March 15, 1966 J. L. GRATZMULLER 3,240,192

FUEL INJECTION APPARATUS FOR INTERNAL COMBUSTION ENGINES

Filed Dec. 13, 1963 4 Sheets-Sheet 1

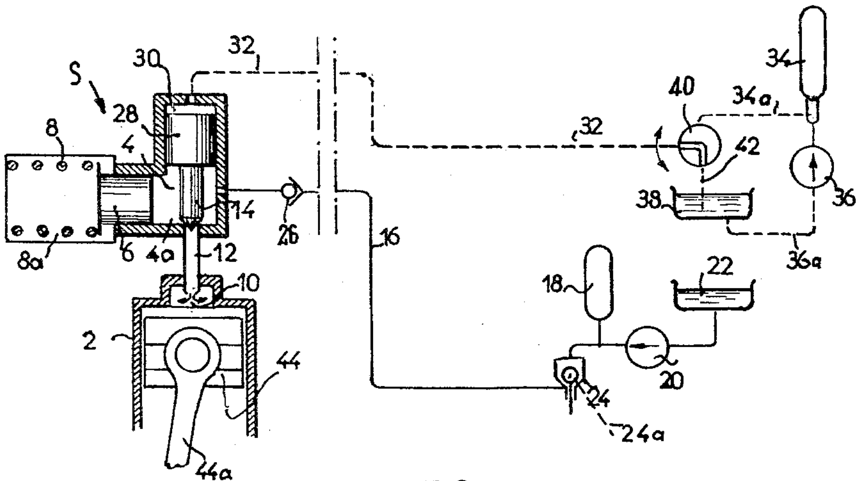


FIG. 1

FIG. 2

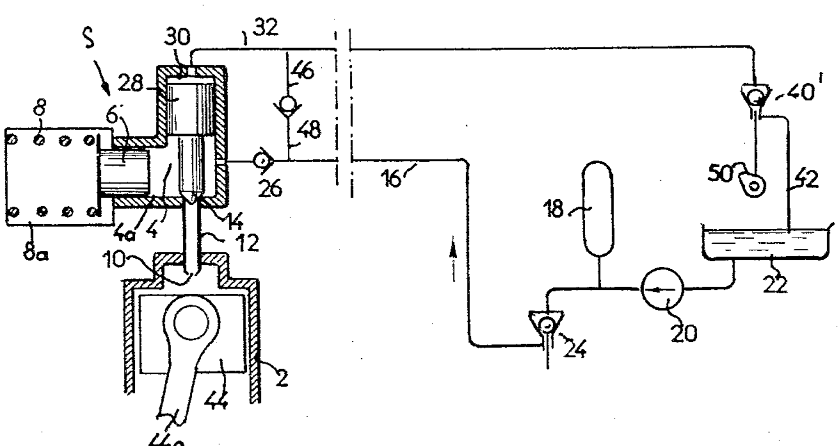
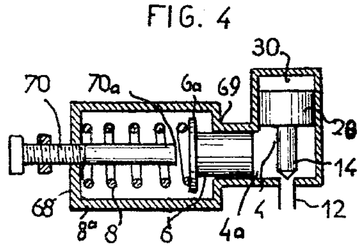


FIG. 4



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FUEL INJECTION APPARATUS FOR INTERNAL COMBUSTION ENGINES

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FIG.3

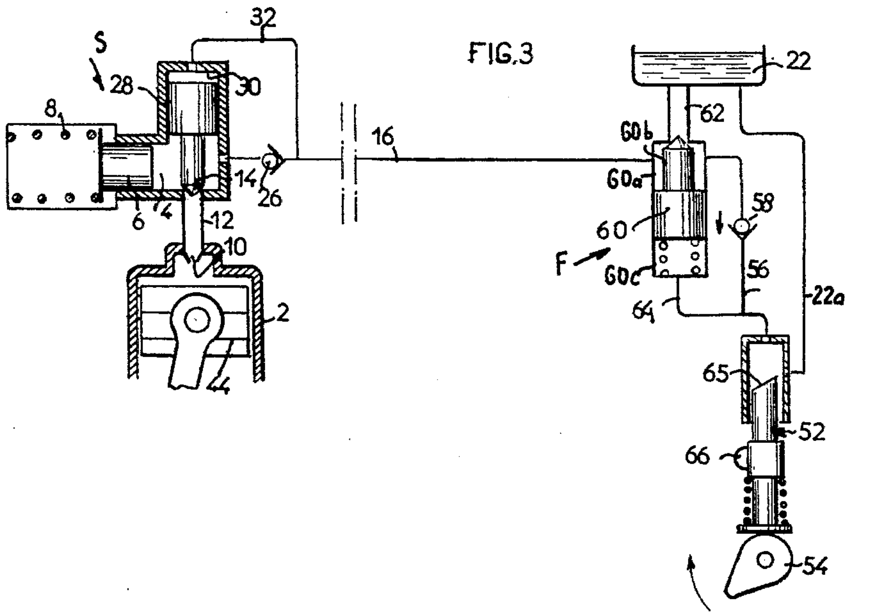


FIG.5

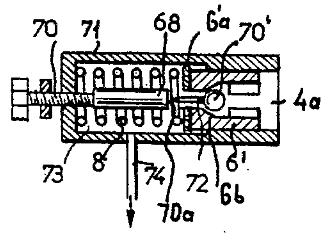
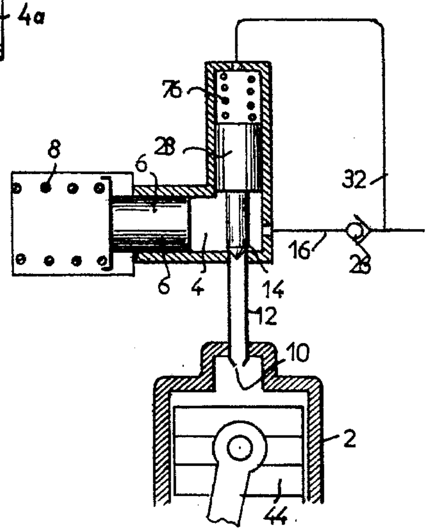


