 12, 1934. I preferably arrange for pumping the fuel in the "rail" to the desired amount prior to any injection, the pressure falling off during the injection while the pump has a zero delivery by reason of the injection valve being open. The elasticity of the fuel in the supply line or "rail" provides the necessary quantity of fuel

injected by reason of the drop in fuel pressure, in conjunction with the fuel pressure at the beginning of injection. The fuel pump is thus preferably arranged to increase the fuel pressure in the "rail" in the interval between successive injection periods and not during injection. I desire to point out however, that my improved fuel pressure supply system may be used in conjunction with other fuel injection apparatuses, and my claims are therefore not limited to any particular type of fuel injection valve or apparatus.

In the illustrated embodiments of my invention, the system includes a valve element which is unseated for injection by fuel pressure, but only after a relatively heavy spring load on the valve element has been relieved by a spring controlling device actuated in properly timed relation with the engine. The valve element is then seated to end injection and such seating preferably takes place independently of the relatively heavy spring, the load of such spring being restored on the valve element preferably after the valve has been seated.

While the heavy spring is designed to load the valve element after the same is seated by other means, there are occasions where said heavy spring is released for loading the valve element at the same time said valve element is seated or prior to the seating of the valve element by said other means, the heavy spring thus seating the valve element. Such an occasion may arise when the engine is operated at peak loads, or when subjected to excessive loading, for the reason that under such conditions of engine operation it is found that the injection period may be abnormally prolonged, resulting in excessive fuel consumption and reduction of power output.

In the present embodiment of my invention I have provided a fuel pressure supply system including a fuel injection apparatus having a light spring for urging the valve element on its seat when the fuel pressure has dropped after injection. In this embodiment it is necessary for the heavy spring to load the valve after injection and prior to the fuel pump pressure restoring action in the supply line or "rail" since the restoration of fuel pressure prior to the loading of the valve by said heavy spring would tend to open the valve prematurely. The heavy spring load is therefore restored on the valve after injection and before the pumping action on the fuel in the "rail" and before the time for the next injection to occur.

This application is a continuation in part of my co-pending application, Ser. No. 479,836 filed September 5, 1930.

For a more detailed understanding of my invention, reference may be had to the accompanying drawings which illustrate several forms which my invention may assume, and in which similar reference characters indicate corresponding parts:

Fig. 1 is a side elevational view of an internal combustion engine of the compression ignition type constructed in accordance with my invention and embodying a system employing a constant stroke pump operated in timed relation with the engine and a cooperating regulable fuel pressure regulator for maintaining a predetermined fuel pressure in said system at the beginning of injection, depending upon the load under which the engine is to be operated,

Fig. 2 is a fragmentary transverse sectional view of the aforesaid engine with the top cover of Fig. 1 removed showing the fuel injection control means including a valve structure and actuating means therefor which controls the injection of the fuel into the engine cylinder, the valve element being shown seated to close communication between the fuel supply line and fuel atomizing device or nozzle,

Fig. 3 is a fragmentary sectional view of the fuel injection control means showing the valve element unseated,

Fig. 4 is a fragmentary plan view of the engine,

Fig. 5 is a side elevational view of an internal combustion engine of the compression ignition type embodying a modified system having a regulable variable stroke fuel pressure pump operated in timed relation with the engine, said pump being operatively controlled to maintain a predetermined fuel pressure in the system at the beginning of injection, depending upon the load under which the engine is to be operated,

Fig. 6 is a detail sectional view of the pump illustrated in connection with the system shown in Fig. 5,

Fig. 7 is a view graphically showing fuel pressure in a diagrammatic manner as plotted against crank angle in connection with the fuel pressure supply system as illustrated in Figs. 1 to 4 inclusive,

Fig. 8 is a view graphically showing fuel pressure in a diagrammatic manner as plotted against crank angle in connection with the fuel pressure supply system as illustrated in Figs. 5 and 6, and

Fig. 9 is a view graphically showing fuel pressure in a diagrammatic manner as plotted against crank angle in connection with a fuel pressure supply system employing a variable stroke fuel pump of modified construction.

