Feb. 19, 1963 R. L. ALLEN 3,077,872

FUEL INJECTION SYSTEM

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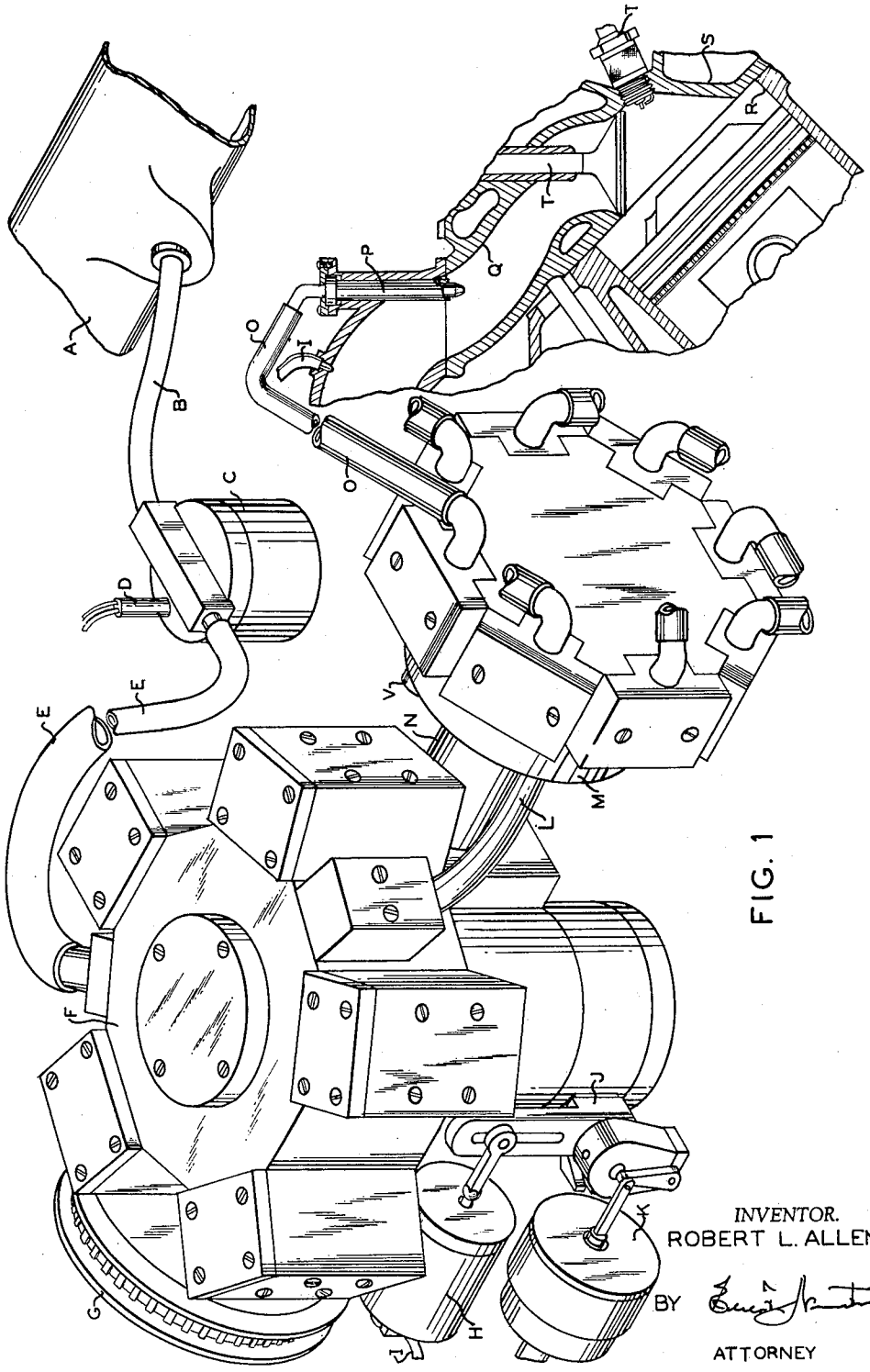


FIG. 1

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FUEL INJECTION SYSTEM

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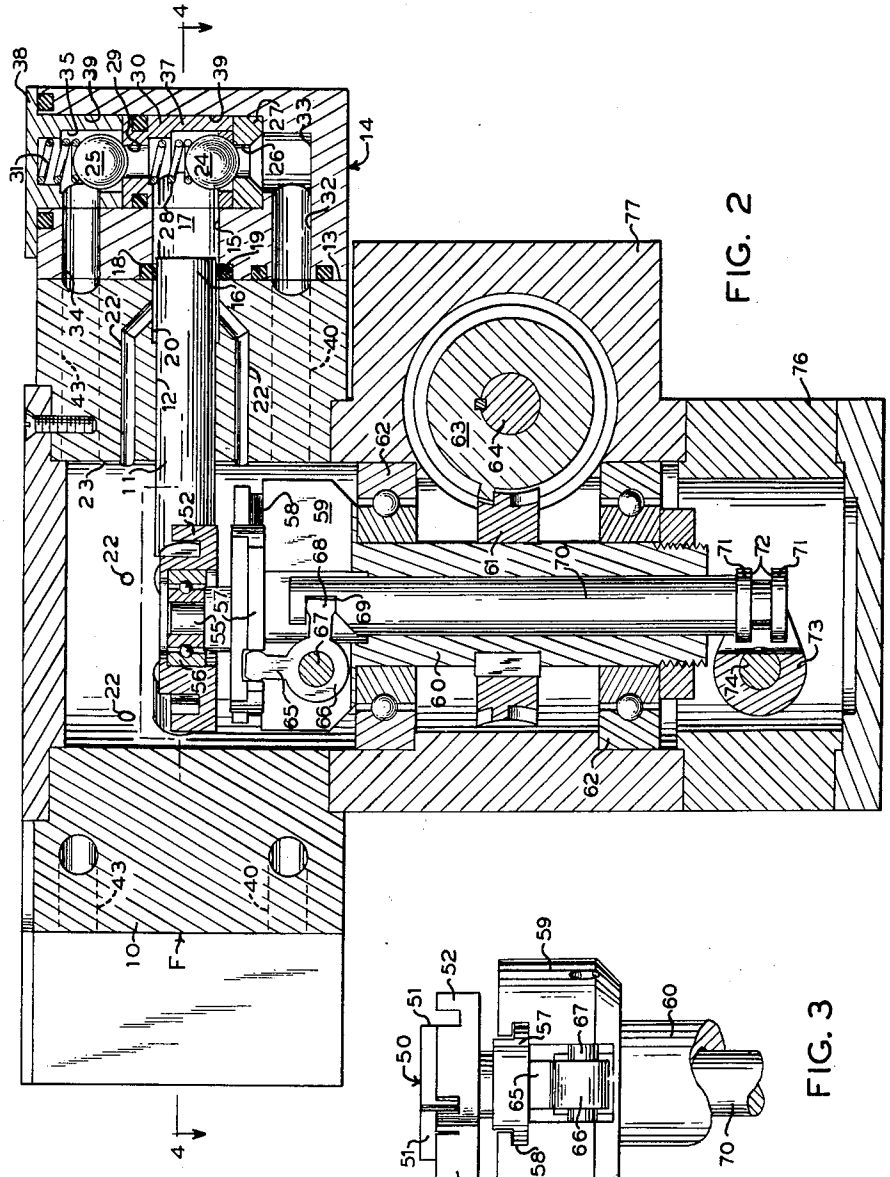