FIG. 6



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FUEL INJECTION APPARATUS FOR INTERNAL COMBUSTION ENGINES

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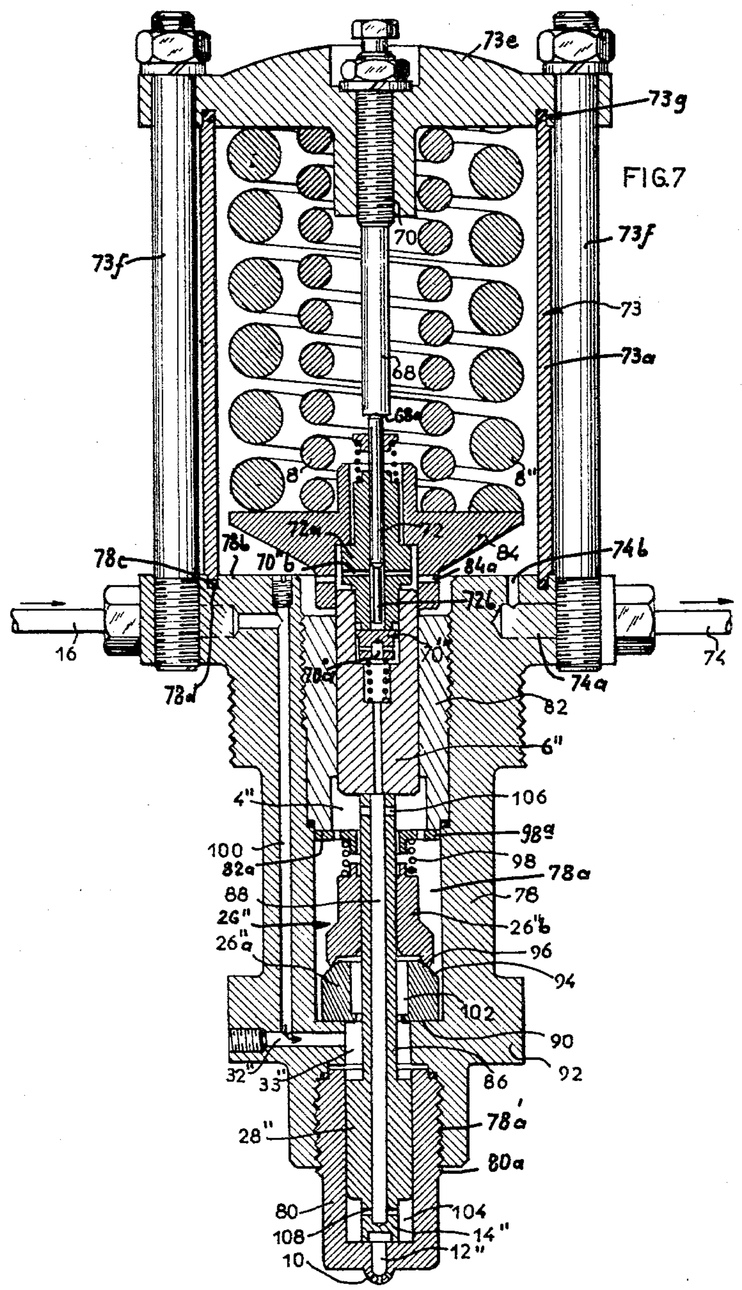
FIG.7



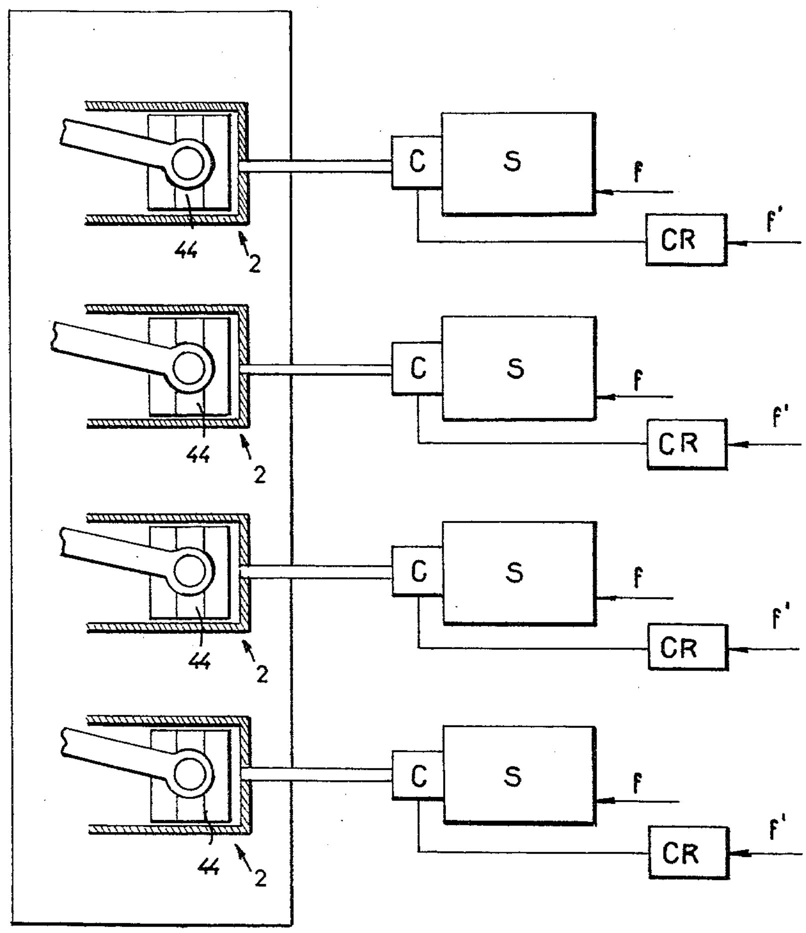


FIG. 8

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FUEL INJECTION APPARATUS FOR INTERNAL COMBUSTION ENGINES

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Claims priority, application France, Dec. 20, 1962, 919,250
12 Claims. (Cl. 123—32)

This invention relates to fuel injection techniques used in supplying fuel to the cylinders of internal combustion engines, and to apparatus for carrying such techniques into practice.

With certain types of internal combustion engines, and particularly Diesel engines, it is desirable to inject an accurately metered quantity of fuel into the engine cylinders, i.e., a quantity which is pre-set relative to the oxygen content of the air contained within each engine cylinder to which the fuel is supplied. Furthermore, it is desirable that an injection technique be used which insures random dispersal of the fuel within such air to effect most efficient combustion. Even further, it is important that the injection commence at a fixed time with respect to the cycle of operation of the engine, and in turn, the cylinder into which the injection is made. Additionally, it is known to be desirable to have a substantially constant pressure throughout the entire injection period since this readily permits a controlled injection of fuel.

Bearing in mind the foregoing, it will be understood that the basic considerations involve (a) precise timing control of the initiation of the fuel injection operation, and (b) maintenance of constant pressure throughout the injection period. Auxiliary to these considerations are the accurate metering and proper mixing aspects.

The instant invention is directed to efficient yet simple techniques, and efficient yet simple apparatus, for accurately controlling the initiation of a fuel injection operation and for maintaining constant pressures during such operation, which techniques and apparatus further provide for, and readily permit, accurate metering of the fuel injected during an injection operation, and proper mixing of the fuel injected with the air in the chamber receiving the injection.