A fuel injection internal combustion engine of the fuel injection type and more particularly of the compression ignition type may be constructed of any suitable engine block structure 10 having one or more cylinders 11 in which the usual form of pistons 12 are reciprocated, said pistons adapted to be connected in the usual way with the engine crankshaft 13. In the aforesaid type of engine, the fuel is sprayed into the cylinder through the atomizing nozzle where it ignites when coming into contact with the compressed air in the cylinder. The means for atomizing the fuel and the means controlling the injection of the fuel into the cylinder are preferably supported by the cylinder head 14 having suitable water jackets 15 communicating with the water jackets 16 about the cylinder 11.

The cylinder head illustrated in the accompanying drawings is preferably provided with a pillar 17 integrally formed with the cylinder head casting and arranged concentrically with respect to the cylinder axis, the pillar being bored out or otherwise constructed with a recess to receive the fuel nozzle and valve structure. The fuel nozzle 18 may be of any standard construction, the same having a central opening 19, a valve seat 20, and one or more openings 21 in the tip of the nozzle. A valve guide 22 is secured in the head by means of bolts 23 or other suitable means. The valve structure, in the embodiment illustrated in Figs. 2 and 3 is constructed of a valve element 24 preferably supported for axial movement in said guide 22, the lower portion of the valve element being provided with a reduced portion 25 guided axially in the bore 19 of the nozzle and having a seating portion 26 at its lower end, a head or flange 27 intermediate its length, and longitudinally extending grooves 28 in said reduced portion 25. The upper portion of the valve element 24 is guided directly in the valve guide 22. A conduit 42a may be provided to conduct away from the

upper end of the valve structure any fuel which might leak past the packing 42b.

The valve element is held on its seat by the pressure of the relatively heavy load of spring 60 acting through the rocker arm 30 which is engaged with the valve structure. Means may be provided for positively actuating the rocker arm, but I have preferably devised a means for releasing the spring pressure from the rocker arm. This is preferably accomplished by compressing the spring by actuating the pull rod 31 through the agency of the eccentric strap and eccentric 32 and 33 respectively, said eccentric being keyed or otherwise secured to the cam shaft 34, said cam shaft 34 being operated in timed relation from the engine crankshaft in the usual manner, and being operated at one half crankshaft speed for the usual four-stroke cycle engine.

In the embodiment of my invention as illustrated in Figs. 1 to 4 inclusive, the fuel is conducted to a pump 35, through a pipe or conduit 36 from a fuel tank F or other source of fuel supply and thence forced into a fuel supply line 37 or reservoir, commonly known as a "rail" by way of the connecting pipes or conduits 36a. branch pipes or conduits 38 connect the "rail" with each of the cylinders, and if desired, suitable valve 39 may be employed for respectively shutting off the supply of fuel to any one of said cylinders. A regulable pressure relief valve 40, which is preferably of the type that may be adjusted or operated during engine operation, may be employed to maintain a predetermined initial fuel pressure in the fuel line or "rail" at the beginning of the injection, such adjustment depending on the load under which the engine is to be operated. I preferably connect the fuel pump up with the engine mechanism in such a way as to actuate the pump to bring the fuel pressure up to a predetermined amount at the beginning of each injection. One or more strokes may be given to the pump, and one or more pump cylinders may be employed, but preferably the pump is constructed so that each stroke of the pump will bring the fuel pressure up to the required amount so as to provide a predetermined pressure in the "rail' at the beginning of injection, said pump having a substantially zero delivery during the injection period.

The specific details of the regulator form no part of the present invention, inasmuch as any suitable regulator will serve the purpose. However, the particular regulator shown in connection with the fuel pressure supply system illustrated in Figs. 1 to 4 inclusive forms the subject matter of a copending application, Ser. No. 515,210, filed February 12, 1931, said regulator being manually adjusted by means of the control devices 40a and 40b for controlling the fuel pressure in "rail" 37.

The fuel pump 35 is driven by gearing 35a from crankshaft 13 in timed relation to camshaft 34 so that the fuel pressure in the "rail" 37 will be restored after any injection, the fuel pump increasing the fuel pressure in the supply line or "rail" subsequently to any injection and preferably prior to the beginning of the next injection thereafter. In other words the pump is not relied on to produce pressure during any injection, the initial pressure at the beginning of injection and the elasticity of the fuel in the supply system providing for the desired quantity of fuel injected in a manner more particularly hereinafter set forth.