FIG. 2

FIG. 3

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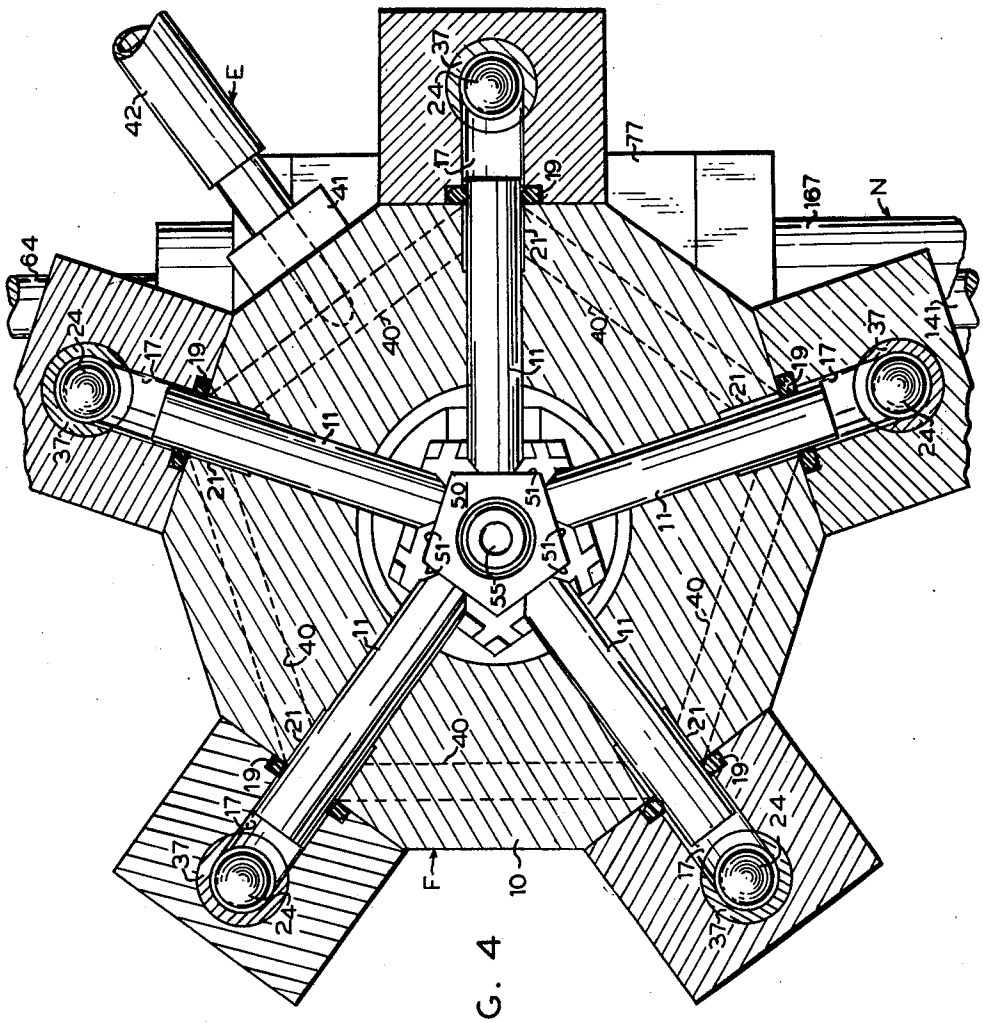


FIG. 4

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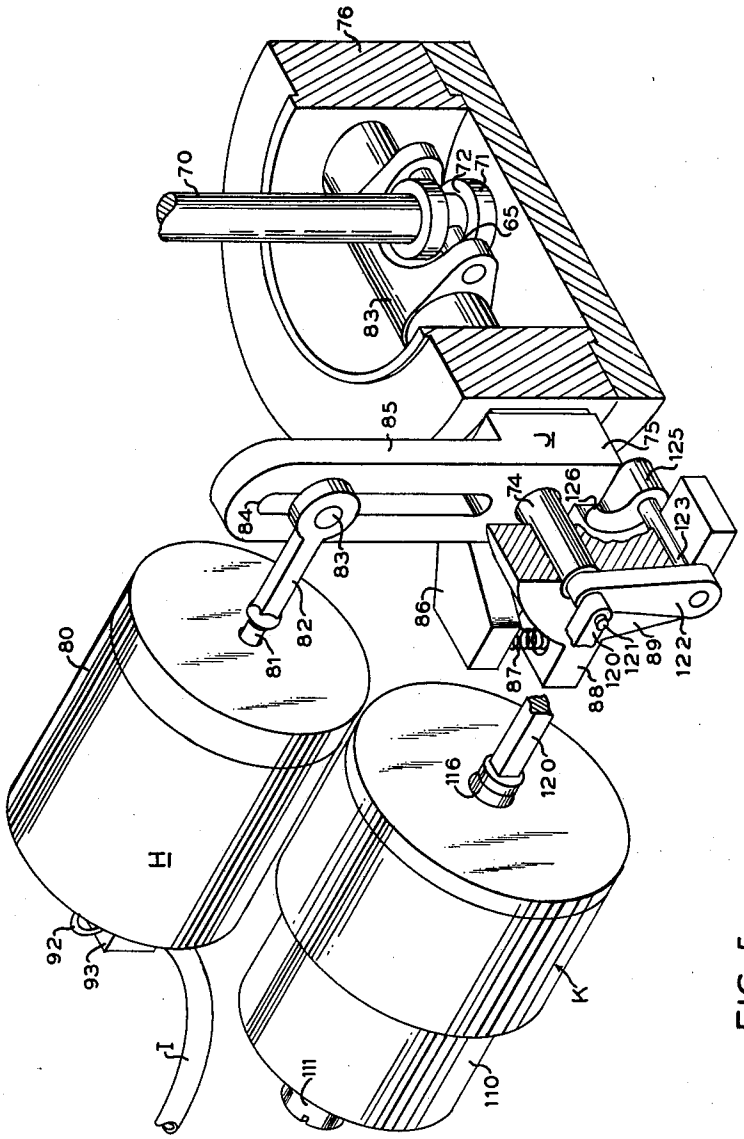


FIG. 5

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FIG. 6

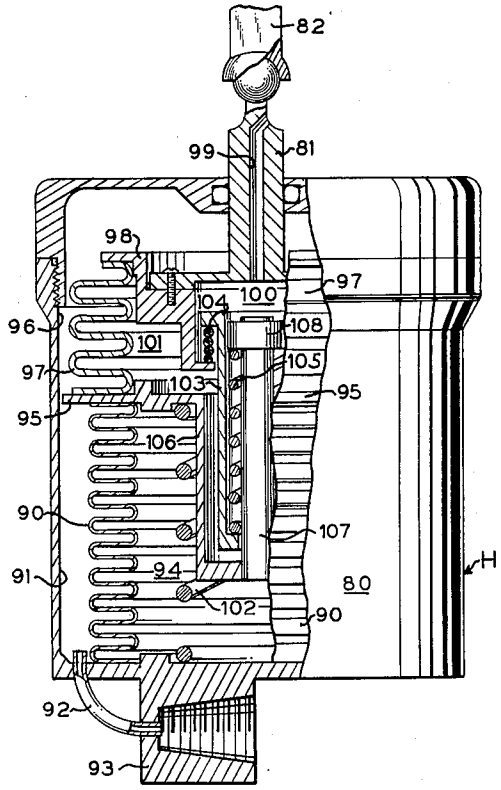
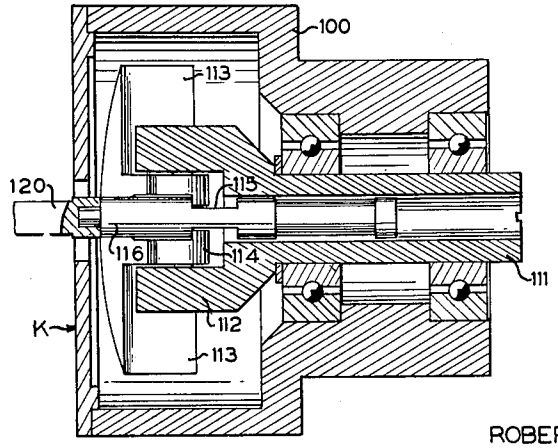


FIG. 7



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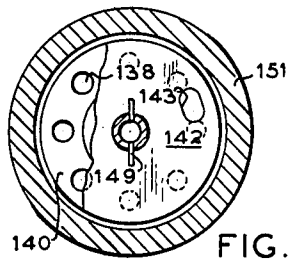