To fully appreciate the invention, it is necessary to comprehend the time characteristics of internal combustion engines to which fuel injection techniques can be advantageously applied. It has been found that the injection of fuel in an internal combustion engine properly takes place over a substantially minor part of the cycle of the engine. For example, in a four-cycle engine, the proper injection period for any given cylinder exists during a 20° displacement or rotation of the engine crankshaft—i.e., a 20° crankshaft displacement corresponds to the injection period of a given cylinder, and the remaining 700° (two rotations) of the cycle corresponds to a dwell or dead period insofar as the injection period for that cylinder is concerned. Translated into fractions, the injection lasts 20/720 of the cycle or 1/36 of the cycle.

Consistent with the above discussion, the importance of instantaneous injection initiation in a Diesel engine, for example, can readily be understood by considering a four-cycle engine operating at 1500 r.p.m. In such engine, the total duration of the injection period for any given one of the cylinders during any given cycle of operation is of the order of 2/1,000 of a second. Within this very short time period, the injection must take place and any control system causing the injection must operate to permit the injection. The control, as known, should be carried out in synchronism with operation of the engine. To this end, the crankshaft, for example, can be used to provide the initiating movement. Yet, the injection takes place at the top of the cylinders, and there is substantial distance between the crankshaft and the top of the cylinders.

The delays such as inherently experienced with conventional mechanical controls linked over such distance cannot be tolerated with short critical times of the order in question. Moreover, with mechanical arrangements, operating temperatures and time irregularities present themselves even with precision equipment, and for this additional reason, conventional mechanical control arrangements are not suitable for use as injection initiation controls.

Previously suggested hydraulic controls are also subject to inaccuracies. Specifically, where the injection is controlled through the application of pressure to the controlling means, there is an inherent delay of the order of 1/1,000 of a second by virtue of the inherent hydraulic problems. While this delay appears small in magnitude, the same is large when compared with the small injection period experienced—i.e., injection periods of the order of 2/1,000 of a second. A similar situation exists where electrical controls are use. Here, current delays are encountered in operating solenoids, for example.

As indicated above, the primary object of the present invention is to provide a method of controlling fuel injection in an internal combustion engine, which method is not subject to the aforesaid disadvantages, and which method insures precise timing of the injection operation. To this end, it is a specific object of the present invention to provide such a method wherein the injection operation is initiated through a lowering or diminishing of hydraulic pressure used for injection control, whereby the response of the control is instantaneous—i.e., extremely small when compared to even the small total injection times encountered.

Consistent with the above objects, it is a further primary object hereof to provide such a method wherein pressure is applied to the controls associated with each cylinder of the engine to permit the filling of a fuel storage chamber for the cylinder during the non-injection phase thereof, and wherein the pressure is diminished during the injection phase to cause injection of the fuel from the storage chamber to the particular cylinder associated therewith.

Still further, it is a significant object hereof to provide such a method wherein the timing of the injection and non-injection steps are performed in synchronism with the operation of the engine itself, and specifically wherein the steps of the method are timed in accordance with operation of an available timing source such as the engine crankshaft.

By utilizing an "engine synchronized" series of steps and by utilizing a pressure decrease to initiate the injection step itself, accurate timing of the injection operation is achieved. Specifically, a decrease in pressure permits an instantaneous response free of problems which are attendant to operations controlled by pressure increases, e.g., vibration and compression problems. The advantage afforded by the invention in this regard is particularly significant, and can possibly be better understood again by way of example. Where a mechanical operation such as the opening of a valve is to be achieved by pressurizing a hydraulic circuit, one faces the problem of first obtaining the pressure, of then compressing any entrapped gas in the hydraulic system, and of then achieving the mechanical movement. With a pressure decrease, the mechanical movement is comparatively instantaneous since no energy need be used to lower the pressure and since other problems, such as gas entrapment problems are eliminated.

In accordance with the invention, the dwell or dead period which constitutes 35/36 of the cycle is used for metering the fuel and obtaining the necessary energy to effect the desired injection. Specifically, in accordance with the method hereof, separate storage chambers are individually associated and separately coupled with each of the cylinders of the engine. The coupling is effected or controlled by hydraulically responsive control means associated with each of the storage chamber-cylinder subsystems. The cylinders, as conventional, operate with respective cyclically repeating injection and non-injection phases—the injection phase as indicated above, being a minor fractional part of the overall cycle for both phases.

Following the method hereof, a metered quantity of fuel under pressure is accumulated in the storage chamber associated with each cylinder during at least a portion of the non-injection phase thereof. Also, during such phase, the hydraulically responsive control means associated with the cylinder assumes an operative condition resulting from the application of fluid under pressure, which prevents fluid transfer between the cylinder and the storage means coupled thereto. In other words, by applying hydraulic pressure, fluid flow is shut-off between each cylinder and its associated storage chamber during the non-injection phase of the cylinder.

To effect the injection, the pressure on the control fluid is diminished—i.e., the pressure is lowered and preferably removed from the fluid which previously was acting on the control means. Consistent herewith, the control means then instantaneously establishes communication between the storage chamber and the cylinder, thus resulting in the injection into the cylinder of the fuel under pressure.

Apart from the method aspects hereof, the invention has certain more important apparatus aspects. In particular, it is an object hereof to provide an apparatus for carrying out the aforesaid methods, which apparatus includes storage chamber means individually and separately associated and coupled with each of the engine cylinders, hydraulically responsive means for establishing and disestablishing communication between the respective cylinders and their individually associated storage means, and hydraulic circuit means coupled with the control means and adapted to be operated from a convenient timing source such as the engine crankcase so as to instantaneously establish communication between any given chamber and its associated cylinder when an injection operation is indicated, and yet so as to disestablish such communication at required periods. Additionally, it is an important object hereof to provide such an apparatus wherein the control means is responsive to a decrease in applied pressure to achieve the instantaneous establishment of communication between the storage chamber and the particular cylinder associated therewith.

In line with the preceding objects, further significant apparatus objects hereof include: (a) the provision of such an apparatus wherein each storage chamber means thereof is so constructed as to effectively meter the quantity of fuel delivered to its associated cylinder during an injection operation; (b) the provision of such an apparatus wheren each storage chamber means is so constructed that it provides substantially constant pressure on the fuel being injected therefrom during the injection operation; (c) the provision of such an apparatus wherein fuel under pressure is not only fed to the storage chamber means but additionally serves as the hydraulic fluid for controlling the injection operation or specifically the operation of the system control means; (d) the provision of such an apparatus which is responsive to the application of pressure on hydraulic fluid fed to the control means thereof to shut off communication between a given storage means and its associated cylinder during a chamber filling operation, and yet also responsive to a decrease in such pressure to establish the communication between the chamber and its associated cylinder whereby the injection is effected instantaneously as required, and whereby the delays encountered by pressure application through the control system take place during the long dwell or dead periods so as to not adversely affect system operation.

