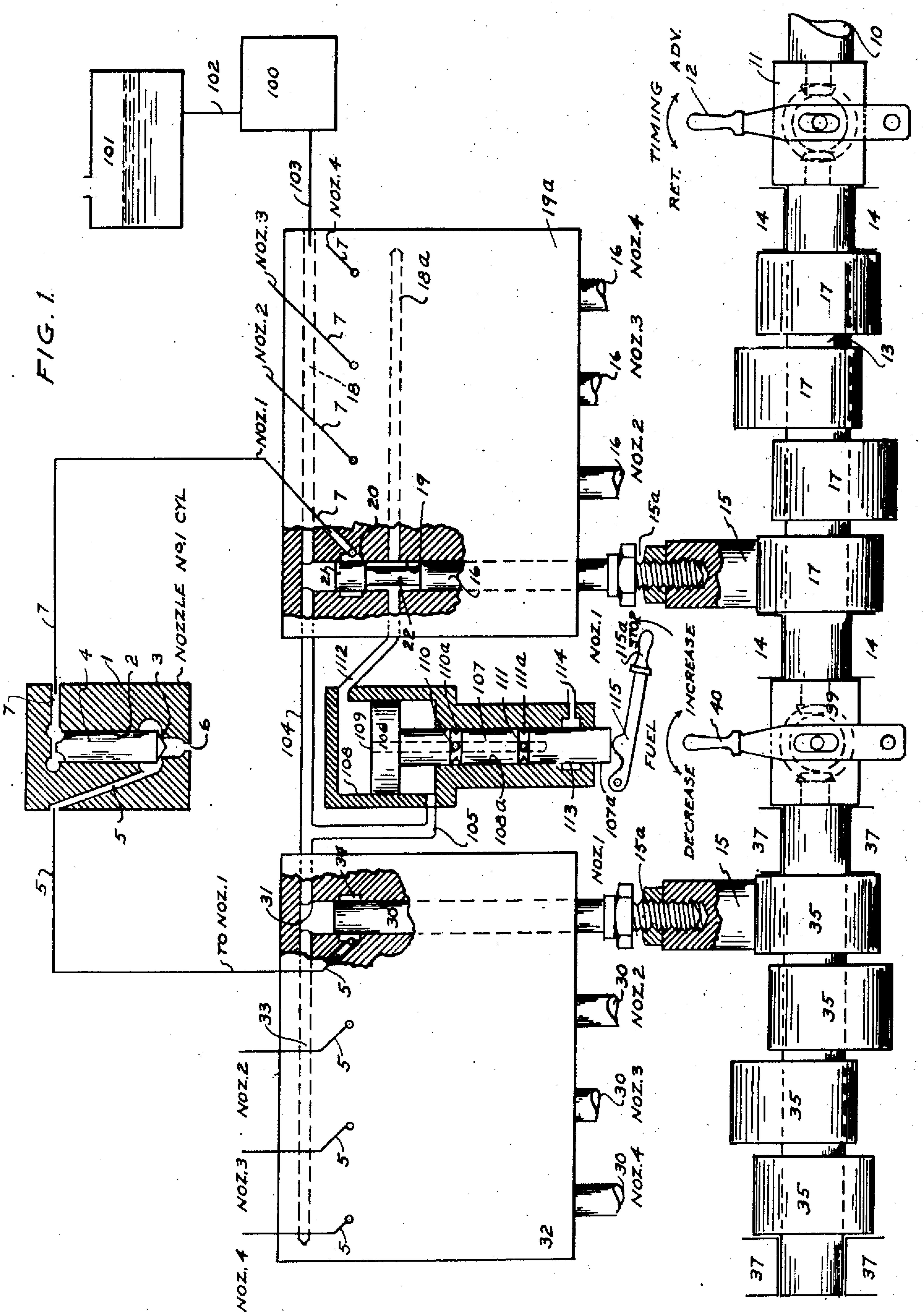
Sept. 29, 1953 C. R. ALDEN 2,653,584

FUEL INJECTION SYSTEM

Filed Sept. 18, 1951 2 Sheets-Sheet 1



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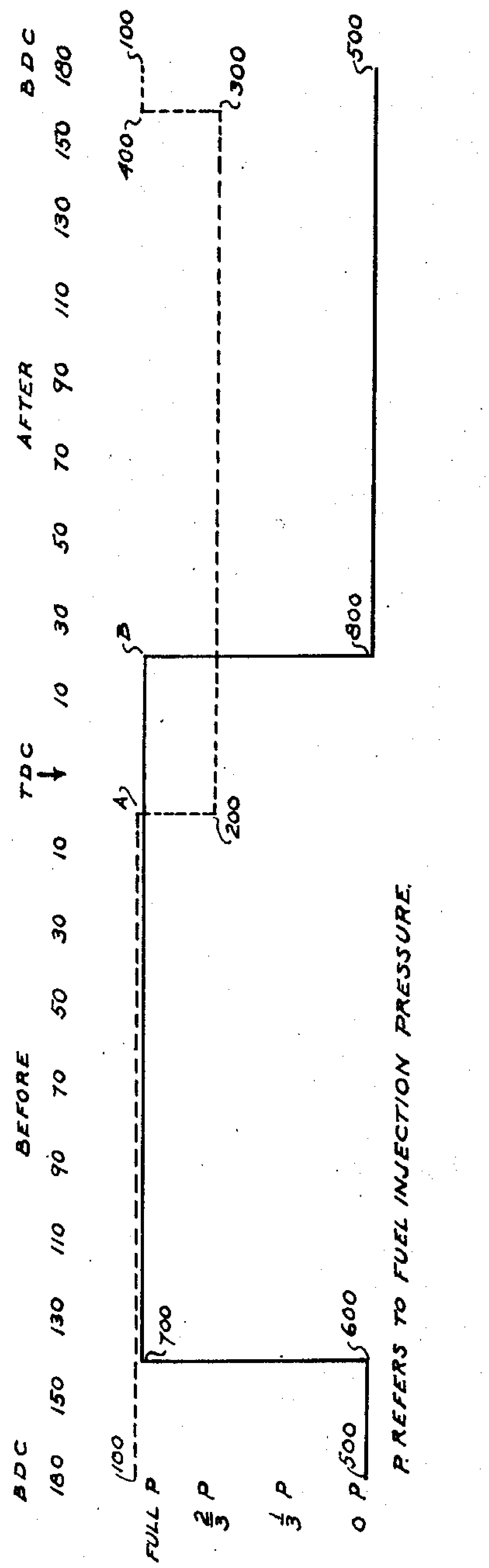

FIG. 2.

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Patented Sept. 29, 1953 **2,653,584**

UNITED STATES PATENT OFFICE

2,653,584

FUEL INJECTION SYSTEM

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Application September 18, 1951, Serial No. 247,079

8 Claims. (Cl. 123—32)

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This invention pertains to an improvement in systems for timed metered injection of fuel as used in connection with internal combustion engines. Such a system was disclosed in U. S. Patents Nos. 2,027,360; 2,069,744; 2,075,949; 2,202,-510; 2,223,590 and included means for opening and closing the several injection nozzles by unbalance of hydraulic pressure applied upon opposite ends of reciprocable valve operating plunger.

The earlier patented system includes a rotary distributing valve for controlling the application of valve actuating pressures sequentially on the several injection nozzles. Such rotary valves present the hazard that stickage of the single rotary member may cause failure of fuel injection from a plurality of injection nozzles controlled by the associated distributor. It is an object of this invention to avoid that hazard.

In the earlier patented system the means controlling the application of hydraulic pressure for actuating the several injection nozzles included no readily alterable adjustment for increasing or decreasing the quantity of fuel delivered from one nozzle independently of all others. It is an object of this invention to provide such a fuel quantity adjustment.