FIG. 8A

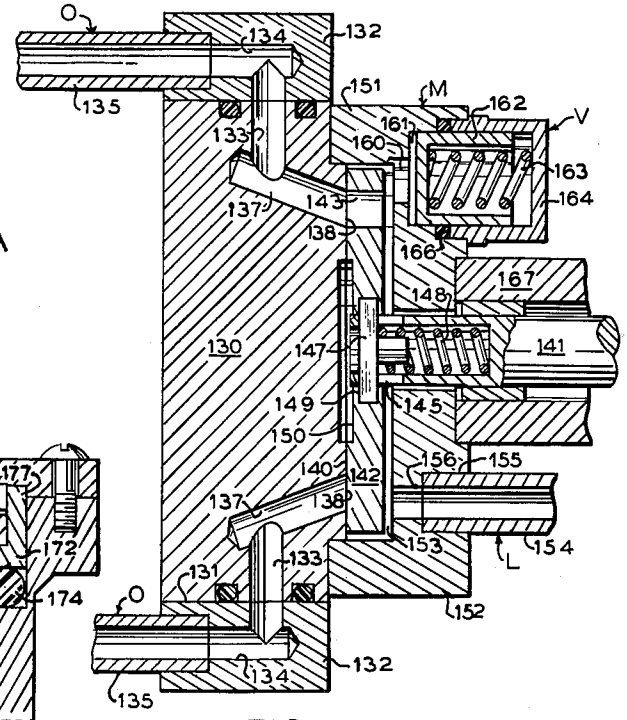


FIG. 8

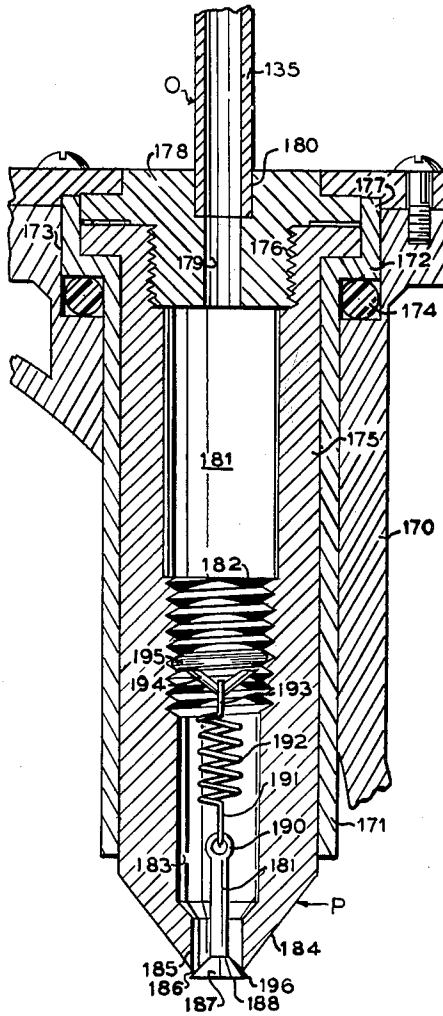


FIG. 10

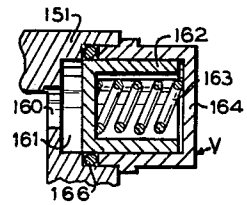


FIG. 9

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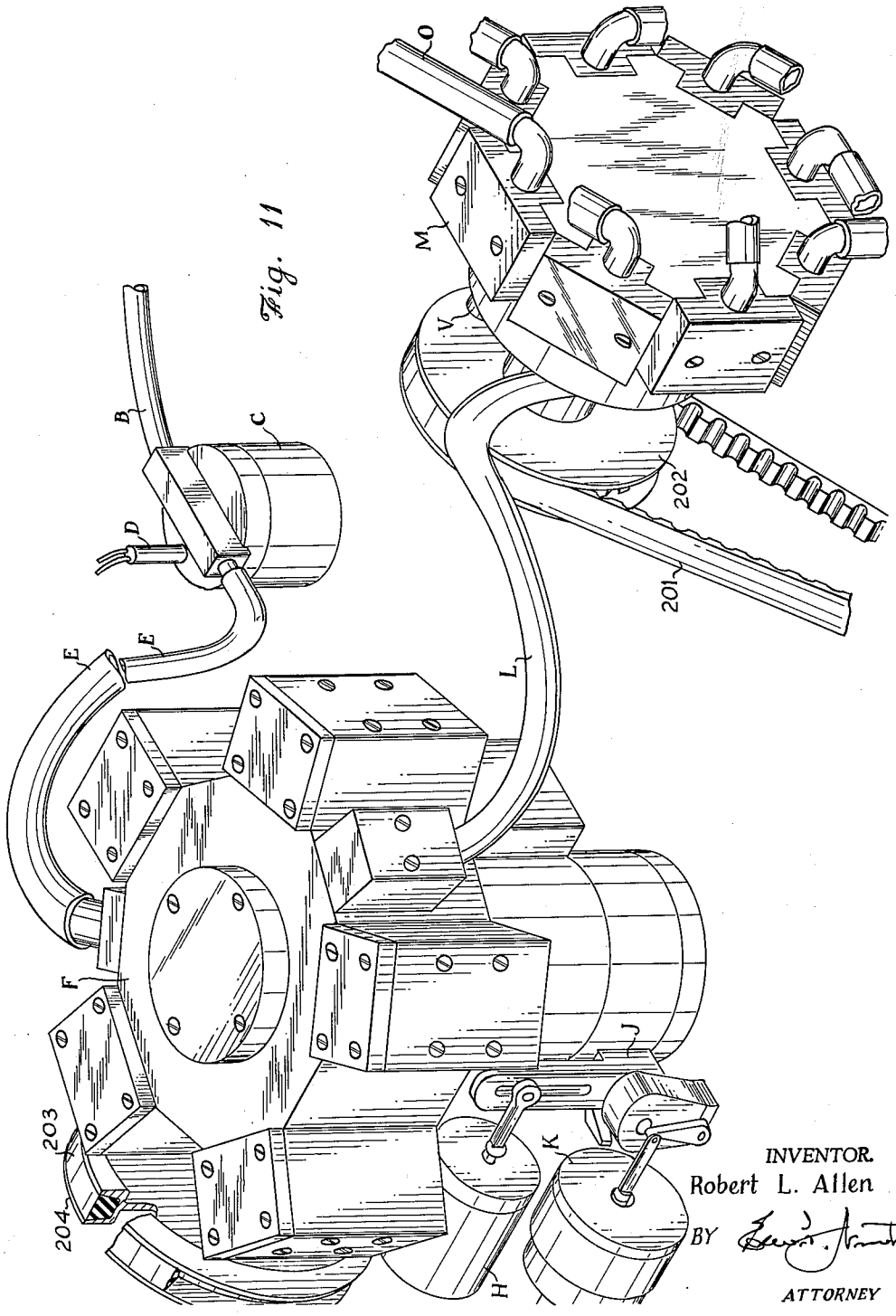
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FUEL INJECTION SYSTEM

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Fig. 11



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United States Patent Office

3,077,872

Patented Feb. 19, 1963

3,077,872

FUEL INJECTION SYSTEM

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Filed July 17, 1961, Ser. No. 124,725
27 Claims. (Cl. 123—140)

This invention relates to a fuel injection system for high speed, four cycle, spark ignition, internal combustion engines, and is particularly concerned with a method of and means for the individual injection of metered increments of fuel in timed sequence with operation of the individual cylinders of the engine.

This application is a continuation-in-part of my co-pending application, Serial No. 703,906, filed December 19, 1957, for "Fuel Injection System."

The supply of fuel for compression ignition or diesel type internal combustion engines has long been carried out by the forceful injection of metered increments of fuel to the cylinder at an appropriate point in the piston cycle; however, this general method has not been completely successful as applied to the supply of fuel for spark ignition, or Otto type, multiple cylinder internal combustion engines primarily because of high speed and because of the necessity for rapid changes in fuel requirements.

In order to obviate some of the difficulties which have arisen, high pressures have heretofore been resorted to. However, such pressures have resulted in air locks, vibration, pounding and the like which have militated against the effective and efficient volume control as well as distribution of the properly metered increments at such uniform pressure as is requried to insure appropriate atomization of the fuel in the combustion supporting medium supplied to the cylinders such high pressures also produce undue abrasive deterioration of parts and militate against a long life of effective and efficient operation. An outstandingly important step toward solution of some of the problems involved is achieved in the present invention by means for maintaining stable pressure conditions throughout the system and so balancing the pressures of related elements as to inhibit binding, locking, turbulence or frictional losses which would prevent high and consistent efficiency. In accomplishing such pressure control and balance, a relatively low range of pressure is utilized and excessive pressures are avoided by the use of pressure responsive, variable volume means. Such means respond, as pressures tend to build up, by at least temporarily accommodating fluid in a variable volume chamber. The desired pressure is maintained, however, by the reacting pressure of such pressure responsive means; and thus a relatively uniform pressure of the fluid supplied to the injection nozzles is insured. Cooperating pressure devices are provided in the form of resiliently mounted diffusion heads in the individual injection nozzles. By relating the closing tension of the diffusion heads with the pressure required for the yielding of the variable volume device, uniformity of total pressures are maintained over a selected low operative range.

Other problems, with respect to fuel injection systems, which have not heretofore been satisfactorily solved, include that of controlling the fuel supply in response to variations of engine demand as reflected by intake manifold pressure. Venturi methods and highly developed carburetor constructions have produced remarkable operating efficiencies. Nevertheless, such devices cannot serve to supply incremental pulses of fuel metered in response to intake manifold pressures and delivered with injection force to the combustion supporting medium of the individual cylinders. Furthermore, while manifold pressure may be relied on throughout most operating conditions as an appropriate means for controlling the supply of fuel, other factors may indicate the desirability of a variable fuel supply under given manifold pressures; thus, at certain ranges of engine speed, particularly low speeds, the fuel requirements may not be in the same rate to manifold pressure as under other conditions. Compensation for varying ambient atmospheric conditions is also required for greater efficiency.

Another problem is the adequate atomization or dispersion of the fuel particles in the combustion supporting gases. Proper operation requires, not only exact timing of the injection, and a complete delivery of the total metered increment with a positive cut off to preclude waste of fuel, pre-ignition or late firing; but, also necessitates such spray pattern as to insure substantially instantaneous combustion and flame front propagation. The injection element both as to design and operating characteristics is therefore of critical importance.

Numerous other problems, many of which may appear secondary in nature, are also involved; however, it has been found that a total and overall high efficiency may follow from an appropriate solution of individual problems, such efficiency being greater than a mere sum of the individual efficiencies of the separate components. In particular, this has been found to be the case with respect to fluid flow conditions throughout the system. Thus by the provision of a high efficient metering pump with appropriate volumetric control, responsive to manifold pressures, as modified by engine speed and ambient conditions, in combination with a distributor designed for coordinated and effective incremental distribution of fuel and an interrelated pressure control arrangement capable of precluding peak pressure conditions and in further cooperation with injection nozzles, balanced in conformity therewith and providing the desired discharge pattern, a total superiority of performance is achieved beyond that foreseeable from a consideration of the separate elements.