The branch pipes or conduits 38 are arranged to be connected with a passage 41 in the valve guide by a union 42 or other suitable fitting. The passage 41 communicates with an enlarged bore 43 within the valve guide, the bore 43 being slightly larger than the head or flange 27 of the valve element 25 to permit the fuel to flow freely past the head and into the chamber 43a beneath the head and thence though the grooves 28 in the lower portion of the valve element into chamber 45. A relatively light load compression coil spring 44 bears on the head or flange 27, yieldingly urging the valve element on its seat. The fuel may flow through the grooves 28 in the valve portion 25 into the nozzle chamber 45 formed by the reduced end portion of the valve portion 25 and thus may flow through the jet openings 21 of the atomizing nozzle when the valve is unseated.

Thus, when the spring 60 is compressed, releasing the rocker arm, the fuel pressure may then lift the valve, this pressure exerting a lifting force on the valve element greater than the remaining forces tending to seat the valve. Immediately on lifting of the valve the fuel is sprayed into the cylinder under pressure, and the pressure of the fuel in the "rail" will drop, as well as the fuel pressure in the bore 43 that is in open communication with the "rail". When the fuel pressure falls a predetermined amount sufficient to allow the spring 44 to overcome the pressure acting to unseat the valve element 24, the spring 44 will force the valve element 24 axially downwardly and seat the seating portion 26 of said valve on the seat 20, thus closing the openings or jets 21.

After the rocker arm 30 is forced down and seated on the head or tappet 24a carried by the valve element, by relieving the compression of spring 60, the valve is held seated until the spring 60 is again compressed releasing the downward pressure of the spring 60 on the valve structure. The fuel pump 35 is timed with the crankshaft 13 as aforesaid and with camshaft 34 so that the pressure of fuel in rail 37 is restored after each injection takes place and preferably prior to the beginning of the next injection, the pump not being operative for restoring the fuel pressure during any injection. Thus, for the four cylinder four stroke cycle engine illustrated, an injection takes place every 180° of crankshaft rotation, as is customary, gearing 35a for pump 35 being indicated as imparting two strokes to the pump for one revolution of crankshaft 13. For other numbers of cylinders and for two-cycle engines the timing of the parts including the pump and camshaft will obviously vary. The pump is timed in such a manner as to not deliver until the load of spring 60 is applied to hold the valve element on its seat.

The pump 35 delivers excess fuel at all loads so that, by adjusting the pressure relief device or regulator 40, the pressure of the fuel in the supply line or "rail" 37 may be varied and in this way the quantity of fuel injected may be governed to control the engine power output, since the amount of fuel injected depends in part on the fuel pressure at the beginning of injection as well as the elasticity of the fuel in the system.

Just by way of example, I have operated engines constructed according to my invention, wherein the fuel pressure in pounds per square

inch in the "rail" 37 varied from approximately 800 to 900 at idling speeds to approximately 4000 at full engine loading, the pressure in pounds per square inch in "rail" 37 falling off after any injection to approximately 300 to 500 at idling speeds and to approximately 1,000 to 2,000 under load. The pressure in the "rail" after injection at idling speed will, of course, depend on the load of the light spring 44, such load being approximately 30 to 40 pounds in the engine referred to while the load of the heavy spring 60 was in the neighborhood of 300 pounds. I do not in any way limit my invention to any particular values of the said spring loads, fuel pressures, etc., as these will vary in different engines and according to the results and performance desired.

It will thus be noted that I have provided means for mechanically controlling the opening of the valve which is unseated by fuel pressure and for automatically closing the valve independently of spring 60 and camshaft 34. The amount of fuel injected in the cylinder may be readily varied by varying the fuel pressure in the "rail" or supply line at the beginning of the fuel injection period by means of the control valve or regulator 40. It may be further noted that it is not necessary to provide a finely adjusted mechanism for controlling the valve lift as the same is lifted the maximum amount at each operation of the fuel injection means, whatever the engine speed or load may be. Thus I have provided what may be termed as a constant stroke means timed with the engine for controlling the opening of the fuel injection valve and independent means regulating the quantity of fuel injected into the cylinder. A quick return of the rocker arm is not necessary as the valve is automatically closed independently of the valve opening mechanism, the rocker arm preferably loading the valve at any time after the valve has been seated and prior to the time for the next pump delivery and obviously prior to the next injection for the same valve.

The successful operation of an engine of the compression ignition type depends largely on the proper timing and control of the fuel injection and my construction is simple but very effective in providing such a control without frequent adjustment. Wear such as will materially affect the operation of an ordinary engine having a constant pressure fuel injection system, will not affect the operation of my engine.