In the earlier patented system the means controlling the application of hydraulic pressure for actuating the several injection nozzles included no readily alterable adjustment for advancing or retarding the start of injection from one nozzle independently of the other nozzles. It is an object of this invention to provide such a nozzle timing adjustment.

A further object of this invention is economically to provide a source of fuel under a constant pressure intermediate atmospheric pressure and the total fuel injection pressure but of magnitude predeterminedly related to the latter for use in controlling the action of the fuel injection nozzles.

A still further object is economically to insure complete cessation of injection when desired without such waste of fuel pressure energy as was heretofore encountered in relieving the fuel injection tubing of pressure following each pressure application thereto particularly when calling for the injection of smaller or zero quantities of fuel per cycle.

Referring to Fig. 1 I provided a nozzle body **1** including an axial bore **2** formed at one extremity with a valve seat **3** which by coaction with a valve plunger **4** reciprocable in the bore **2** is adapted to control the flow of fuel from an injection conduit **5** to a nozzle discharge orifice **6** which may be single or multiple, annular or of any form suited to the fuel spray characteristics favorable to the associated engine (not shown). In the open position of valve **3** the entire and area of the plunger **4** which is then exposed to the pressure of fuel in conduit **5** is effective to urge the plunger toward its openmost position. In its seated or closed position that area encircled by the seat **3**, which, illustratively, may well be approximately one fifth of the total end area of the plunger, is not exposed to fuel pressure and, neglecting such relatively insignificant pressure as may be applied by engine cylinder gases beneath the seat **3**, the force, according to the present example, which is applied to lift the valve from the closed position may be reckoned as $\frac{4}{5}A \times P$ where A represents the total area of the valve plunger and P the pressure of the fuel in supply conduit **5**. After the valve **4** has lifted from its seat **3** the force tending to hold the valve open is $A \times P$. A cut-off valve later to be described is adapted alternatively to admit fuel at pressure P to the remote end of conduit **5** or to cut off such communication. When so cut off conduit **5** is without opening unless plunger **4** opens valve seat **3**.

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Though the valve plunger **4** may be biased toward its closed position by a spring, not shown, such is not essential. The end of valve plunger **4** opposite that which coacts with seat **3** is of area A and under all circumstances is acted upon by the pressure of fuel in a control conduit **7** which is in constant communication therewith. The pressure applied on the remote end of conduit **7** and therefore on this end of the plunger **4** is alternated, by a distributor valve presently to be described, between the full injection pressure P and, according to this example, an intermediate pressure of approximately $\frac{2}{3}$P.

The forces tending to move plunger **4** toward its seated position are thus seen to alternate between $A \times P$ and $\frac{2}{3}A \times P$.

It may now be seen that an any time the remote end of conduit **5** becomes cut off from the supply of fuel at pressure P even the minimum available force of $\frac{2}{3}A \times P$ acting to move valve **4** toward its closed position will be effective to do so and injection of fuel from orifice **6** will promptly be cut off by closure of valve **3**.

It may also be seen that, so long as the full fuel pressure P is applied to the remote end of conduit **7** the force effective to close valve **3** is $A \times P$. It therefore follows that so long as valve **3** is closed, full fuel pressure P may be applied to the remote end of conduit **5** without lifting plunger **4** as the effective opening force then is but $\frac{4}{5}A \times P$ which is less than the closing force $A \times P$; however, upon applying the alternative intermediate pressure ⅔P to the remote end of conduit **7** the closing force at once crops to $\frac{2}{3}A \times P$ which, being less than $\frac{4}{5}A \times P$, allows piston **4** immediately to move to that position which opens valve **3** and initiates injection of fuel.

Summarizing: In each cycle of operation full fuel pressure P is applied to the remote end of conduit **7** an appreciable time before initiation of fuel injection is desired. At a later time, but still appreciably before initiation of injection is desired, full fuel pressure P is applied to the remote end of fuel injection conduit **5**.