Therefore, the present invention sets forth a complete fuel injection system including both appropriate apparatus and method steps for the successful application of principles of fuel injection to spark ignition type, high speed, multiple cylinder combustion engines. An important distinguishing characteristic of the present system, with respect to some contemporary systems, is its purely mechanical nature which avoids the necessity for complicated electrical circuitry and equipment.

Briefly, the apparatus of the present system includes a fuel pump preferably operated by and in synchronism with the operation of the engine. The preferred pump is a multiple cylinder pump, the volumetric output of each cylinder is variable in accordance with engine demands for fuel. Primarily this variation is controlled by intake manifold pressure; however, compensating means are provided by which the volumetric output may be modified in accordance with ambient atmospheric conditions. A further and preferably overriding compensation means is provided by which the volumetric output of the pump may be modified in accordance with certain speed conditions of the engine, such as low speed, in which a relatively increased fuel supply may be required. The system of the present invention also includes a distributor by which the relatively continuous stream of fuel supplied by the pump, in accordance with engine demands for fuel, is distributed from such generally continuous flow into accurately metered individual increments directed to the individual cylinders of the engine.

Since excessive high pressures have been found to cause pressure vapor locks, turbulence, pounding and inefficient delivery of accurately timed and metered increments of

fuel as well as undue abrasion, the present invention operates at a relatively low pressure, as for instance in the range somewhat below 100 p.s.i. Volume compensating means in the form of one or more expensible chamber pressure responsive devices, such as accumulators, are provided by which varying volumes of fuel may be accommodated without the normally inherent variations in pressure. The present system further includes a novel and improved nozzle, the general design and configuration insures a rapid and complete discharge of each metered fuel increment. This is accomplished not only by insuring a rapid pressure drop at the nozzle orifice, but by providing sharp and abrupt flow edges precluding clinging and adhesion of fuel droplets. An important feature of the invention is the design and balance of the spring mounting of the nozzle diffusion head and its variable tension as related to system pressure.

The method of the present system includes the steps of supplying fuel by a pump preferably of variable capacity, variations of which may be controlled by a plurality of variations in characteristics of engine operation and which may be modified by ambient conditions. Another step in the method is the division and distribution of total fuel flow as individual increments for delivery as required by the engine. Accurate metering is accomplished through the combined operation of the pump for supplying a highly precise responsive variable flow and a distributor for dividing and distributing this flow in responsive variable increments without distortion due to mechanical or pressure disturbances. The total method also embraces the step of ultimate fuel discharge to the engine. In its presently preferred form such discharge is individual and complete as to each increment, and the discharge is at such pressure and through such means as to insure a uniform repetitious miscible spray into the combustion supporting medium.

A more overall characteristic of the present method is the superior effectiveness and efficiency resulting from the avoidance of excessive pressures or pressure variations through the system. One contributing factor of such avoidance is the step of maintaining relatively low and substantially uniform pressure. The ultimate discharge pressure is within a range primarily dominated by spring controlled resistance at the individual discharge nozzles. In keeping with the low pressure character of the whole system such spring resistance is relatively low. Such pressure control as may be effected by the discharge nozzle is however not an independent instrumentality. By a related adjustment of pressure valves between the accumulator and the nozzle a relatively low, consistent and uniform selected pressure range may be maintained through the distributor discharge lines. Since the pressure maintained by the accumulator is in the nature of, through necessarily exceeding for flow purposes that of the nozzle resistance, a full incremental discharge is insured as well as a sharp terminal cut off avoiding residual droplets and dribble which would militate against optimum operational characteristics. In the actual operation of this system there has been noted a vibratory type of fluctuation in the discharged pattern of the nozzles which can be, at least in fact, accounted for by the similarity between accumulator pressure and diffusion head resistance. Since these values are compatible, a hunting action may be induced. Vibratory characteristics of the discharge patterns may be defined as progressive annular undulations of outwardly increasing amplitude and of corresponding decreasing frequency on the surface of the hollow conical spray. It is also to be noted that the effect of the accumulator may be reflected back to the pump. Since the accumulator will accommodate, at least temporarily, increases in fluid volume and hence smooth out pressure surges and peaks, it follows that high pressure build up at the pump discharge is precluded, despite output volume changes.

The primary object of the present invention is, therefore, to provide a fuel injection system, including both novel apparatus and novel method steps for the effective and efficient injection of incremental fuel pulses to high speed, multiple cylinder, spark ignition type, internal combustion engines.

More specifically, it is among the objects of the present invention to provide a system of the character set forth, operative at relatively low pressures throughout the system and so constructed and arranged as to avoid peak pressures exceeding a predetermined relatively low pressure range.

It is also an object of the present invention to provide a system which is simple in construction, and purely mechanical in operation, for carrying out the requisite functions, and one which may attain a long life of effective and efficient operation while complying with the demands of economic manufacture.

The objects of the invention also include that of providing a combination and interrelation of independent functional elements and method steps, each of which independently contributes improved functions which in combination and cooperation provide highly effective and efficient means for the fuel injection of highly miscible, accurately metered, pulsations of fuel increments to the combustion supporting gases of a multiple cylinder, high speed, spark ignition type, internal combustion engine.

The objects of the invention also embrace the individual objectives set forth with respect to the individual elements of the combination as delineated in the separate applications filed concurrently herewith in connection with such separate instrumentalities as here enumerated, which applications are incorporated by reference and attention is directed thereto for further and more detailed consideration of the construction and operation of such individual instrumentalities:

Variable Displacement Pump
Speed Responsive Control Modulating Device
Fluid Pressure Responsive Control Mechanism
Variable Volume Fluid Distributor
Spray Nozzle
Fuel Injection Nozzle and Method of Injecting Fuel for Internal Combustion Engines

Numerous other objects, features and advantages of the present invention will be apparent from consideration of the following specification taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic perspective view of one assembly of structural elements of the present invention.

FIG. 2 is a vertical cross-section of that form of pump used in the present system.

FIG. 3 is a detailed side elevation of the drive head of the pump.

FIG. 4 is a horizontal cross-section taken on line 4—4 of FIG. 1.

FIG. 5 is a detailed perspective view of the volumetric control system for the pump.

FIG. 6 is a side elevation, partly in cross-section, of the manifold pressure responsive control for the pump.

FIG. 7 is a vertical cross-section of the speed responsive control for the pump.

FIG. 8 is a vertical cross-section of the distributor.

FIG. 8A is a fragmentary cross-sectional view illustrating the distributor plate mounting and its relation to the individual distribution ports.

FIG. 9 is a detailed cross-section of the accumulator adapted for use in the distributor at FIG. 8.

FIG. 10 is a fragmentary detailed cross-section of a form of injection nozzle used.

FIG. 11 is a schematic perspective view of a modified assembly of certain of the structural elements of the present invention.

Referring more particularly to FIG. 1 of the drawings, there is presented one structural embodiment of the present inventive concept which has been successful competitive

operation with contemporary injection systems. The system contemplates a conventional fuel supply such as a gas tank fragmentarily indicated at A from which fuel is supplied through the pipe B to a primary pump C. The pump C is here indicated as a conventional electric automotive type fuel pump energized through the conductors D to provide an ample and constant supply of liquid fuel, such as gasoline, through the pipe E to the variable volume pump F. The pump F is driven by the engine through pulley G, at a speed synchronized therewith. The volumetric output of the pump, however, is variable in response to intake manifold pressure applied to the cylinder H through pressure conduit I communicating with the intake manifold. The piston of cylinder H acts through a linkage mechanism J for controlling the amplitude of pump piston movement. Volumetric pump response may be modified by speed responsive mechanism indicated at K also associated with linkage J. Fuel supplied to the pump F is delivered from pump F through supply tube L to a distributor M operated with the pump F and hence from pulley G through shafting N. Distributor M divides the fuel supplied into individual increments which are individually supplied through lines O to injection nozzles P illustrated as located in the inlet passages Q of the individual cylinders R of a multicylinder, high speed, spark ignition engine S. Each individual cylinder R is provided with a conventional intake valve T, and spark plug U. An important feature of the invention is the provision of a pressure responsive accumulator V in the fuel supply line, preferably located, as shown at the distributor M, in the fuel inlet side thereof and so arranged to preclude build up of peak pressure within the system. While some of the elements of the system thus set forth are entirely conventional, as the tank A, the electric pump C and the engine with its spark plugs, cylinder and valves, other elements are novel, per se, and constitute the subject matter of the copending applications hereinbefore identified.