The invention lies in methods of fuel injection and in apparatus combinations and arrangements for carrying out the methods. The invention will be better understood, and objects other than those set forth above will become apparent, when consideration is given to the following detailed description. Such description refers to the annexed drawings presenting preferred and illustrative embodiments of the invention.

In the drawings:

FIGURE 1 is a schematic diagram of a fuel injection system constructed in accordance with the present invention, such system operating in accordance with one embodiment hereof wherein the system hydraulic control circuit is independent of the system fuel supply circuit;

FIGURE 2 is a schematic diagram of a modified fuel injection system constructed in accordance herewith wherein the fuel itself is used as the fluid in the system control circuit;

FIGURE 3 is a schematic diagram of a further modified form of fuel injection system constructed in accordance herewith wherein the injection is controlled in accordance with fuel supply pressure and using the fuel itself in the system control means;

FIGURE 4 is a fragmental sectional view of a storage chamber means constructed in accordance herewith and having therein control valve means and metering means operated in accordance with the invention;

FIGURE 5 is a fragmental sectional view of a modified metering means adapted to be used in a storage chamber means constructed in accordance herewith;

FIGURE 6 is a fragmental view, partially in section and partially schematic, showing a further modified storage chamber means constructed in accordance herewith and particularly adapted to be used advantageously in the system of FIGURE 3; and,

FIGURE 7 is a longitudinal sectional view of a preferred form of storage chamber means constructed in accordance herewith.

FIGURE 8 is a general schematic diagram of an overall system constructed in accordance herewith and associated with a plurality of cylinders of an internal combustion engine.

Although the invention is applicable to the injection of fuel in each cylinder of an internal combustion engine, the injection sequence and control is essentially the same for each cylinder and thus FIGURE 1 presents the system hereof as associated with a single cylinder of an internal combustion engine. Such cylinder is designated by the numeral **2**, and as conventional, has a piston **44** reciprocal therein. Piston **44** is coupled with a rod **44*a*** which leads to the engine drive shaft (not shown). The cylinder **2** is fed with fuel through an injection tube or nozzle **12** which leads from a fuel storage means S particularly associated with the cylinder **2**. The storage means S, as shown, has a chamber **30** therein, and a piston **28** is reciprocally movable in the chamber **30**. Such piston carries a depending valve member or arm **14** which is adapted to seat on the upper end of the injection tube **12** to close off fluid communication between the storage means S and the cylinder **2**.

The method of the invention contemplates operating such an arrangement whereby fuel is injected into the cylinder **2** above the piston **44** at a given time, i.e., during the injection phase of cylinder **2**, and whereby the storage means S accumulates a metered quantity of fuel therein during the non-injection phase of the cylinder **2**. It will be remembered from the above discussion that each cylinder of the internal combustion engine has both an injection phase and a non-injection phase. During the injection phase, fuel is injected through the tube **12** into the cylinder **2**, whereas during the non-injection phase, no fuel is injected into the chamber.

Consistent with such method aspects, the system of FIGURE 1 includes a fuel line **16** which leads into the chamber **4** of the storage means S through a one-way non-return valve **26**. This fuel line is supplied with fuel under pressure, such fuel being transferred from the fuel reservoir **22** to a conventional hydropneumatic reservoir **18** via a conventional auto-regulating pump **20**. A control valve **24** is coupled in the line **16** between the hydropneumatic reservoir **18** and the chamber **4** of the storage means S.

The valve **24** is controlled by any suitable means such as, for example, a cam (not shown) which is coupled to the engine crank shaft to sychronize the operation of the valve **24** with the normal cycles of operation of the engine. The valve **24**, according to the invention, only opens the line from the reservoir **18** to the chamber **4** during the non-injection phase of operation of the cylinder **2**. During the injection phase, the valve **24** closes the line **16** so that the chamber **4** does not communicate with the reservoir **18**.

With the above system, and the operation described, fuel is supplied to the chamber **4** of the storage means S during at least a portion of the non-injection phase of such cylinder. As the fuel is supplied to the chamber **4**, the chamber **4** essentially expands. To this end, it will be noted that the storage means S or more specifically the chamber **4** therein has an auxiliary branch **4*a*** in which a piston **6** is reciprocally movable. The piston **6** is normally biased inwardly of branch **4*a*** toward the main chamber **4** by a biasing means which, as shown, takes the form of a spring **8**. The spring **8** is supported in a suitable frame **8*a*** whereby the piston **6** can react against such spring moving to the left as shown in the branch **4*a*** thereby increasing the effective capacity of the storage chamber **4**.

In fact, when fuel under pressure is supplied through the line **16**, it serves to move the piston **6** rearwardly or to the left in the chamber **4*a*** thereby compressing the spring **8**. The movement of the piston **6** is controlled by the compressibility of the spring **8** and the movement of the piston **6** permits the metering of a given quantity of fuel determined by the timed operation of valve **24**, as explained more fully below.

During the non-injection phase of the cylinder **2**, and while a metered quantity of fuel under pressure is accumulated in the storage means S, the piston **28** therein is being urged downwardly whereby the valve member **14** closes the injection tube **12**. Specifically, hydraulic fluid under pressure is supplied through the line **32** to the chamber **30** to urge the piston **28** downwardly, and this application of hydraulic fluid under pressure serves to maintain the injection tube or nozzle **12** closed. The valve member **14** and injection tube **12** can properly be considered as a hydraulically responsive outlet means associated with the storage means S, and consistent with this terminology, the outlet means is, through the application of hydraulic fluid under pressure maintained in operative condition to prevent fluid transfer between the cylinder **2** and the storage means S coupled thereto at least during the filling of the storage means S with fuel and immediately prior to the start of the injection phase.

The line **32** is part of a hydraulic control circuit which further includes a three-way valve **40**, a hydropneumatic reservoir **34**, and an auxiliary reservoir or sump **38**. The reservoir **34** is charged by a pump **36** which is coupled in a line **36*a*** leading from the sump **38** to the reservoir or accumulator **34**. When the valve **40** is rotated from the position shown in FIGURE 1 to the position where it couples the line **34*a*** leading from the accumulator **34** with the line **32**, hydraulic fluid under pressure is applied to the top of the piston **28** thereby effecting the condition described immediately above.

When, however, the valve **40** is rotated to the position shown in FIGURE 1, then the line **32** is connected with the sump **38**, and the pressure is removed from the top of the piston **28**. Consistent herewith, the valve **40** is operated by suitable means such as a cam (not shown) carried on the engine crank shaft so that the valve **40** assumes the position shown in FIGURE 1 when the injection phase of the cylinder **2** is to be initiated and so that the valve **40** communicates the line **32** with the line **34*a*** during at least a portion of the non-injection phase of the cylinder **2**.