To initiate fuel injection the remote end of conduit **7** is alternated from communication with the source of full fuel pressure P to an intermediate pressure ⅔P. This unbalances the forces which have held plunger **4** in its valve closing position and valve seat **3** lifts exposing the full lower area A to the fuel pressure P.

To terminate injection the remote end of injection conduit **5** is cut off from the source of fuel pressure. There is thereafter no force effective to hold piston **4** and valve **3** in open position and the opposed force of $\frac{2}{3}A \times P$ acts immediately to close the valve. Note that in closing the plunger **4** acts as a pump plunger to inject its displacement volume at a pressure ⅔P. At any convenient time in the cycle subsequently to closing the valve **3** the pressure applied to the remote end of conduit **7** may be alternated to the full pressure P without other incident and at any convenient time between this last and the initiation of the next injection the remote end of fuel injection conduit **5** may be connected to full fuel pressure P without incident thus completing preparation for the next injection.

In practice I prefer to maintain the durations of alternative conditions on conduits **5** and **7** of fixed durations in relation to the length of one complete cycle of valve operations but to vary the phase relation of the cyclical occurrences affecting these respective conduits to effect advance or retard of the point in the cycle at which injection is initiated and to variably control the duration of injection between the limits of zero and the maximum permissible.

In Fig. 2 the times before and after top dead center (TDC) have been expresed in degrees of engine crank travel as for a two stroke cycle engine, dotted curve **100—400** represents the magnitude and timing of one condition of pressure applications, as in conduit **7**, which continuously but with varying force influence plunger **4** toward its valve closing position. Curve **500—800** represents one condition of pressure application, as on conduit **5**, which influences plunger **4** toward its valve opening position. The occurrence of pressure reduction on conduit **7** at point A which here occurs 5° before TDC denotes an unbalance of forces on plunger **4** which initiates injection at this point in the engine cycle and the occurrence of cut off of fuel supply at the remote end of conduit **5** as at point B, which here takes place 15° after TDC, denotes termination of injection at that point in the engine cycle.

The greater the number of degrees by which the point B lies to the right of point A, the greater the duration of injection. This may be controlled by means to be shown. By this last means curve **500—800** may be shifted bodily with respect to curve **100—400** without altering the form of either. In like manner if point B be caused to come earlier in the cycle than point A, or to fall to the left of point B on the diagram of Fig. 2, a condition of absence of injection is indicated. Means also will later be shown whereby both curves **100—400** and **500—800** may be shifted bodily in relation to TDC and without disturbing their mutual relation. This denotes an advance or retard of injection with respect to the engine cycle without altering the duration (or quantity) of fuel injected.

At **10** in Fig. 1 is shown a drive shaft running at equal speed with the crank of the associated (two stroke cycle) engine. To enable phase shift of events A and B with respect to TDC (Fig. 2) cam shaft **13** is driven from shaft **10** through a well known phase change coupling **11** under the control of means **12**. The cams **17** on shaft **13**, which is rotatable in bearings **14** may, through adjustable tappets **15** give reciprocation to valves **16** for the purpose of alternating the hydraulic pressures applied on the so-called remote ends of fuel control conduits **7** by which, when this pressure suffers reduction as at point A in Fig. 2, injection of fuel from the associated nozzle is initiated. Though only one valve **16** is detailed one for each engine cylinder is provided and each, by proper positioning of its actuating cam **17** on shaft **13**, closely co-ordinates the valve movements with the piston movements of the associated engine cylinder. This co-ordination may be more exactly determinable by adjustment of the tappets **15**.

Specifically control means **12** permits all timed functions of the entire injection system to occur earlier or later in respect to events of the engine cycle (such as TDC of a reference piston) without altering the duration of the injection period.

To permit the valves **16** to operate at high reciprocating speeds without requiring excessive return force as by spring pressure to insure that the valves and their tappets will follow the cams, I prefer that the cams shall closely approximate simple eccentrics which impart to the valves a substantially harmonic reciprocation. By so doing the application of fuel pressure on the upper ends of the valve stems may exert sufficient force to eliminate the necessity for valve return springs.