VARIABLE VOLUME PUMP

One form of variable valve pump T for the present system is presented in detail in FIGS. 2, 3 and 4 of the drawings. As therein disclosed the pump T is in the form of a decagon shaped body 10, the five alternate segments of which form pentagonally arranged segmental piston and cylinder units. In each unit a piston 11 reciprocates with radial rectilinear movement within the radial bores 12. On each alternate face of the body 10, upon the vertical outer walls 13 of each unit there is mounted a pumping head 14. Each head 14 defines a central inwardly directed bore 15 aligned with the bore 12 of each associated unit. The bores 15 receive the pumping heads 16 of the pistons 11 to constitute a pumping chamber 17. A unique sealing arrangement is provided between the chamber 17 and the pumping head 16 of pistons 11 by the provision of an annular rabbit 18 confronting the outer face of the segment to which the head 14 is secured. Fitted within these annular recesses 18 are O rings 19. The recesses formed by the rabbit 18 are of generally rectangular form and of less cross-section in either direction than the normal diameter of the O rings; hence in assembly of the O rings are forced into position to provide generally rectangular seals against which the outer faces of the pumping heads 16 are slidable. The deformation of the O rings in the limited space of the recess precludes a rolling action as the piston is reciprocated, and thus an effective seal is provided without incurring the danger of undue wear due to movement of the ring by rolling action as is customary in normal installations of O rings as seals in like instances.

For lubricating the pistons 11, the outer end of the bore 12 is counterbored as at 20 to provide an annular elongate lubricant space 21 outwardly sealed by the O ring 19 and through which lubricant may be circulated by the ducts 22 leading from a lubricant filled central chamber 23 formed within the body 10.

Each head 14 mounts inlet and outlet pumping check valves in the form of valve balls 24 and 25, respectively. The inlet valve ball 24 is adapted to seat against the central port 26 of an annular inlet valve seat 27 under the influence of its spring 28. The upper outlet valve ball 25 is adapted to seat against the port 29 of an annular outlet valve seat 30 under the influence of its spring 31. Each head 14 also defines an inwardly extending fuel supply duct 32 leading to a supply chamber 33 communicating with the port 26 of the annular inlet valve seat 27 below the ball 24. Each head further defines a fuel outlet delivery duct 34 communicating with an outlet chamber 35 in which the ball 25 is located above the duct 29 and seat 30. The annular valve seats 27 and 29 are spaced by a central valve cage 37 and are secured by an upper securing cage 38, both being located in the vertical central bore 39 of each head 14.

In the pumping operation, as each piston 11 moves inwardly in the direction of the central chamber 23, fuel is drawn into its chamber 17 through the inlet valve seat 27 and past the ball 24 which moves against the tension of its spring 28. On the opposite outward movement of each piston, its ball valve 24 is seated against its valve test 27 while the outlet ball valve 25 is moved from its seat against the tension of its spring 31 to deliver the fuel from the chamber 17 through the delivery duct 34. As more clearly illustrated by the dotted lines of FIG. 4, the individual supply ducts 32 are supplied with fuel through the interrelated channels 40 from a fuel inlet nipple 41 connected with the pipe 42 corresponding to the pipe E of FIG. 1. A like system of ducts 43 lead from the discharge ports 34 to deliver the pumped fuel through a supply tube (not shown) corresponding to the tube L of FIG. 1.

PUMP DRIVE

Continuous reciprocation of the pistons 11 in successive phase relation is secured by the orbital rotation of a piston driving head 50 formed as a pentagon with faces 51 corresponding to each piston 11, each face being disposed in a plane normal to its axis of its piston. Adjacent each face 51, the head 50 is formed with a vertically upstanding lip 52 which engages within a corresponding downwardly open slot 53 at the inner end of each piston 11. This arrangement is such that as the head 50 moves in its orbital path a rectilinear reciprocation will be imparted to each piston 11, the amplitude of which corresponds with the radius of the orbital movement of the head 50.

Orbital movement at a selectively variable radius is imparted to the head 50 by the mounting thereof upon a vertical stud 55 through the intermediary of an anti-friction bearing indicated at 56. The stud 55 is formed preferably as an integral part of a transversely slidable plate 57 mounted within transverse guideways 58 of a rotatable driving head 59 carried by a cylindrical drive shaft 60. The shaft 60 is rotated in synchronism with the rotation of the engine by a worm gear 61 mounted centrally thereon between shaft bearings 62 and driven through a worm 63 on the shaft 64 which receives its drive from the engine through the pulley G of FIG. 1. The relative lateral position of the plate 57 on the driving head 59, and thus the relative eccentric location of the stud 55 with respect to the rotary driving head 59, is controlled by the upper arm 65 of a crank 66 freely rotatable on a shaft 57 carried by the head 59. The crank 66 further includes a radially extending, relatively horizontal arm 63 which engages a notch 69 in a vertically reciprocable pump volume control rod 70 which is mounted centrally for reciprocation within the shaft 60. A lower end of the rod 70 is formed with spaced flanges 71 defining an annular groove 72 which receives the operating detent of an operator 73 mounted on an oscillating control shaft 74. It will be understood that as the shaft 60

is rotated with a speed commensurate to that of the engine for rotation of the head **59** therewith, the shaft **70** also rotates therewith but is subject to vertical movement in response to the oscillation of the shaft **74**. As the shaft **70** is moved vertically the crank **66** will be rotated, and therewith the arm **65** will slide the plate **57** with respect to the head **59** to alter the transverse location thereof and hence the eccentricity of the stud **55**. Since eccentricity of the stud **55** controls the radius of the orbital movement of the head **50** and since such radius controls the amplitude of movement of the pistons **11** and further since such amplitude of piston motion will control the volumetric output of the pump in response to each rotation of the shaft **60**, it will be seen that the volumetric pump output is variable in response to the setting of the shaft **74**.

From the foregoing it will be seen that the present invention includes as an element thereof a multi-piston rotary pump of variable volumetric output, the volume of which may be readily adjusted through control of the shaft **74**, and that the pump will provide a volumetric output responsive to the engine speed as modified by the setting of the shaft **74**. By virtue of the multiplicity of cylinders and piston units, it will be seen that the pump discharge while responsive to the combined control of engine speed and setting of the shaft **74** will constitute a continuous flow of fuel. As will be apparent from further consideration of the pump control instrumentalities hereinafter described, it will be noted that the supply of fuel from the pump is variable in accordance with the demands of fuel by the engine and that such supply constitutes a relatively constant stream of fuel from the pipe E indicated in FIG. 1 to the supply tube L of FIG. 1.

PUMP VOLUME CONTROL

Since the pump head **50** is rotated by the shaft **60**, driven from the pulley G of the engine, it will of course be understood that the volumetric output of the pump will be responsive to engine speeds; however, since the amplitude of piston reciprocation is directly responsive to the radius of orbital movement of the head **50** which in turn corresponds to the eccentricity of the stud **55**, it will be seen that volumetric output of the pump is also directly responsive to the setting of the plate **57** carrying the stud **55**. The transverse position of the plate in turn corresponds to the vertical position of the control rod **70**. It will of course be noted that should the plate **57** be so adjusted as to bring the stud **55** into a position corresponding to the axis of rotation of the shaft **60** there will be no reciprocation of the pistons **11** since the head **50** will rotate on its own axis without any orbital movement. As heretofore stated, it is among the objectives of the present invention to provide a fuel supply corresponding to the intake manifold pressure of the engine. This objective is obtained by the vertical adjustment of the rod **70** in response to such intake manifold pressure.

As more clearly disclosed in FIGS. 5, 6 and 7, the rod **70** is adjusted in its vertical position to control the eccentricity of the stud **55** and hence the amplitude of motion of the pistons **11** by the shaft **74**. Shaft **74** mounts a boss **73** having detent fingers **75** located between the flanges **71** within the groove **72** of the rod **70**, as hereinbefore noted. The structure is mounted within an annular housing **76** engaged below the housing **77** for the shaft **60** which also mounts the shaft **64** and which in turn is seated against the lower face of the pump body **10**, this structural arrangement being disclosed in FIG. 2.

For adjusting the vertical position of rod **70** in response to variations in intake manifold pressure there is provided the cylinder H of FIG. 1, shown in greater detail as cylinder **80** of FIGS. 5 and 6. Responsive to pressure variations within the cylinder **80** an actuating rod **81** is reciprocated. The rod **81** is connected through a link **82** to a pin **83** mounted through an elongate central slot **84** of a lever **85**, as shown in FIG. 5. Lever **85** is mounted for free pivotal movement on the shaft **74**. The lever **85** carries at its lower end a laterally projecting plate **86** which is coupled through a spring **87** to a laterally extending parallel plate **88** projecting from a head **89** secured to the shaft **74**, thereby movements of said head will be imparted to the shaft **74** to provide oscillatory movement thereof for vertically adjusting the rod **70**. By this arrangement it will be seen that rectilinear movements of the rod **81** in response to variations of intake manifold pressure will operate through the spring **87** to tend to move the head **89** and hence the shaft **74** for vertically adjusting the rod **70**.