Assume that the chamber **4** and the branch **4*a*** have fuel under pressure accumulated therein by virtue of the supply of fuel through the line **16** as described above. Assume further that the valve **24** has been moved to its closed position. Assume further that the valve **40** is moved to the position shown by virtue of its coupling, for example, with the crank shaft. At this time, the previously existent pressure in the chamber **30** is removed. This diminishing of the pressure is achieved instantaneously, i.e., the pressure drop is transmitted at the speed of sound. Instantaneously, the fuel under pressure in the chamber **4** and branch **4*a*** exerts its force on the lower face of the piston **28** thereby moving the same immediately upward from the position shown and in turn, opening the injection tube or nozzle **12** by virtue of the consequent lifting of the valve member **14**. Under the action of the spring **8**, the piston **6** moves to the right as shown, and fuel is forced through the injection tube **12** under a substantially constant pressure maintained by the spring **8** biasing the piston **6** to the right. It should here be noted that the removal of pressure in the chamber **30** permits instantaneous action since it is not dependent on shock vibrations, gas compression, or the like. Moreover, the action of the piston **6** is instantaneous and thus there is an instantaneous discharge of fuel through the injection tube **12** when the valve **40** is moved to the position shown in FIGURE 1. The amount of fuel dispensed through the injection tube **12** is controlled or metered depending upon the timing of valve **24**, i.e., the time of fuel supply through line **16**. There is thus the desired accurate metering and instantaneous injection initiation. It will be readily appreciated that the injection tube or nozzle **12** can have a conventional dispersing outlet to insure proper mixing and that the fuel is maintained under substantially constant injection pressure by the piston **6**.

Following the injection described above, the valve **40** moves to its other position communicating the line **34*a*** with the line **32**. At this time, the piston **28** is moved downwardly to its initial position by virtue of the pressure exerted thereon by the fluid supplied to the chamber **30**. The fact that some delay might be encountered in moving the piston **28** downwardly and thereby in closing the injection tube **12** with the valve member **14** makes little difference because the time of termination of the injection is not critical and instead, as explained above, the time of initiation of the injection is the critical factor.

The time of operation of the valve **24** in the fuel line **16** is important because in this instance it controls the metering. The operation of the valve **40** is important from the time standpoint, but this valve, like valve **24**, can be located adjacent the crank shaft so as to minimize any time delays in operation. The distance between such valve and the storage means S makes little difference since the operation of the valve **40** at the critical injection time—i.e., at the start of the injection operation, effects a lowering of the pressure in the line **32** which in turn permits instantaneous response from the piston **28**.

To those familiar with the art, it will be understood that valve **40** can easily be a rotary valve that it is controlled in synchronization with the motor crank shaft by means of gears, cams, or the like (not shown). It will further be understood that the system of FIGURE 1 can be used with each of the cylinders in an internal combustion engine. To this end, each cylinder would have its own storage means S and its own hydraulic control circuit. The hydropneumatic reservoir or accumulator **18** need not be repeated for each cylinder since they can be commonly connected to all of the storage means through respective valves **24**.

It is important to note that the end of the injection operation is not fixed by closing of the induction tube **12** by the valve member **14**. Instead, the termination of the injection is fixed by the reduction in the total amount of fuel expelled from the chamber **4**—the storage means being so arranged that the induction tube **12** only receives fuel from the chamber **4** during movement of the piston **6** to its extreme inner position.

The system of FIGURE 2 operates basically in the identical manner as the system of FIGURE 1, but here the hydraulic fluid which controls the movement of the piston **28** constitutes the fuel itself. Insofar as the storage means S is concerned, and insofar as the valve **26**, line **16**, valve **24**, accumulator **18**, pump **20**, and reservoir **22** are concerned, the system of FIGURE 2 is identical with the system of FIGURE 1. In the control circuit of FIGURE 2, the arrangement differs however.

Specifically, by referring to FIGURE 2, it will be noted that a branch line **48** leads from the fuel line **16** of FIGURE 2 and such branch line feeds through a one-way non-return valve **46** to the line **32**, and in turn to the chamber **30** for piston **28**. The line **32** is itself coupled by return line **42** to the reservoir **22** through a one-way valve **40'** interposed in the line **32–42**. During at least a part of the normal non-injection phase of the cylinder **2** of FIGURE 2, the valve **24** is open and fuel under pressure feeds from the accumulator **18** through the line **16** and the branch line **48** into the line **32** and in turn into the chamber **30**. The one-way valve **40'** is closed at this time. The one-way valve **26** is constructed to have a slightly greater operation time than the one-way valve **46** and thus the fuel exerts its pressure on the piston **28** before the same enters the chamber **4**. Accordingly, during the filling of storage means S the valve member **14** is maintained in blocking or closing relation to the induction tube **12**. The chamber **4** and the branch **4**a consequently fill with fluid—the piston **6** moving outwardly as explained in connection with FIGURE 1.

At the time the injection operation is to be initiated, the cam **50** operated, for example, with rotation of the crank shaft, opens the one-way valve **40'** thereby establishing return to the reservoir **22** from the line **32** through the line **42**. The pressure of the fluid in the chamber **30** is diminished and the injection operation is initiated just as described above, with the pressure change being transmitted at the speed of sound.

With the arrangement of FIGURE 2, however, no auxiliary hydraulic fluid is required, and instead, the fuel itself is used for the hydraulic control. In this instance, the one-way valve **26** prevents expulsion of fuel from the chamber **4** through the inlet, just as it did in the system of FIGURE 1. The one-way valve **46** prevents a coupling of the line **32** with the line **16** thereby preventing any tendency of fuel return from the line **32** to the line **16**.

In the arrangement of FIGURES 1 and 2, the quantity of fuel to be dispensed from the storage means S is controlled by the quantity of fuel fed thereto. Accordingly, the fuel is metered by the time during which the valve **24** remains open. In contrast, the arrangement of FIGURE 3 provides a different type of fuel metering. Still further, the arrangement of FIGURE 3 provides for controlling the injection timing by the fuel supply pressure itself. It should here be noted that the cyclic variation in fuel supply pressure to be discussed can be caused in various different ways, as for example, by a pump having a controlled supply. Still, the system of FIGURE 3 is a preferred arrangement.

By referring to FIGURE 3, it will be noted that the storage means S shown therein is essentially the same as the storage means used in FIGURES 1 and 2. The line **32** of FIGURE 3, however, leads directly into the line **16** on the supply side of the one-way valve **26**. With such an arrangement, when fluid under pressure is supplied to the line **16**, the same exerts its pressure on the piston **28** thereby causing the valve member **14** to block the opening through the injection tube or nozzle **12**. At the same time, fuel is introduced into the chamber **4** and the branch **4**a thereof causing outward movement of the piston **6** as described above.

In this type of system, when pressure is removed from the fuel in the line **16**, the piston **28** can move upwardly due to the diminished pressure in the chamber **30**. Still, the fuel within the chamber **4** and its branch **4**a in excess of the standard reserve quantity is injected under the action of the piston **6**, and upon the upward movement of the valve member **14** resulting from the lowering of the pressure in the chamber **30**.