Each of the several valves **16**, of which there are one for each engine cylinder served by the injection system, reciprocates in a co-acting bore **19** in a block **19a**. The bores **19** are open at their upper or innermost ends to the full fuel pressure P applied through a passage **18**. Spaced from the passage **18** is a second parallel passage **18a** intersecting all bores **19** which is continuously open to fuel at an intermediate pressure such as ⅔P. Intermediate these parallel passages the plunger bore **19** which receives valve **16** is recessed as at **20**, the so-called remote ends of conduits **7** are connected respectively to these recesses. The upper ends **21** of valves **16**, for a length substantially equal to or but slightly greater than the axial length of recesses **20**, are a close fit in their surrounding bores. Below the end portions **21** the valves **16** have a portion **22** of reduced diameter. When the lower edge of head end portion **21** of any valve **16** is above the lower end of its co-acting recess **20** the associated conduit **7** communicates reduced pressure, as at ⅔P, to be applied on associated nozzle plunger **4** to urge it toward closed position. When the upper edge of end portion 21 is below the upper end of recess 20 conduit 7 communicates full fuel pressure P to be similarly applied on plunger 4.

As I prefer that the change from one to the other of the two pressures alternatively applied to conduit 7 shall take place as rapidly as may be, I prefer to cause this change to occur when the movement of the valve is taking place at its highest velocity or approximately at the mid point of its strokes. This also causes the change in events accomplished by this valve to be separated from each other by approximately 180° of engine crank travel as indicated on Fig. 2.

A second set of plain cylindrical valves 30 are similarly reciprocated in bores 31 formed in block or body 32. A conduit 33, similar to conduit 18 connects the upper ends of these bores continuously to full fuel pressure P. The bores 31 are formed with a recess 34 similar to the recess 20 spaced from their upper ends. The recesses 34 are constantly in communication with conduits 5. When the upper edge of any valve 30 is below the upper edge of recess 34 fuel under full pressure P flows through conduit 5 to be injected from orifice 6 subject to the control of valve 3 as previously described. I prefer that this communication shall be established while valves 30 are substantially midway of their outward strokes and cut off at substantially the same point on their inward strokes as indicated in Fig. 2.

Valves 30 are reciprocated by adjustable tappets 38 acted upon by cams 35 on a shaft 36 which rotates in bearings 37. To permit the phase of the valving events occasioned by valves 30 all to be simultaneously changed with respect to those of valves 16 for the purpose of controlling the duration and thereby the quantity of fuel injected per cycle as set forth in the discussion of Fig. 2, shaft 36 is driven from shaft 13 through a second phase change coupling 39 which may be controlled by means 40. Tappet adjustment means 15a permits the events of an associated valve to be advanced or retarded independently of all others as for minute correction of the duration of injection of individual nozzles.

A fuel pump 100 of any suitable construction may be arranged to draw fuel from a tank 101 through a conduit 102 delivering the same under pressure P through conduit 103 to the passages 18 and 33 respectively of valve blocks 19a and 32.

A conduit 104 joins high pressure fuel passages 18 and 33. A branch 105 from this conduit supplies fuel at pressure P to be applied on the differential area of a compound piston comprising a head 106 of larger diameter coaxially arranged with a stem portion 107 of reduced diameter and reciprocable in coaxial stepped bores 108 and 108a. A passage 109 is formed axially of the composite piston. Spaced cross bores 110 and 111 intersect bore 109 and terminate respectively in circumferential grooves 110a and 111a. When the composite piston is midway of its axial position in the stepped bores, groove 110a is spaced from and covered by the innermost end of bore 108a and groove 111a is spaced from and covered by the opposite end of this portion of the bore. The lower face of piston 106 is in continuous communication with passage 104 through conduit 105. As the full area of piston 106 bears to the differential area exposed to full fuel pressure P the ratio of 3:2 the pressure applied on the upper face of piston 106 will be ⅔P.