By referring to FIG. 6 it will be noted that the cylinder **80** provides means for modifying the responses of the rod **86** to changes in intake manifold pressure in accordance with ambient atmospheric conditions, such as changes due to altitude, and to balance such responses against relatively fixed pressure conditions so as to provide a relatively absolute response control. For this purpose the cylinder **80**, as shown in FIG. 6, is provided with an internal pressure responsive bellows **90** internally spaced from the walls of the cylinder to form a chamber **91** to which intake manifold pressure is admitted through the duct **92** leading from a fitting **93** communicating by the tube I of FIG. 1 to the intake manifold. The internal chamber **94** formed by the bellows **90** is preferably evacuated to approximate zero pressure, or some inert non-responsive gas may be enclosed, so as to provide for a positive response of the bellows **90**. On the upper end of the bellows **90** there is provided a floating bridge **95** spaced from the inner surface of the walls so as to permit the admission of intake manifold pressures to the upper chamber **96** surrounding an upper pressure responsive bellows **97**. The upper bellows **97** is closed by head **98** to which the actuating rod **81** is secured for movement therewith for modifying the movements of the rod **70** in response to fluctuations in the intake manifold pressure by ambient atmospheric conditions. The rod **81** is formed with a duct **99** opening externally to the atmosphere and opening internally to the chamber **100** communicating with the internal chamber **101** formed within by the upper bellows **97**. This construction further provides an internal spring **102** within the chamber **94** bearing against bridge **95** and an internal capsule **103** urged upwardly by an internal spring **104** and reacted by an internal spring **105**. The bridge **95** defines a central cylinder **106** formed with an axial rod **107** on which is mounted a head **103** against which the upper end of the internal spring **105** bears. This arrangement is such that, while the atmospheric pressure admitted through the duct **99** to the chambers **100** will react against the pressures applied by the intake manifold, the cylinder **106** and the head **108**, through the action of their respective springs, will act as stops to limit the reaction to ambient atmospheric pressure conditions. It will thus be seen that movement of the rod **81** is primarily in response to intake manifold pressures but provides means for modification of the reaction of the rod **91** in accordance with ambient conditions and that the pressure condition within the chamber **94** provides positive responsive action against the fixed pressure condition within the bellows **90**.

Means are also provided for modifying the reactive movement of the rod **90** with respect to the movement of the rod **81** in response to predetermined engine speed conditions. For this purpose there is provided a governor type control mechanism, as illustrated in FIG. 7, housed within a casing **110** which is the element identified by the letter K in FIG. 1. This instrumentality includes a shaft **111** adapted to be driven in synchronism with the engine through the belt leading from the pulley G or the equivalent thereof. Internally, the shaft is formed with a head **112** pivotally mounting centrifugally responsive fly weights **113**, the inner ends **114** of which engage a notch **115** of an externally extending operating rod **116**. As the engine is rotated at low speeds, as in starting, the rod **116** will be in its full outer position; and, as the engine increases in

speed to normal operating ranges, the rod 116 will be withdrawn into the casing 110.

Referring again to FIG. 5, it will be seen that the rod 116 is connected by a link 120 and pin 121 to arm 122 mounted for pivotal movement by a transverse shaft 123 extending through the lobe 124 of the head 89. The shaft 123 carries upon its inner end a latch 125, the outer end of which bears against the shoulder 126 formed at the lower end of the lever 75. An important feature of this arrangement is that the upper end of the link 111 is normally in registration with the rod 64, so that when the link 110 is retained in stationary position with the link 111 the movements of the rod 71 will be imparted through the lever 85 and through the spring 87 to directly move the shaft 60 is response to such movements of the rod 81. While the control of the rod 70 and the volumetric output of the pump is, in general, in direct response to the intake manifold pressure as modified by the ambient atmospheric conditions through the action of cylinder 80, under low speed conditions the rod 116 is withdrawn in the casing 110, and the link 120 and therewith the shaft 123 supporting it is thus rocked in counterclockwise position from that shown in FIG. 5. Such movement will tend to withdraw the latch 125 from the shoulder 126, and such tendency toward withdrawal will permit the spring 87 to rock the lever 85 to maintain bearing of the shoulder 126 against the latch 125. Such movement will produce a decrease in spring tension which must be overcome by otherwise excessive movement of the rod 81 in response to intake manifold pressures, and hence a modification of the responses is provided by which increased relative supply of fuel with respect to intake manifold pressure is provided during the low speed starting operation of the engine.

DISTRIBUTOR

From the variable volume pump driven at engine speed with piston displacement variable in response to intake manifold pressure as modified by ambient atmospheric conditions and/or certain ranges of engine speed, the fuel as a consistent flow is delivered to the distributor M of FIG. 1 through the supply pipe L. The distributor is disclosed in structural detail in FIG. 8. The body of the distributor 130 is formed in a generally octagonal shape, the side walls defining eight fluid discharge octagonal shape, the side walls defining eight fluid discharge faces 131 upon each of which is fitted an individual fluid discharge head 132. Each head 132 is formed with a right angularly directed discharge duct 133 including an axially extending branch 134 to which mounts an individual cylinder supply line 135 corresponding to the lines O of FIG. 1. Each duct 133 also includes a radial branch 136 communicating with individual radial passages 137 of the body 130 which in turn communicate with forwardly inclined individual circularly arranged ports 138 of the body 130. It will of course be understood that this delivery duct arrangement is in conformity with the number of cylinders of the engine. The structure here presented is octagonal in form in order to provide eight individual duct and port arrangements for the 8 cylinder engine disclosed in FIG. 1. Should the system be designed for 6 or 12 cylinder engines the distributor will accordingly be provided with the appropriate number of port arrangements and discharge lines.

The circularly arranged ports 138 are uniformly distributed in the body 130 to provide a uniform circular series of apertures through the front face 140 of the body 130. Mounted for rotation over the face 140 and in contact therewith, driven by a shaft 141, at one-half engine speeds, there is a distributor disc 142 formed with a single arcuate distributor port 143. The arcuate length of port 143 is less than the spacing between any adjacent pair of ports 133, as indicated in FIG. 3A, so as to preclude the registration of the port 143 simultaneously with any adjacent pair of apertures 138. In the present construction, the disc 142 is mounted on the outer surface of the hollow cylindrical end 144 of the shaft 141, the outer end being furcated as at 145 to receive a cross head 147 carried for rotation by the shaft and urged outwardly by a spring 148. The cross head 147 is seated within a transverse groove 149 of the disc 142. Thus, spring 148 provides a uniform yielding tension for urging the disc 142 in sealing contact against the face 140 of the body 130. Conforming recesses indicated at 150 of the contacting surfaces between the body and disc provide for reduction of friction therebetween and insure a sealing seat of the disc 142 on the face 140.

The disc 142 is enclosed within the annular flange walls 151 of a distributor cover 152, the walls 151 defining an internal cylindrical chamber 153 surrounding the disc 142 and extending outwardly therefrom to provide ample space for a quantity of fuel. Fuel from the pump F is supplied to the chamber 153 from the tube 154 corresponding to the tube L of FIG. 1. The tube 154 is secured in the cover 132 as at 155 for communicating with port 156 leading to the chamber 153.

In the operation of the distributor, fuel is delivered from the pump as a continuous stream through the supply tube 154 to the chamber 153 at a volume commensurate with the engine requirements for fuel. The disc 142 is rotated in exact timing with the rotation of the engine so that the port 143 of the disc will successively register with the successive apertures 138 to deliver fuel in successive increment pulses through the ducts and passages 138, 137, 136 and 134 to the individual supply lines 135. Since the arcuate length of the port 145 is less than the distance between any two adjacent apertures 138, there is no possibility of simultaneous delivery of fuel through any two lines 135.

ACCUMULATOR

Since the rate of fuel delivery from the pump varies in response to engine requirements, a fluctuation in supply volume will take place under varying operational conditions. An important feature of the present system is the provision of pressure responsive, variable displacement means in the form of an accumulator here shown as communicating with the chamber 153 by a port 160 to accommodate such fluctuations. The accumulator is formed by the combination of a cylindrical counterbore 161 extending from the port 160 outwardly to the outer face of the cover 152 in combination with an inverted cup-like accumulator piston 162 slidably mounted within the cylinder 161. The piston 162 is spring urged by a coil spring 163 mounted therein and enclosed within a cup-shaped cap 164 sealingly engaged in a second counterbore 165, the piston walls and cap being sealed by a compress O ring 166. The engine driven shaft 141 is enclosed within a suitable housing 167 fitted within a receiving recess on the outer face of the cover 152.

Under rigid conditions in a system where the only resiliency is that of the compressibility of the fuel, volume fluctuations will result in wide pressure variations and peak pressure conditions. In the present construction, by the use of the accumulator, such volume variations may be accommodated by a yielding of the accumulator piston to increase the available volume of the accumulator cylinder to admit momentary volume increases while the spring 163 will maintain a uniform pressure. It will be understood that the total pressure throughout the system is preferably relatively low, the pump being so constructed and arranged as to deliver adequate fuel without excess pressure. In the consideration of the total system it will be noted that the effectiveness of the accumulator is not entirely local with respect to the distributor. The effect of the accumulator extends through the supply line 154 to preclude the buildup of excessive pressures at the variable volume pump and also is extended through the delivery pipes 135 to maintain a uniform and predetermined pressure at the discharge nozzles. As also further discussed with respect to the nozzles, the pressure setting of

the accumulator by the spring 163 is adjusted, maintained and balanced with respect to the resistance of flow at the nozzle so as to provide a balance of pressures, not only precluding peak pressures and their inherent problems and insuring an adequate discharge pressure, but also providing responsive pressure reactions between the accumulator and the nozzle for the discharge of fluid by the nozzle in a highly miscible condition.