It will be further noted that my construction is well adapted for use with an engine of the heavy oil compression ignition type as well as with engines employing light fuel oils or other fuel.

In operation of the construction illustrated in Figs. 1 to 4 inclusive, the fuel pressure prior to injection tends to unseat valve 18. In Fig. 2, the rocker 30 is holding valve 18 seated. In Fig. 3 injection is taking place, rocket 30 having been moved to unload spring 60 and the fuel pressure having unseated valve 18. When the fuel pressure drops sufficiently spring 44 then moves the valve element 18 toward its seat ending the fuel injection. The fuel pump 35 is timed so that the fuel pressure in "rail" 37 is not restored until after rocker 30 again transfers the load of spring 60 to the valve, since otherwise the valve would tend to unseat in response to the pump and not in response to rocker 30. Thus, after any injection takes place, the rocker arm associated with the valve controlling such injection must be restored to load the heavy spring 60 on such valve element prior to a pressure impulse of pump 35 in "rail" 37. In other words, when pump 35 is actuated to restore the fuel pressure to the "rail", all rocker arms 30 must be in the position of Fig. 2, loading the associated valves.

However, the timing of camshaft 34 and pump 35 may be as follows. After injection of any valve, the valve will automatically seat due to the drop in fuel pressure. After valve seating, the camshaft 34 may restore the load of spring 60 on the valve, and then pump 35 may restore the fuel pressure in rail 37, the system then being ready for the next injection in the engine firing order. As stated before, in such instances where the load of spring 60 is applied before the fuel pressure drops an amount sufficient to permit spring 44 to seat the valve, at such times when the engine is operated at peak loads, the spring 60 actually does the closing of the injection valve, but it will be obviously understood that this occasion will only arise during those rare occasions when said engine is operated at peak load or under excessive loading, the spring 44 for the most part, being depended upon to seat the valve element 24 and end fuel injection.

In Figs. 1 to 4 inclusive, the valving structure controlling injection of fuel in this embodiment of my invention may be referred to as including the valve element 18 and the valve controlling element or rocker arm 30 which, by reason of its contacting relation with the head or tappet 24^a, cooperates with the valve element. The valve may seat ahead of restoration of the load of spring 60 on the valve in all embodiments of my invention.

Figs. 5 and 6 illustrate a modified embodiment of my invention and more specifically it will be noted that this modified fuel pressure supply system is particularly distinguished from the construction illustrated in Figs. 1 to 4 inclusive, by reason of the provision of a regulable variable stroke pump A instead of the constant stroke pump 35, and in the absence of a fuel pressure regulator 40, this regulable pump "A" being such as to control the fuel pressure in the fuel supply line or "rail" at the beginning of injection.

It will be understood that any suitable type of variable stroke fuel pump may be incorporated in my fuel pressure supply system, but in order to clearly illustrate this embodiment of my invention, I have chosen to illustrate a suitable type of variable stroke fuel pump, as hereinbefore described, that has proved satisfactory in actual use.

This pump structure "A" includes a low pressure pump unit 70, preferably consisting of cooperating gears 70^a and 70^b driven by shaft 71, which is in turn driven from the engine crankshaft 13 in timed relation therewith by suitable gearing 72, similar in many respects to the gearing 35^a for driving the pump 35. An eccentric 73, driven by the shaft 71, actuates the plunger 74 by reason of its engagement with the roller 75 carried by said plunger 74. The plunger carries a piston 76 movable axially in the high pressure pump chamber 77, the fuel in said pump chamber being thereby pumped into line 78 through the exhaust outlet 79. The line 78 communicates directly with the fuel pressure supply line or "rail" 37 and thence through the communicating conduits 38 to the fuel atomizing devices associated respectively with the engine cylinders, the communication between the "rail" and atomizing device being controlled by the same type of fuel injection control means as in Figs. 1 to 4

inclusive including a valve element opened by fuel pressure.

In the operation of this pump "A", the fuel is conducted to the low pressure pump 70 through the conduit or pipe 80 connecting the fuel tank F with the inlet 80' of said pump 70. The outlet of the pump 70 is connected with the conduit or pipe 81, which is in turn connected with the suction side of the high pressure pump unit. The suction side or intake of the high pressure pump is controlled by a poppet valve 82 which is opened and closed in timed relation to the operation of the plunger 74, the rocker arm 83 being so actuated as hereinafter described to effect the actuation of said valve 82. A chamber 84 is provided behind or above the valve 82, this chamber communicating with a passage 85 in the pump casing that communicates with the conduit or pipe 31. Preferably a filter 86 is inserted in conduit 81 for filtering the fuel.