While as indicated the variation in the fuel supply pressure may be achieved in various ways, as for example through the use of an uninterrupted supply pump, such variation is preferably obtained from a fuel supply means such as that shown in FIGURE 3, and generally designated by the letter F. This fuel supply means includes a piston pump **52** which is reciprocated by a cam **54** attached, for example, to the crank shaft of the engine. The pump **52** discharges fuel, upon upward reciprocation of the piston thereof, into a supply line **56**, the pump receiving its fuel from the line **22**a leading from the fuel reservoir **22**. A one-way non-return valve **58** is interposed in the line **56** which couples with the line **16** through a chamber **60**a. The chamber **60**a is coupled with the supply reservoir **22** by a tube **62**, which tube is closable by the valve member **60**b extending upwardly from the piston **60**. The piston **60** is reciprocal in the chamber **60**a and is normally biased upwardly by a spring **60**c to cause the valve member **60**b to block the tube **62**.

When the piston of piston pump **52** is moved upwardly with rotation of the cam **54**, it moves the fuel disposed above the face **65** thereof into the line **56** as well as into the line **64** coupled in parallel therewith. Simultaneously, the line **22**a is shut-off. The fuel moving into the line **64** immediately urges the piston **60** upwardly thereby adding this effect to spring **60**c to block the outlet of the tube **62**. At the same time, fuel is forced through the line **56**, the one-way valve **58**, and the chamber **60**a into the line **16**. The quantity of fuel so moved is dependent upon the stroke of the piston pump **52**. The pressure on the fuel so moved serves to force the piston **28** downwardly. Moreover, the fuel is introduced into the chamber **4** thereby charging the same.

With the system of FIGURE 3, fuel is accumulated in the storage means S immediately preceding the injection phase of the cylinder **2**, such accumulation being effected with upward movement of the piston pump **52** in the manner described. Cam **54** eventually releases the piston of piston pump **52** so that the same moves downwardly thereby releasing the pressure applied to the piston **60** through the fluid traveling in the line **64**. This results in an immediate diminishing of the pressure in the line **16** whch is then coupled through the comparatively large conduit or tube **62** with the reservoir **22**. The reduction of pressure in the line **16** in turn results in a reduction in pressure in the line **32**, and a reduction in pressure in the chamber **30**, the result being the immediate initiation of the injection phase.

If desired, and for purposes of insuring termination of the injection cycle as desired, the storage means F of FIGURE 3 can be constructed as shown in FIGURE 6. The arrangement is basically the same as disclosed above, but in this instance an auxiliary biasing spring **76** is incorporated, such spring serving to urge the piston **28** downwardly so that the valve member **14** normally automatically assumes its closed position. Such spring **76** has a lower biasing force than the spring **8** acting on the piston **6** so that the spring **8** still serves through the piston **6** to apply the injection pressure and control the injection operation.

While FIGURE 3 meters the fuel supplied to the storage means S through utilization of the piston pump **52** and its associated components, the metered quantity can be varied. For example, a control element **66** of conventional type can be associated therewith so as to position the tapered face **65** of the piston pump **52** in a selected lowermost position. A different form of metering can equally effectively be achieved with the systems of FIGURES 1 and 2. Specifically, the chamber expansion means of the storage means S of FIGURES 1 and 2 can be modified.

Consider initially FIGURE 4. Here, the metering means includes the piston **6**, the spring **8** and the frame or housing **8***a*, as in FIGURE 1. Additionally a stop adjustment means is incorporated. The stop adjustment means comprises a screw **70** threadably received in the rear wall **68** of the frame **8***a*. The forward end **70***a* of the screw **70** limits outward movement of the piston **6** thereby limiting the quantity of fuel which can be introduced into the chamber **4** and specifically branch **4***a* thereof during a charging or accumulation operation of the storage means S. With the movement of the piston **6** being controlled outwardly by the screw **70**, and with the movement of the piston **6** being controlled inwardly by engagement of the piston head **6***a* with the forward wall **69** of the frame means **8***a*, the quantity of fluid expelled from the chamber **4** through the injection tube **12** can be closely controlled.

A modified metering arrangement is presented in FIGURE 5. Here, the frame means takes the form of a closed housing **71** with the screw **70** threadably received in the rear wall thereof. The housing communicates through an outlet line **74** with the fuel supply reservoir **22**. The piston, designated as **6'** in this instance, is centrally recessed and carries a ball valve **70'** therein. The ball valve has a plunger stem **72** leading rearwardly thereof. The ball valve **70'** normally seats on the wall **6***b* of the recess making the piston **6'** essentially a closed piston like the pistons **6** described above. When, however, the piston **6'** is displaced to the left as shown in FIGURE 5, the valve stem **72** engages the forward end **70***a* of the screw **70** and the ball valve **70'** is unseated. At such time, the piston **6'** becomes an open piston and fuel flows therethrough into the chamber **73** in the housing **71** and from there through the line **74** to the fuel supply reservoir **22**. Still, the ball valve **70'** is not unseated until the piston **6'** has moved to its outermost position. Thus, a selected metered quantity of fuel is introduced into the branch **4***a* before the valve **70'** is unseated. This quantity remains constant and is adjusted by adjustment of the screw **70**. When the metering means of FIGURE 5 is associated with a storage means S such as shown in the other figures, and when the valve member **14** moves upwardly at the beginning of the injection phase, the piston **6'** moves inwardly with the ball valve **70'** again seating itself on the wall **6***b*. The piston **6'** then operates in the same manner as the piston **6** causing the expulsion of a metered quantity of fluid from the associated storage means S, the quantity being limited by the inward movement of the piston **6'** as controlled by the engagement of the head **6'***a* with the forward wall of the chamber **73**.

Although the various storage chamber means discussed above have practical utility in their own right, the preferred form of storage chamber means used in accordance with the invention is constructed as shown in FIGURE 7. This storage chamber means has many features which are common with the features of the storage chamber means described above, but some differing structural aspects affording significant advantages.

Corresponding to the embodiments discussed above, the arrangement of FIGURE 7 includes a hydraulically responsive outlet or control valve means including the piston member **28''**, a one-way valve means **26''** for selectively permitting fuel flow into the storage chamber means, and a metering means including the piston **6''**. These various means are coaxially disposed in the arrangement of FIGURE 7, yet operate in essentially the same manner as that described in connection with corresponding means of other figures.