If, by reason of insufficient volume of fuel under pressure ⅔P the composite piston moves too far upwardly, groove 110a will be uncovered at the upper edge of bore 108a. The communication thus established will enable the deficiency to be made up by fuel passing through bores 110 and 109. If there should be an excess of fuel under pressure ⅔P groove 111a will be uncovered at the lower edge of bore 108a and the excess will pass through bores 109 and 111, into recess 113 and may be returned to the fuel tank via conduit 114.

In such a system it is not unknown, under conditions of long injection conduits 5 of large diameter and more particularly if the tubing walls are thin and resilient, for a very small quantity of fuel to be injected upon decrease of pressure in conduit 7 even though this reduction should occur after the remote end of conduit 5 had previously been closed to fuel pressure as by a valve 30. This is because of the release of pressure energy stored elastically in conduits 5. The quantity of fuel which is injected in this way may be progressively reduced by increasing the intermediate pressure which, according to the present example, is ⅔P. Obviously, according to the present example, as this pressure approaches ⅘P the force tending to lift plungers 4 upon reduction of pressure in conduits 7, as at event A in Fig. 2, approaches zero and if the intermediate pressure available for application to conduits 7 by valves 16 becomes anything in excess of ⅘P the valves 3 in the injection nozzles will not be opened.

The intermediate pressure may be influenced in the increasing direction by applying an upwardly acting force as on the extension 107a of the composite piston 106, 107. As this method of completely eliminating all possibility of fuel injection from the nozzles becomes useful only when desiring to completely stop the associated engine I have shown a cam 115 and control means 115a by which stem 107a may be raised until full pressure fuel passes through groove 110a, bores 110 and 109 to equalize hydraulic pressures on either side of piston 106. When this is done full pressure P is supplied continuously on conduits 7 by equalizing pressures between passages 18 and 18a. This will insure against the possibility that any pressure which can be applied on injection conduits 5 will be adequate to lift valve plungers 4. Transiently, while lifting member 107a, resistance to motion will be experienced due to the body of fuel trapped above piston 106. As a practical matter this is of little or no consequence as the lifting force itself increases the intermediate pressure toward, or perhaps in excess of, the full pressure P. Even under unusual conditions of elasticity in the injection conduits 5 such a resulting increase of the intermediate pressure need persist only for a few seconds to stop all injection of fuel and enable the associated engine to come to rest from that minimum speed which is obtainable by causing event B (Fig. 2) to occur before event A as influenced by control means 40 (Fig. 1). Such normal minimum injection, even under aggravated conditions probably will be less than sufficient to maintain engine idling speed.

It is to be understood that the means here described for obtaining an intermediate pressure proportionally related to the full fuel pressure may be replaced by other known pressure regulator means suitable to maintain the pressure relations of the present example.

Only one injection nozzle 4 with its controlling valves 16 and 30 have been shown. I have however indicated the conduits 5 and 7 for connection to additional injection nozzles 2, 3 and 4 as in a system adapted for use with a four cylinder engine.

The sequence of operation of the injection valve 4 is as follows:

At the end of injection flow to the lower face of the valve is cut off by raising the plunger 16 associated with the injection valve. Full pressure is next applied through line 112 to the top of the valve by further raising the plunger 16 which has no effect on the movement of the valve. Full pressure is restored beneath the valve by lowering plunger 30 which also has no effect on the movement of the valve. Injection is then started by raising plunger 16 to reduce pressure on the top of the valve by connecting the space at the top of the valve to line 112 which allows the valve to lift.

I claim:

1. In a fuel injection system for internal combustion engines, in combination, an injection nozzle, a nozzle valve movable toward open or closed position by unbalance of hydraulic pressures cyclically and opposedly applied thereon, first reciprocable valve means for alternatively and sequentially applying full fuel injection pressure and a fractional intermediate pressure to urge said valve toward a closed position, means for reciprocating said first valve means, second reciprocable valve means for alternatively and sequentially admitting and preventing admission of fuel at full injection pressure to urge said nozzle valve toward its open position, means for reciprocating said second valve means, and means for altering the phase relations of the cyclical reciprocations of said first and second reciprocable valve means.