This suction valve 82 is preferably actuated in timed relation with the high pressure pump operation. The rocker arm 83 is actuated by a push and pull rod 87 which is pivoted thereto as at 88, the lower or inner end of said rod being connected with the plunger 74 by reason of its connection with the extension 89 of the stub shaft 90 that supports the roller 75 on the plunger 74. The rocker arm 83 is fulcrumed within an adjustable member 91 and as the cam 73 lifts the plunger 74 it imparts a corresponding movement to the push rod 87 thereby rocking the rocker arm and permitting the suction valve 82 to close.

It will be noted that during the delivery stroke of the piston 76 the fuel which has been drawn into the chamber 77 past the open suction valve 82 is pushed outwardly of the piston chamber 77 and is not forced by the discharge valve 79^a which is associated with the fuel outlet until the suction valve 82 is closed by reason of its actuation by the said rocker arm structure. Thus the effective stroke of the high pressure pump is less than the full stroke of the piston 76 when the suction valve 82 is opened during a portion of the stroke. The closing of this suction valve may be varied by adjusting the fulcrum member 91, said adjustment being controlled by moving the actuating lever 92 attached to this adjustable fulcrum member, rotation of this member providing an adjustment of the fulcrum point of the rocker arm and it is thus possible to close the suction valve earlier or later during the working stroke of the piston 76. In the device shown in connection with Figs. 5 and 6, it is noted that the beginning of the effective stroke of the high pressure pump is varied for controlling the effective stroke of the pump, the greater the effective stroke the higher the pressure which will be introduced into the fuel pressure supply line or "rail" 37.

In Fig. 8 I have graphically illustrated the variation in pressure which is obtained by reason of the adjustment of this variable stroke pump incorporated with my modified fuel pressure supply system. For relatively low engine load operation I have preferably illustrated the fuel pressure variation in the system by curve I, and it will be noted that the effective stroke of the pump begins at 93, the pressure rising as shown by the curve 94 until the end of the pump stroke is reached as at 95. Injection begins at 96, preferably in advance of the time the piston reaches its outermost position of travel or T. D. C., and the fuel pressure drops as shown by the curve 97 until the pressure is such as designated by the point 98 when the spring 44 overcomes the fuel pressure and seats the valve element thereby ending fuel injection into the engine cylinder.

By adjusting the variable stroke pump, the suction valve may be caused to close earlier during the stroke of the piston 76 and in Fig. 8 I have shown by a curve II in solid lines the pressure rise in the fuel supply line or rail which takes place with an adjustment of this type. It will be noted that at point 93^a the effective stroke of the pump begins, the curve 94^a representing the rise in pressure during the pump stroke, the point 95^a represents the end of the pump stroke, and it will be noted that the pressure at 95^a is greater than the pressure at 95 and that the end of the pump stroke in curves I and II occurs at the same time in the engine cycle. Injection begins at 96^a and continues as shown by the curve 97^a, representing a fuel pressure drop until the pressure again reaches the point where the spring 44 may close the valve element controlling the fuel injection into the engine combustion chamber, this point being designated as 98^a.

A further adjustment of the pump provides for a further increase in the fuel injected into the engine combustion chamber and I have preferably illustrated this condition of engine operation by means of a curve III of dot and dash lines representing fuel pressure variation as plotted against crank angle in Fig. 8, this curve III showing the effective pump stroke beginning at 93^b and ending at 95^b, the curve 94^b representing the increase in fuel pressure as a result of this effective pumping stroke. The fuel injection begins at 96^b, the fuel pressure dropping as represented by the curve 97^b until the pressure is dropped to such a point which will permit the spring 44 to seat the valve element, thereby shutting off the injection, this closing of this injection valve occurring when the pressure has dropped to a point as represented on the curve III by the point 98^b. This last mentioned curve is representative of an operation for substantially full engine load.