The storage chamber housing of FIGURE 7 includes essentially three sections, namely, a central section **78**, a lower section **80**, and an upper section **73**. The lower section **80** includes a threaded upper portion **80***a* which is threadably received in a threaded bore **78'***a* at the lower end of the central section **78**. The upper section **73** includes a sleeve **73***a*, having its lower end sealingly engaged with the upper face **78***b* of the central section **78**. To this end a sealing gasket **78***c* is disposed in a recess **78***d* in face **78***b*, and recess **78***d* receives a lower end flange portion on the sleeve **73***a*. A cover member **73***e* is sealingly received on the upper end of the sleeve **73***a* and fixed in position by means of longitudinally extending bolts **73***f*. The sealing arrangement **73***g* is the same as the sealing arrangement associated with the sealing gasket **78***c*, and further description thereof appears unnecessary.

The lower section **80** is centrally bored or hollow and provides a piston chamber for the piston **28''** and an outlet chamber **104** receiving valve means **14''**. The valve means **14''** takes the form of a projecting lower end stem on piston **28''**; which stem normally blocks the injection passageway or nozzle **12''**. The stem forming valve means **14''** is of smaller diameter than the interior diameter of the section **80** so that a chamber **104** is formed interiorly of the lower end of the section **80** and about the stem or valve means **14''**.

Extending upwardly from the piston **28''** is a hollow stem or rod **86** having a longitudinally extending bore or passageway **88** therein. The stem **86** passes axially into, and partially through, the central section **78** of the housing. Slidably received thereon are a pair of valve elements **26''***a* and **26''***b*. The central section **78** of the housing has a shoulder **90** formed toward the lower end thereof which shoulder normally receives the base of the valve element **26''***a* in sealing contact therewith. On the other hand, the valve element **26''***b* carries at its lower end a tapered ring flange **96** which normally seats on the spherically tapered upper face **94** of the valve element **26''***a*. The valve element **26''***b* is biased such that the flange **96** thereof normally bears in sealing relation on the surface **94**, such biasing resulting from the provision of a spring means **98** compressible between the upper end of the valve element **26''***b* and a transverse partition **98***a* disposed interiorly and across the hollow portion of the central section **78**. As should be apparent, the shoulder **90** and the partition **98***a* serve to define therebetween a chamber **78***a* in the central section **78**, which chamber has the valve elements **26''***a* and **26''***b* therein.

The partition **98***a* is maintained in the position shown not only by the spring **98**, but also by a sleeve **82** which is threadably received in the upper portion of the central section **78**. The sleeve **82** has its lower edge **82***a* disposed to prevent upward movement of the partition **98***a*. Moreover, the sleeve **82** is provided with a central bore which slidably receives the piston **6''**. This piston corresponds in construction to the piston **6'** shown in FIGURE 5. The piston is recessed and carries therein a valve member **70''** which operates in the same manner as the ball valve member **70'** described in connection with FIGURE 5. The piston **6''** is normally biasted downwardly by a bearing block **84** which itself is urged downwardly by biasing spring means **8''**.

The specific details of construction of the piston **6''** and of the valve member **70'** associated therewith have been described above in connection with FIGURE 5, the arrangement of FIGURE 7 in this regard being the same as that shown in FIGURE 5. Certain passageways are provided in the arrangement of FIGURE 7 to cooperate with the valve means **70''**, and similarly, certain other passageways are incorporated to provide for fuel introduction and flow in association with the other valve means **28''** and **26''** of FIGURE 7. These passageways and the functions performed thereby can be better understood from the operation of the embodiment of FIGURE 7 now to be described.

With the coaxial arrangement of FIGURE 7, fuel under pressure is fed into the system through the line **16**, and such fuel passes through the longitudinally extending passageway formed by the bore **100** and through the lateral passageway formed by the bore **32''**. The fuel enters a chamber **33''** above the piston **28''** and then passes upwardly about the stem **86** into a recess chamber **102** in the valve element **26''***a*. When under pressure, such fuel maintains the piston **28''** in its downward position thus in turn maintaining the valve means **14''** in blocking or closing relation to the injection tube or nozzle **12''**. Still, the fuel under pressure exerts sufficient force on the valve element **26''***b* to cause the same to move upwardly against the action of the spring **98**. This breaks the seal between the flange **96** and the surface **94** thereby permitting the fluid to flow into the chamber **78***a*. The fluid then travels through such chamber and through apertures in the partition **98***a* into the chamber **4''** above the partition. The piston **6''** communicates or faces this chamber **4''**. When the fuel reaches the chamber **4''**, it passes into the lateral openings **106** in the valve stem **86** and then flows downwardly through the passageway **88** and into the chamber **104** through the lateral passageways **108** in the stem forming valve means **14''**.

Once the fuel has filled the various chambers described, then when additional fluid is sent through the line **16** into the arrangement of FIGURE 7, the same causes the piston **6''** to move upwardly thereby expanding the chamber **4''**. Upward movement of the piston **6''** continues until the valve means **70''** opens whereupon additional fuel supply passes through the valve means **70''** in the piston **6''** and then laterally outward through the passageways **70''***b* and **84***a* into the chamber formed by the sleeve **73**. This escaping fuel is returned to the supply by the line **74** which communicates with the interior of the sleeve **73** through the bores **74***a* and **74***b* in the central section **78** of the housing.

Consistent with the above, a metered quantity of fuel is accumulated in the storage means. Such quantity of fuel is injected into a cylinder associated with the storage means during the injection phase. Here again, the injection is initiated when the pressure in the line **16** is diminished.

Specifically, with the relief in pressure on the fuel in the line **16**, the pressure is relieved on the fuel in the bore **100**, in the bore **32''** and in the chamber **33''**. Similarly, the pressure is relieved on the fuel in the recess chamber **102** of the valve element **26''***a*. Such reduction in pressure effects two results, namely, the valve element **26''***b* immediately returns to a position where the ring flange **96** is in sealing engagement with the surface **94**, and the piston **28''** moves upwardly, the piston **6''** having been previously moved upwardly during the fuel accumulation period. Pressure is still maintained on the fuel in the chamber **4''**, in the passageway **88**, and in the chamber **104**, so the fuel is injected through the injection tube or nozzle **12''** until such time as the piston **6''** returns to its initial position. At this time, the piston **28'** has returned to its initial position, and the arrangement is ready to again be charged with a metered quantity of fuel just as described above.

The concentric arrangement of the various moving elements permits one to obtain precision in operation without extreme precision in construction of the moving parts and associated elements. A simple machine finish is sufficient to prevent fluid leaks within the arrangement. The provision of the tapered ring flange on the valve element **26''***b* in cooperation with the spherically tapered surface **94** on the valve element **26''***a* permits these cooperating valve parts to adjust themselves for a proper seal therebetween.