Applicant's system is characterized by low operating pressures of less than 100 p.s.i., and this contrasts sharply with the high pressures necessarily resorted to in prior art systems in order to attain timely delivery of fuel from the pump to the nozzles, the pressure in those systems building up to peaks in the order of thousands of pounds per square inch at the pump and elsewhere in the system.

INJECTION NOZZLE

From the individual lines 135 of the accumulator of FIG. 8, corresponding to the lines O of FIG. 1, the individual pulse increments of metered fuel are delivered to the individual injection nozzles, as shown in FIG. 10 and corresponding to the injection nozzles P of FIG. 1. As indicated in FIG. 1, the individual nozzles are mounted in the intake passageway in a position adjacent the intake valve, for example as through the intake manifold structure depicted in FIG. 10 by the numeral 170. Each nozzle is supported in a cylindrical sleeve 171. The upper end of each sleeve 171 is formed with a shoulder 172 that is received through a conforming recess 173 of the intake manifold, an O ring seal 174 being provided. The nozzle includes a generally cylindrical body 175, the upper end of which is formed with a shoulder 176 receivable within the flange 177 of the shoulder 172 of the sleeve 171. The upper end of the body 175 is closed by threaded head 178 having a central port 179 with which the terminal end 180 of the supply tube 135 is secured.

Below the head 178 the body 175 defines an upper central fluid chamber 181 and a central threaded portion 182 communicating with a lower discharge chamber 183. The terminal lower outer wall of the casing 175 is formed as a conical surface 184 tapering inwardly to a cylindrical discharge passage 185 which with the wall 184 defines a sharp annular seating edge 186. The sharp annular edge 186 is adapted to receive the outer peripheral edge of the inwardly and upwardly directed frusto-conical surface 187 of a diffusion head 188, here shown as formed as an integral terminal portion of a shank 189 of the diffusion element. The shank 189 is supported at a terminal eye 190 by the hooked end 191 of a coil spring 192. The upper end of the spring is freely supported for pivotal movement by the hooked end 193 of the spring 192 engaging the lower apex of a transverse supporting bar 194 extending transversely across an annular ring 195 threadably engageable within the threads 182. It will be noted that the outer base of the head 188 is in a plane normal to the axis of the shank to form a sharp circumferential edge 196 similar in sharp angularity to the orifice edge 188. It will also be noted that the circumference of the head 188 is in close conformity with the diameter of the orifice 185 so that when fluid forces the diffusion head from the seat there is a minimum of overhanging edge of the diffusion head with respect to the orifice opening. Therefore, the pressure drop of fluid after emission is substantially instantaneous and the sharp related edges preclude the adherence of droplets of fuel. In view of the free suspension of both the spring from the cross member 194 and the shank from the hook 191, it will be seen that the diffusion head is freely movable against the tension of the spring to be diverted laterally as well as axially from its seat against the annular orifice 166.

It will be noted that the annular ring 195 is threadably adjustable in the threads 182 to vary the tension applied by the spring 192 to the diffusion head. In one successfully operating form of the present invention the tension of the spring 182 is set at approximately 60 pounds so that the incremental and pulsating fuel pressure must be delivered to the nozzle at slight excess over such resistance of the spring. An important feature of the present system is the balancing of the tension of the spring 192 of the injection nozzle of FIG. 10 with the tension in the spring 192 of the accumulator of the distributor of FIG. 8. As has been previously noted the present system is preferably maintained at a total low pressure value for the fuel throughout the entire system. The minimum pressure for operation must of course exceed the resistance of the spring 192 in order to permit the fuel increments to be discharged past the pulsating diffusion head 188. The maximum pressure obtainable throughout the system is limited by the spring 163 of the accumulator which in the event of the tendency of increased pressure will yield to accommodate fluid to preclude any such increase of pressure beyond the resistance of the spring 163. Thus in one operative embodiment of the invention which has been successfully operated for a substantial period of time the tension of the spring 163 of the accumulator has been set to provide a pressure of approximately 90 p.s.i. cooperating with a spring in the nozzle providing a resistance of approximately 60 p.s.i.

In the operation of the nozzle, it will be understood that as pressure builds up within the nozzle body to overcome the tension of the spring 192 and unseat the diffusion head for the discharge of fuel, the pressure drops immediately as the fluid leaves the orifice 186. Such pressure drop tends to relieve the internal pressure tending to unseat the diffusion head, and therefore a vibratory movement of the head may be set up to cause a fluctuation in the discharge pattern. This fluctuation has been noted as annular surface undulations of the hollow conical discharge pattern, which undulations increase in magnitude and decrease in frequency as they move outwardly from the orifice 186. This hunting action between the fuel pressure and the nozzle resistance, by the spring 192, producing vibration of the diffusion head may have its counterpart in the hunting action between the tension of the spring 163 of the accumulator and the tension of the spring 192 of the nozzle. Since the accumulator pressure as applied by the spring 163 passes through the lines 135 to the nozzle where it is resisted by the spring 192, it will be seen that as the diffusion head is moved from the orifice 186 this pressure is relieved and the accumulator may thus respond with vibratory action similar to the vibrations produced by a hunting action between the fuel pressure at the nozzle and the resistance of the spring 192. Such hunting action may be independent of or contribute to the vibratory movement of the nozzle produced solely by spring 192 by which the discharge pattern partakes of the annular fluctuations herein referred to.

MODIFICATION OF PUMP AND DISTRIBUTOR DRIVE

FIG. 11 shows a modified arrangement wherein the pump F and the distributor M are separately driven. Although the distributor is driven in timed synchronism with the engine, it need not be driven synchronously with the pump which requires merely to be driven at a speed commensurate with engine speed; that is, the pump may be driven at a variable speed which is a constant function of engine speed and which is independent of the speed of the distributor. Thus the pump may be driven at a speed which is not a multiple of the speed of the distributor, and may be driven either faster or slower than the speed of the distributor. Instead of being driven from the same pulley G, as in FIG. 1, the distributor M is here shown (FIG. 11) driven from the engine (not shown in this view) by the timing belt 201 running over pulley 202, and the pump F is here shown driven from the engine by the V-belt 203, which need not be a timing belt, running over pulley 204.

OPERATION

In the operation of the present system here exemplified as applied to an automotive type engine, the fuel, presumably liquid hydro-carbon, is supplied from a suitable tank, as fragmentarily illustrated by the tank A of FIG. 1, usually located at the rear of the automobile chassis and frequently at a level below the elevation of the engine fuel feed mechanism. Such location requires a primary fuel pump for elevating the fuel from the tank to the engine fuel supply mechanism. Pumps for this purpose are frequently operated by and with the engine through crankshafts, cam shafts, or the like. However, in some instances, independently operated electromechanical pumps are deemed preferable and in the disclosure of FIG. 1 this type of pump has been selected to supply the adequate volume of fuel from the tank A to the variable volume pump F in an effective and efficient manner compatible with structural and operational economy. The electromechanical pump is here indicated by the numeral C energized through the cable D, the fuel supply being from tank A to electromechanical pump C through supply line B and from electromechanical pump C to the variable volume metering pump F through supply line E.

The fuel supplied to the pump F is delivered equally to the individual pump cylinders through the tube 42 and the interconnecting ducts 40 of the body 10 of the pump. As hereinbefore noted, each piston of the pump moves in a reciprocating fashion, each with a phase operation lagging behind that of the piston next adjacent on one side and in advance of the next adjacent piston on the opposite side. In the present form of the pump, the direction of rotation is immaterial, being whatever may be convenient for the direction of rotation for the shaft 64 from which the pump receives its motion in direct speed responsive synchronism with the speed of rotation of the engine. The reciprocation of each individual piston delivers fuel upwardly past its check valve 24 and outwardly past its check valve 25 to an interrelated series of discharge ducts, arranged in the manner of those shown at 40 in FIG. 4, to the outlet L.

The pump herein shown is designed for operation from a fuel supply ranging from a supply below the pump level and under atmospheric pressure where the pump may act to draw the liquid into its cylinder to a supply at a pressure not exceeding the maximum pressure desired for the system. Where the fuel supply is at maximum pressure for the system, the operation of the pump may be purely in the nature of a metering mechanism without providing pressure for the system. In such case, the pump serves only to control the delivery of fuel at a flow rate determined by the engine requirement for fuel. Where the supply pressure is below the pressure required for the system, the pump may supply each required pressure as well as meter the volume in accordance with engine requirements.