In the construction of the engine as shown in the illustrated embodiment of my invention, I have preferably provided a cam means or its equivalent for compressing and releasing the spring 60 for respectively unloading or loading the valve element. In the diagram (Fig. 8) the beginning of injection occurs with the initial unloading of the valve element and is represented by the dot and dash line 99, indicating the beginning of fuel injection, and the releasing of this spring 60 and the consequent loading of the valve element is designated by the dot and dash line 100. It will thus be noted that at full engine loading the drop of fuel pressure in the fuel supply line to the point where spring 44 effects a seating of the valve element preferably occurs substantially at the same time as the spring 60 is released for loading said valve element, while in the operation of the engine at loads less than full load operation the valve is seated prior to the loading of the valve element. Occasions may arise where the engine is subjected to peak loads and under these conditions the suction valve 82 is probably closed at the beginning or very near the beginning of the stroke of the piston 76. The pressure rise due to this operation of the engine at an excessive loading is graphically illustrated by the dotted line curve V in Fig. 8 in which the point 93^c designates the beginning of the effective pump stroke, curve 94^c designates the rise in pressure during the pump delivery, point 95^c represents the end of the pump stroke and 96^c represents the beginning of injection in response to

the lifting of load induced by spring 60 from the valve element 24. The pressure of the fuel in the system will drop during injection, since the pump is not delivering at this time, the drop in pressure being graphically illustrated by curve 97^c. The fuel pressure drop is such as to reach a point designated on the curve at 98^c at the time when the pressure of spring 60 is loaded on the valve element for seating same. It will be noticed that the pressure at 98^c is greater than the pressure which permits the spring 44 to seat the valve element and therefore under this extreme condition of engine loading the cam or its equivalent acts to seat the valve.

It will be observed that when the engine loading is increased over and above the condition as represented by curve III that the minimum fuel pressure in the fuel supply line or "rail" intermediate the fuel injection periods is greater than the minimum pressures obtained in the operation of the engine under normal load conditions.

I have preferably illustrated by the curve IV a slight overload condition of engine operation, this curve showing an effective pump delivery as represented by a fuel pressure rise from point 93^d to 95^d which indicates graphically a certain definite quantity of fuel which is pushed or delivered to the fuel supply line or "rail" 37. The curve intermediate points 96^d and 98^d represents the delivery of fuel from the supply line into the engine, and it will be noted that there is less fuel injected into the engine than is delivered by the pump to the supply line or "rail" so that the minimum pressure following injection is greater than the fuel pressure before injection and the initial pressure at the beginning of the next pump stroke is greater than that at the beginning of the preceding pump stroke. The minimum of pressure in the system intermediate the ending of injection and the beginning of the next pump stroke is represented by the horizontal line 101^d, and during the next pump delivery the fuel pressure will be increased a greater amount than during the preceding pump stroke as represented by the curve 102^d until at the end of the pump stroke the pressure is indicated by the point 103^d. In the following injection period a proportionally greater amount of fuel is injected into the combustion chamber through the fuel atomizer and it will be observed that after a few injections the amount of fuel discharged from the fuel supply line into the combustion chamber through the atomizer will balance with the amount of fuel delivered into said fuel line or "rail" by the pump. When this balanced condition is reached, it will be noticed that there is no more increase in the peak pressures obtained in the fuel supply line, the curve V representing the rise and fall in pressures resulting respectively from the operation of the pump and the injection of the fuel into the engine cylinders under such peak load engine operation.

In Fig. 9 I have graphically illustrated by curves 1A, 2A, 3A and 4A the variations in fuel pressure in the fuel supply line resulting respectively from a relatively low load engine operation, a medium load engine operation, full load engine operation and a peak load engine operation. These curves are representative of the fuel pressure variations obtained with the employment of a variable stroke pump of modified construction in which the ending of the effective pump stroke is varied instead of the beginning as graphically illustrated in Fig. 8. A pump of this character is very similar in construction to that illustrated in Fig. 6, with the difference that the suction valve 82 is controlled by suitable mechanism which holds the same closed at the beginning of the stroke of the piston 76, but which opens the valve at various times during the stroke of the piston, thereby providing an adjustable cut-off of the pump delivery.

The results obtained with the pump such as represented by the curves shown in Fig. 9 are substantially the same as obtained with the preferred type of pump which is illustrated in detail in Fig. 6 and whose action is graphically illustrated in Fig. 8.