The concentric disposition of the elements of FIGURE 7 serves to yield not only efficient operation without requiring extreme precision in the parts, but also permits the use of longitudinally and laterally extending bores in the housing of the storage means. This latter feature affords substantial advantage from the construction standpoint over presently available control valve systems which require oblique bores and passageways. It is important to note with respect to FIGURE 7:

(1) that at the very moment that the cyclic decline of the fuel supply pressure is produced, the decline in pressure which is the signal for initiating the injection, the pressure falls within chamber **33** so that simultaneously one-way valve **26''** is closed and piston **28''** is lifted by the reverse pressure differential upon its two faces; and

(2) that the metered quantity of fuel accumulated is completely injected within the engine cylinder under the action of piston **6''**, and at the end of its stroke, piston **6''** comes to rest on stem **86** thereby maintaining valve stem **14''** over bore **12** of the injection nozzle. Upon recovering essentially the initial position, all of the chambers and passageways within the system remain completely filled with fuel.

As previously indicated, any of the arrangements and systems described above can be used with multi-cylinder internal combustion engines, even though in the preceding descriptions a single cylinder has been used in each instance for a basis of explanation of the various embodiments. Regardless of the particular embodiment employed, the general arrangment is as shown in FIGURE 8.

By referring to FIGURE 8, it will be noted that the overall system includes a plurality of storage chamber means S and a plurality of hydraulically responsive control means C. Each control means C couples one of the storage chambers S with one of the cylinders **2**. Each control means C is operative to establish and disestablish communication between the storage chamber means S and the cylinder **2** coupled together thereby.

Hydraulic circuit means CR are coupled with each of the control means for respectively applying fluid under pressure thereby to diestablish communication between the storage chamber **2** coupled together thereby during at least a part of the noninjection thereof and for diminishing the pressure applied to the respective control means C during the injection phase of the cylinder **2** coupled therewith.

The detailed construction of each control means C, storage chamber means S, and hydraulic circuit means CR will vary with the particular embodiment. For example, if the embodiment of FIGURE 1 is used, the input lines *f* will receive fuel from a given source, and the input lines *f'* will receive hydraulic fluid of suitable type, from a separate source. With the embodiment of FIGURE 3, the input lines *f* and *f'* would both receive fuel. Still, it should be appreciated readily that regardless of the embodiment utilized, the basic arrangement, and basic function of the respective means corresponds to the general arrangement of FIGURE 8.

Having now described illustrative and preferred embodiments of the invention in considerable detail, it should be apparent that the objects set forth at the outset of the present specifications have been fully satisfied. It should further be apparent that various modifications can be made to the particular embodiments described without departing from the scope and spirit of the invention. Accordingly,

What is claimed is:

1. Injection apparatus for use with an internal combustion engine having a plurality of cylinders, said apparatus comprising:

a plurality of storage chamber means;

a plurality of hydraulically responsive control means, each of said control means coupling one of said storage chamber means with one of said cylinders, each of said control means being operative to establish and disestablish communication between the storage chamber means and the cylinder coupled together thereby;

hydraulic circuit means coupled with each of said control means for respectively applying fluid under pressure thereto to disestablish communication between the storage chamber means and the cylinder coupled together thereby during at least a part of the non-injection phase thereof and for diminishing the pressure applied to the respective control means during the injection phase of the cylinder coupled therewith;

each of said storage chamber means including a common housing having a main chamber and a branch chamber communicating therewith;

said control means being movably mounted only in said main chambers;

a piston movable in said branch chamber to vary the capacity thereof; and

biasing means for normally urging said piston in a direction minimizing the capacity of said branch chamber.

2. Injection apparatus as defined in claim **1** wherein each of said storage chamber means further includes means for metering a predetermined quantity of fuel stored therein.

3. Injection apparatus as defined in claim **2** wherein said means for metering includes an adjustable screw which can be variably positioned to act as a stop for limiting movement of said piston against the urging effect of said biasing means.

4. Injection apparatus as defined in claim **1** further including said housing having an injection outlet; said control means comprising piston operated valve means normally closing said injection outlet, said housing having a fuel inlet and a non-return valve means disposed in said housing in the fluid path between said inlet and said main chamber, said main chamber communicating interiorly of said housing with said injection outlet, said non-return valve means comprising a pair of valve elements, at least one of which is reciprocally movable with the other, said piston means, said piston operated valve means and said non-return valve means being coaxially disposed.

5. Injection apparatus as defined in claim **4** wherein said piston operated valve means includes a piston stem extending axially of said housing and having a passageway therethrough communicating said main chamber with said injection outlet, and wherein said valve elements are slidably received about said stem.

6. Injection apparatus as defined in claim **5** wherein said valve elements have mating surfaces respectively of ring shape and spherical contour adapted to form a fluid seal there-between, the element having the spherical mating surface contour also having an opposed planar face, said housing having a planar abutment therein mating with said planar face.

7. Injection aparatus as defined in claim **4** wherein said storage chamber means includes metering means having at least one movable element coaxially disposed with said piston means, said piston operated valve means and said non-return valve means.

8. Injection apparatus as defined in claim **7** wherein said metering means includes a valve member carried by said piston means.

9. In a fuel injection apparatus for use with an internal combustion engine having cylinders therein, the combination comprising:

storage chamber means coupled to said cylinders;

hydraulically operable control means in each of said storage means;

each of said control means being movable between a

first position which disestablishes communication between a cylinder and its associated storage chamber means and a second position which establishes such communication;

hydraulic circuit means adapted to be connected to a fuel supply source for delivering fuel therefrom to said storage chamber means;

fuel pump means in said hydraulic circuit to selectively deliver said fuel from said supply source to said storage chamber means;

release valve means in said hydraulic circuit connected respectively between said fuel pump means, said fuel supply source and said storage chamber means;

said release valve means being maintained in a first position by pump pressure while said fuel pump means delivers fuel from said supply source to said storage chamber means;

said control means being maintained in their first position while said release valve means is maintained in its first position by the pressure of the fuel delivered to said storage chamber means;

said release valve means moving from said first position to a second position when said fuel pump means terminates fuel delivery and decreases pump pressure upon said release valve means, thereby creating a reduction of pressure in said hydraulic circuit means;

said reduction in pressure in said hydraulic circuit means thereby permitting said control means to move from said first position to said second position to thereby establish communication between said storage chamber means and said cylinders to thus initiate injection of the fuel from said storage chamber means into said cylinders.

10. The combination defined in claim **9** wherein said hydraulic circuit means includes a line extending from said fuel pump means to said release valve means, and a valve in said line permitting flow from said pump means to said release valve means but preventing back flow therefrom.

11. The combination defined in claim **9** wherein said control means and said release valve means each include a piston having a valve stem projecting therefrom and adapted to mate with an associated valve seat.

12. The combination defined in claim **9** wherein said control means includes a pair of spaced pressure receiving faces, one disposed nearer said cylinder and one disposed further away therefrom, said hydraulic circuit means including a line extending from said release valve means to said storage chamber means and connecting adjacent sair nearer face, an auxiliary line branching from said line to said storage chamber means and connecting adjacent said further face, and a valve in said line permitting flow into said storage chamber means but preventing backflow therefrom.

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