2. In a fuel injection system for internal combustion engines, in combination, an injection nozzle, a nozzle valve movable toward open or closed position by unbalance of hydraulic pressures cyclically and opposedly applied thereon, first reciprocable valve means for alternatively and sequentially applying full fuel injection pressure and a fractional intermediate pressure to urge said valve toward a closed position, means for reciprocating said first valve means, second reciprocable valve means for alternatively and sequentially admitting and preventing admission of fuel at full injection pressure to urge said nozzle valve toward its open position and means for reciprocating said second valve means, means for altering the phase relations of the cyclical reciprocations of said first and second reciprocable valve means, and additional means effective at will simultaneously to alter the timing of cyclical events of both said first and second valve means in relation to any reference point in the cycle of an associated engine without altering the cycle of alternations accomplished by either said first or second reciprocable valves and without altering the phase relation of complete cycles of events performed respectively by said first and said second reciprocable valves in their relations one to the other.

3. In a fuel injection system including a fuel injection nozzle valve movable alternatively to an open or closed position by unbalance of two related hydraulic pressures both greater than zero opposedly applied thereto, a source of fuel at the pressure applied on said nozzle valve during injection, a source of fuel at a lesser intermediate pressure of magnitude predeterminedly related to said first pressure and supplied from said first source, means for deriving the fuel of said second

source from said first source including in combination, a housing formed with a stepped bore of two diameters, a compound piston of two like diameters slidable in said stepped bore, means for closing the end of said major bore to enclose said piston in said housing and to define a fluid chamber between the major diameter of said piston and the end thus closed, a conduit for passing fluid at said intermediate pressure from or into said chamber, a second chamber defined between the step in the bore and the major piston diameter and defining an annular differential piston area less than and opposed to the major area of said piston, a conduit continuously communicating said second chamber to the source of fuel under full pressure, means regulated by reciprocation of said piston whereby upon approaching the extremity of its movement in the direction of its major face fuel is admitted from the second said chamber to the first said chamber and upon approaching the extremity of its movement in the opposite direction fuel is released from the piston face of major area.

4. In a fuel injection system including a fuel injection nozzle valve movable alternatively to an open or closed position by unbalance of two related hydraulic pressures both greater than zero opposedly applied thereto, a source of fuel at the pressure applied on said nozzle valve during injection, a source of fuel at a lesser intermediate pressure of magnitude predeterminedly related to said first pressure and supplied from said first source, means for deriving the fuel of said second source from said first source including in combination, a housing formed with a stepped bore of two diameters, a compound piston of two like diameters slidable in said stepped bore, means for closing the end of said major bore to enclose said piston in said housing and to define a fluid chamber between the major diameter of said piston and the end thus closed, a conduit for passing fluid at said intermediate pressure from or into said chamber, a second chamber defined between the step in the bore and the major piston diameter and defining an annular differential piston area less than and opposed to the major area of said piston, a conduit continuously communicating said second chamber to the source of fuel under full pressure, means regulated by reciprocation of said piston whereby upon approaching the extremity of its movement in the direction of its major face fuel is admitted from the second said chamber to the first said chamber and upon approaching the extremity of its movement in the opposite direction fuel is released from the piston face of major area and means for applying at will an additional force urging said compound piston to move in the direction of its major face to increase the magnitude of said intermediate pressure to that extent determined by said additional force.