In Fig. 7 I have indicated by means of curves 1B, 2B and 3B the variations in fuel pressure as obtained with a fuel pressure supply system as employed with the embodiment as illustrated in Figs. 1 to 4. In this embodiment a constant stroke pump is employed in cooperation with a fuel pressure regulator, said regulator controlling the fuel pressure at the beginning of injection.

Curves 1B and 2B graphically represent the fuel pressure variations for relatively low load engine operation and full load engine operation respectively. Referring to curve 1B it will be noted that the pump stroke begins at 110 and ends at 111 at which point the pressure regulator is actuated to discharge excess fuel into the fuel tank F. The regulator 40 maintains the fuel pressure substantially constant as represented by curve 112 until at 113 fuel injection begins by reason of the fact that the load of spring 60 is released on the valve element permitting this fuel pressure to open the valve for injection of the fuel into the engine. At 114 fuel injection ends due to the closing of the valve element by the spring 44 after a predetermined drop in the fuel pressure. For high load engine operation, the pump stroke is effective to increase the fuel pressure in the fuel supply line from point 110^a in curve 2B to point 111^a at which time the regulator 40 is actuated to discharge the excess fuel delivered by the fuel pump into the fuel tank. Injection begins at 113^a, but due to the fact that the initial pressure at the beginning of injection is greater than in the case illustrated by curve 1B where the engine is operated under low load, more time is consumed in permitting the fuel pressure to drop to a predetermined degree where the spring 44 may seat the valve element to cut off or end injection. The end of injection is indicated at point 114^a.

An engine equipped with a fuel pressure supply system as shown in Figs. 1 to 4 inclusive, may be also operated at peak loads in excess of the normal high load engine operation, the curve 3B representing the variations in fuel pressure in the fuel supply line under such peak engine load operation. In such peak load operation the fuel pressure is increased by the pump, the maximum pressure being regulated by the regulator which controls the pressures at the beginning of injection. In this instance, the pump stroke begins at 110^b and ends at 111^b, where the regulator comes into action. The peak pressure obtained at 113^b is greater than the peak pressure obtained at 113^a, and the injection of the fuel into the combustion chamber results in a drop in fuel pressure until the point 114^b is reached, at which time the spring 60 again loads the valve element. In this peak load engine operation it will be observed that the closing of the valve element is obtained by reason of the positive closing of

the same when the spring 60 loads the valve element. The balancing of the input with respect to the output is attained in substantially the same way as with the variable stroke pump as illustrated in Figs. 5, 6 and 8 and graphically illustrated by curve IV.

The operation of the two fuel pressure supply systems as illustrated in the accompanying drawings are broadly similar. It will be observed that during most of the range of engine load operation that the fuel injection valve element is preferably seated by means of the relatively light spring 44 prior to the loading of said valve element by spring 60. In all cases employing valve elements of this type, the valve element is loaded by spring 60 prior to the beginning of the pump delivery. In all cases the pump is preferably not delivering during injection of fuel under pressure to the engine combustion chamber, and the quantity of fuel injected depends on the fuel pressure in the system at the beginning of injection and the elasticity of the fuel in the system.

Although it is preferred to have an engine operation in which the fuel pump delivery positively ends before injection begins, I wish it to be understood that this operation is not necessary under all conditions, since the pump delivery may be timed with the engine operation in such a way as to end slightly after injection begins but in no event shall the overlapping of pump delivery and injection occur at the end of injection, and the extent of such overlapping shall not exceed 25% of the injection period, for control of engine idling would then be difficult since the quantity of fuel delivered to the engine would then exceed that amount which is required for steady engine operation at idling speeds. In the claims where it is specified that the pump has substantially zero delivery during injection, I wish it to be understood that the scope of the claims is such as to lie within the limits as aforesaid.

In cases where fuel injection valve elements of the character, as specifically shown and described in my co-pending application, Ser. No. 706,414, filed Jan. 12, 1934, in which a two part valve element is employed and a pressure seating of the lower valve element is provided for to supplement the seating action of the spring, it is not necessary that the spring 60 load the valve element prior to the beginning of the pump delivery, though in order to provide for accurate fuel delivery to the engine, it is necessary that the pump delivery take place after one injection period ends and before the next injection period begins.

In some instances, it will be found desirable to slightly advance or retard the beginning of injection, this being especially desirable in engines having a relatively wider speed range, the timing of injection beginning being attained in any well known manner. The graphical representations in Figs. 7, 8 and 9 correspond to an engine operation in which the beginning of injection is held constant, it being understood that variations in this injection timing lie well within the scope of my invention, the only necessary condition being that the fuel pump delivery must end prior to the earliest point of injection.

It will be apparent to those skilled in the art to which my invention pertains that various modifications and changes may be made therein without departing from the spirit of my invention or from the scope of the appended claims.

What I claim as my invention is:

1. In a fuel injection system for a multi-cylinder internal combustion engine of the fuel injection type having cylinders each provided with a fuel inlet opening and an associated fuel atomizing device, a fuel supply line communicating with said fuel atomizing devices, a fuel injection control means including a pressure opened fuel injection valve one for each cylinder for controlling the communication between said supply line and atomizing device, mechanical means for holding said valve closed and operable in timed relation with the engine for releasing said valve to permit the pressure in said fuel supply line to open said valve, said valve being closed in response to a predetermined drop of pressure in said fuel supply line, and fuel supply means delivering fuel under pressure to said fuel supply line, said fuel supply means being driven in timed relation with said engine timed means whereby to deliver the fuel to said supply line intermediate successive injections of fuel to the engine, and to provide for substantially zero fuel delivery from said fuel supply means to said supply line during injection to any of said cylinders associated with the aforesaid fuel supply line under substantially normal engine operation, said mechanical means being operatively timed relative to the operation of said fuel supply means to hold the valve closed prior to delivery of fuel by said fuel supply means.

2. In a fuel injection system for a multi-cylinder internal combustion engine of the fuel injection type having cylinders each provided with a fuel inlet opening and an associated fuel atomizing device, a fuel supply line communicating with said fuel atomizing devices, a fuel injection control means including a pressure opened fuel injection valve one for each cylinder for controlling the communication between said supply line and atomizing device, non-regulable mechanical means for holding said valve closed and operable in timed relation with the engine for releasing said valve to permit the pressure in said fuel supply line to open said valve, said valve being closed in response to a predetermined drop of pressure in said fuel supply line, and fuel supply means delivering fuel under pressure to said supply line, said fuel supply means being driven in timed relation with said engine timed means whereby to deliver the fuel to said supply line intermediate successive injections of fuel to the engine, and to provide for substantially zero fuel delivery from said fuel supply means to said supply line during injection to any of said cylinders associated with the aforesaid fuel supply line under substantially normal engine operation, said mechanical means being operatively timed relative to the operation of said fuel supply means to hold the valve closed prior to delivery of fuel by said fuel supply means.

3. In a fuel injection system for a multi-cylinder internal combustion engine of the fuel injection type having cylinders each provided with a fuel inlet means, a fuel supply means for maintaining a supply of fuel under pressure and including a fuel pump, a fuel injection apparatus associated with each of said fuel inlet openings and including a fuel injection valve one for each cylinder, means actuated in timed relation with the engine for controlling the opening of said valve to permit the discharge of fuel into the engine cylinder and causing the dropping of fuel pressure in said fuel supply means, said valve closing in response to a predetermined drop in fuel pressure in said fuel supply means, said fuel

pump delivering fuel to said fuel supply means substantially during the time the valves associated with any of the cylinders associated with the aforesaid fuel supply are closed and having substantially zero delivery when said valves are open, said means controlling the opening of the valve being actuated in timed relation with respect to the fuel pump operation to hold the valve closed prior to delivery of the fuel by said pump.

4. In a fuel injection system for an internal combustion engine of the fuel injection type having a cylinder provided with a fuel inlet opening and an associated fuel atomizing device, a fuel supply line communicating with said fuel atomizing device, a fuel injection control means including a pressure opening fuel injection valve for controlling the communication between said supply line and atomizing device, mechanical means for holding said valve closed and operable in timed relation with the engine for releasing said valve to permit the pressure in said fuel supply line to open said valve, said valve being closed in response to a predetermined drop of pressure in said fuel supply line, fuel supply means delivering fuel under pressure to said fuel supply line and including regulable means for controlling the pressure of the fuel delivered to said fuel supply line, said fuel supply means being driven in timed relation with said engine timed means whereby to deliver the fuel to said supply line and to provide for substantially zero fuel delivery from said fuel supply means to said supply line during injection into said cylinder under substantially normal engine operation, said mechanical means for holding the valve closed being actuated to hold the valve closed prior to delivery of fuel from said fuel supply means to said fuel supply line.

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