5. In a fuel injection system for internal combustion engines, in combination, an injection nozzle, a nozzle valve movable toward open or closed position by unbalance of hydraulic pressures cyclically and opposedly applied thereon, a plurality of reciprocable valve means for alternatively and sequentially applying full fuel injection pressure and a fractional intermediate pressure to urge said valve toward a closed position, and a like plurality of second reciprocable valves in accordance with the number of cylinders of an associated engine and means to reciprocate each of said reciprocable valves in suitably timed relation with the reciprocation of the piston in the associated engine cylinder for alternatively and

sequentially admitting and preventing admission of fuel at full injection pressure to urge said nozzle valve toward its open position and means for reciprocating said second valve means, means for altering the phase relations of the cyclical reciprocations of said first and second reciprocable valve means, and additional means effective at will simultaneously to alter the timing of cyclical events of both said first and second valve means in relation to any reference point in the cycle of an associated engine without altering the cycle of alternations accomplished by either said first or second reciprocable valves and without altering the phase relation of complete cycles of events performed respectively by said first and said second reciprocable valves in their relations one to the other.

6. In a fuel injection system for internal combustion engines, in combination, an injection nozzle, a nozzle valve movable toward open or closed position by unbalance of hydraulic pressures cyclically and opposedly applied thereon, a plurality of reciprocable valve means for alternatively and sequentially applying full fuel injection pressure and a fractional intermediate pressure to urge said valve toward a closed position, and a like plurality of second reciprocable valves in accordance with the number of cylinders of an associated engine and means to reciprocate each of said reciprocable valves in suitably timed relation with the reciprocation of the piston in the associated engine cylinder for alternatively and sequentially admitting and preventing admission of fuel at full injection pressure to urge said nozzle valve toward its open position and means for reciprocating said second valve means and adjustable means for altering minutely the relation of the timing of the occurrence of a given valving event of one of said first reciprocable valve means in relation to the piston of its associated cylinder without altering the timing of others of said first reciprocable valves in relation to their respective associated engine pistons.

7. In a fuel injection system for internal combustion engines, in combination, an injection nozzle, a nozzle valve movable toward open or closed position by unbalance of hydraulic pressures cyclically and opposedly applied thereon, a plurality of reciprocable valve means for alternatively and sequentially applying full fuel injection pressure and a fractional intermediate pressure to urge said valve toward a closed position, and a like plurality of second reciprocable valves in accordance with the number of cylinders of an associated engine and means to reciprocate each of said reciprocable valves in suitably timed relation with the reciprocation of the piston in the associated engine cylinder for alternatively and sequentially admitting and preventing admission of fuel at full injection pressure to urge said nozzle valve toward its open position, means for reciprocating said second valve means, and means for altering the phase relations of the cyclical reciprocations of said first and second reciprocable valve means, and adjustable means for altering minutely the relation of the timing of the occurrence of a given valving event of one of said first reciprocable valve means in relation to the piston of its associated cylinder without altering the timing of said first reciprocable valves in relation to their associated engine pistons.

8. In a fuel injection system for internal combustion engines, in combination, an injection nozzle, a nozzle valve movable toward open or closed position by unbalance of hydraulic pressures cyclically and opposedly applied thereon, a plurality of reciprocable valve means for alternatively and sequentially applying full fuel injection pressure and a fractional intermediate pressure to urge said valve toward a closed position, and a like plurality of second reciprocable valves in accordance with the number of cylinders of an associated engine and means to reciprocate each of said reciprocable valves in suitably timed relation with the reciprocation of the piston in the associated engine cylinder for alternatively and sequentially admitting and preventing admission of fuel at full injection pressure to urge said nozzle valve toward its open position and means for reciprocating said second valve means, means for altering the phase relations of the cyclical reciprocations of said first and second reciprocable valve means, and additional means effective at will simultaneously to alter the timing of cyclical events of both said first and second valve means in relation to any reference point in the cycle of an associated engine without altering the cycle of alternations accomplished by either said first or second reciprocable valves and without altering the phase relation of complete cycles of events performed respectively by said first and said second reciprocable valves in their relations one to the other and adjustable means for altering minutely the relation of the timing of the occurrence of a given valving event of one of said first reciprocable valve means in relation to the piston of its associated cylinder without altering the timing of others of said first reciprocable valves in relation to their respective associated engine pistons.

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