As hereinbefore discussed, the amplitude of reciprocatory motion of the individual pistons 11, and hence the output value or rate of flow, is controlled by the radius of orbital movement of the pump driving head 50. Such radius is controlled by the eccentricity of the mounting stud 55 which in turn responds to the vertical setting of the pump control shaft 70. The frequency of piston reciprocation is in exact response to engine speed by rotation of the head carrying plate 57 by the engine driven shaft 64. The setting of the shaft 70 is primarily controlled by the intake manifold pressure of the engine modified by the action of the cylinder 80 in which the effectiveness of such intake manifold pressures may be modified by ambient atmospheric conditions and/or related to a relatively fixed pressure by the evacuation of the internal cylinder or the confinement therein of a relatively non-responsive inert fluid. As has been noted, the responsiveness of the control rod 70 is further modified by a speed responsive means so that under a given range of intake manifold pressure the volumetric response of the pump may be altered, as in starting and at low speeds. Thus the volume of fuel delivered by the variable volume pump F is a product of both engine speed and intake manifold pressure as it may be modified under varying ambient atmospheric conditions and with differential speed response. As in the conventional operation of engines of the present type, operator control may be provided, as by a foot controlled butterfiy valve, for the operator control of intake manifold pressure as a means of accelerating and decelerating the engine and operator compensation for varying loads. Since the term "engine demands for fuel" contemplates demands under the control of the operator, through his manipulated effects on intake manifold pressure, as well as the automatic response of the engine under varying speeds and loads, it is to be recognized that the above term is generic in nature and does not exclude such variations in demands as may be imposed by the operator. Thus the pump F will be seen to provide an instrumentality for the delivery of fuel at varying appropriate volumes in accordance with a multiplicity of factors including engine speed, operator manipulated intake manifold pressure, automatically responsive intake manifold pressure, ambient atmospheric conditions and speed range variations. Variable settings for adjustment of such volume as may be dictated by varying types of fuel, differing combustion supporting media, supercharging and spark ignition timing, or the like, are of course contemplated.

From the variable volume pump F, the fuel flows as a generally uniform continuous stream varying in volume as the engine demands vary. It will be noted that the multiplicity of pistons and the sequential phase relation of the operation is such as to minimize pump discharge pulsations; however, the present election of the number of pistons unequal to the number of cylinders of the engine is not without intent. Careful analysis and theoretical considerations will of course indicate some pulsation of the discharge flow from the variable volume pump reflecting the number of pump pistons. Such pulsation may be taken advantage of by the synchronization of the pump rotation with that of the operating cycles of the individual cylinders of the engine. It is thus within the scope of the invention to provide a pump in which the number of pistons is equal to the number of cylinders of the engine or multiples or divisions thereof. In such case the pulsations may conform with the successive individual demands for fuel by the individual cylinders to minimize a tendency toward peak pressures.

The construction, operation and functional characteristics of the distributor itself require little amplification. The distribution chamber 153 receives the metered continuous fuel from pump F through line L (154 FIG. 3). The distributor disc 192 is provided with but one discharge orifice. Since the disc is rotated at a speed exactly coordinated with that of the engine speed, the disc orifice registers successively with the individual discharge ports 133 leading the individual injection nozzles supply lines 135. It will thus be seen that these nozzles are individually supplied with individual increments of the total fuel supply, the volume of each increment being determined by the volumetric output of the variable volume pump F. Since the fuel is under pressure, the registration of the disc aperture with the successive individual apertures will provide for the successive pulse flows of the fuel increments through the successive supply lines. An important feature of the distributor is the arcuate configuration of the disc aperture and the limitation of the arcuate extent thereof to a degree substantially equal but not exceeding the spacing between adjacent edges of adjacent individual discharge ports. Thus as the disc rotates it is impossible for simultaneous registration with more than one discharge port. Hence there is no liability of inaccurate incremental discharge due to the robbing of flow to one individual discharge port from another, thus the flow through each discharge port will be an accurately determined and complete increment. It will

of course be understood that while the distributor of the present invention divides the fuel supplied thereto into synchronized individual metered increments, the distributor itself is not a metering device in the sense that it can determine the volume of the individual increments. Conversely, while the variable volume pump F does determine the volume of fuel delivered therethrough for the individual cylinders, it does not determine the number of increments into which its discharge is to be divided nor the rapidity with which these increments are distributed as individual pulses to the individual injection nozzles. However, the variable volume pump in combination with the distributor may be considered as cooperation and combining instrumentalities for the discharge of metered fuel increments and in this sense the distributor is an element of the metering instrumentality of the present system.

A vital element of the preferred form of the system is the accumulator of FIG. 1. As shown in FIGS. 8 and 9, the accumulator is associated with the intake chamber of the distributor M of FIG. 1, shown at **153** in FIG. 8. As there shown, the accumulator is built into the distributor as a combining and cooperating instrumentality. No such specific location of the accumulator is mandatory however. As hereinbefore discussed, the peak pressure inhibiting influence of the distributor has its effect from the discharge of the variable volume pump F and into the cylinders thereof as well as forwardly with the flow of fluid from the distributor and through to the injection nozzle where it may have an effect contributing to a vibratory action of the dispersion head where such is desirable. The inventive concept therefore contemplates the accumulator at any desired point in the entire system from as far as in advance of the pump to the use of individual accumulators at any point in advance of the dispersion head of the individual nozzles. Reiteration of the discussion of the construction, design, operation and function of the accumulator is not believed further required. Suffice it therefore to summarize the function of the distributor as being that of accepting fluctuating increases of fluid volume delivered by the pump and tending toward the buildup of peak pressures during interims when the full free passage of fluid is inhibited by the cooperative action of the distributor disc with its individual outlet ports for the individual injection nozzles. The function of the accumulator is also to provide a reserve of energy potentially available for the rapid, accurate and adequately pressurized pulse flow of the individual fuel increments from the distributor to the injection nozzles. The accumulator also provides for a balancing of pressures with respect to the flow resistance by the spring of the diffusion head of the individual nozzles. This relation of pressures is such as to maintain an adequate balance throughout the system without the necessity for exceedingly high pressures, characteristic of prior art systems, to insure adequate delivery of the accurately determined increments. The accumulator may also be instrumental in determining some of the diffusion characteristics of the flow pattern of the nozzle by being so related in pressure responsiveness to the pressure responsiveness of the diffusion head as to induce a reciprocal hunting action therebetween which may be such as to influence a vibratory type of discharge to increase the miscible characteristic of such discharge.

From the distributor M, the individual fuel increments are discharged as individual pulses to the individual lines O, indicated by the numeral **135** in FIG. 8, to the individual injection nozzles T, one of which is disclosed in detail in FIG. 10. Such increments are supplied under pressure to the chamber **181** of each nozzle and pass therefrom over the spring **192** to engage the diffusion head **187** and urge it outwardly against the tension of the spring **192**. Such unseating of the head **187** from its sharp annular seat **186** permits the increment to be sprayed outwardly with a substantially instantaneously pressure drop and resultant diffusion. Since the spring **192** is suspended for free pivotal movement from the bar **194**, and since the shank **187** of the diffusion head is freely suspended from the hook **191** of the spring, it will be seen that the diffusion head is freely suspended for lateral movement and vibration as the fuel increment is discharged over the diffusion head. As has been stated, since the lip of the diffusion head is of a diameter in close conformity with the diameter of the orifice, there is a minimum drag of the fuel particles over any extended lip and hence frictional retardation of the rapid dissemination of the total fuel increment in the combustion supporting gases is insured. The sharp angular edges of the orifice **186** and the diffusion head at **196** act to inhibit the clinging of fuel particles which might otherwise retard the full and effective release of the metered charge.

Since the opening of the diffusion head under pressure of the fuel increment is against the tension of the spring **192**, and since the pressure is instantaneously reduced as the fluid leaves the nozzle orifice, there may be a tendency for the diffusion head to vibrate as a result of the hunting actions between the fuel pressures and the resisting spring tension. In the absence of any such vibration the fuel is emitted as a pressurized conical hollow body diverging from the orifice as guided by the frustoconical surface **186** of the diffusion head with a rapidly increasing wall thickness and diminishing density providing a rapid dispersion, diffusion and/or atomization of the fuel particles. In the operation of this nozzle as studied through high speed microphotography, vibration of the diffusion head has been indicated by the presence of undulations in the peripheral wall of the conical discharge. Such undulations are observable as annular rings moving outwardly with the discharge of the fluid in continuously increasing amplitude and with a corresponding decrease in frequency. Such vibration of the discharge pattern and such undulations are believed to be advantageous in producing a more miscible characteristic of the discharged fuel increments. Since the accumulator is also pressure responsive and since its pressure is effective in the delivery of individual increments through their supply lines, there may also be a reaction of the pressure characteristics of the accumulator with respect to the spring resisted motion of the atomizing head. There may thus be set up an independent or secondary hunting action between the urge of the spring of the accumulator against the incremental fuel pulse and the resistance of the pressure generated through the accumulator by the spring **192**. As has been noted, the system contemplates a close relationship between the tension applied by the spring **192** against the diffusion head and the tension of the spring **163** of the accumulator. As these spring tensions approach each other in magnitude it will be seen that the tendency toward a hunting action therebetween will be increased. In the present invention, it is contemplated that such tensions will be of such relationship as to induce such hunting action to contribute to the vibrational characteristics of the spray pattern emitted from the nozzle.

In summation, it may therefore be seen that the present invention provides a system including means for supplying adequate source of liquid fuel at an appropriate pressure to a metering and dispensing pump of volumetrically variable characteristic, the volume of which is responsive to varying conditions while the pump is operated by and with the rotation of the engine so that the metered discharge from such pump is faithfully responsive to the requirements for fuel by the engine. The metered constant supply of fuel from the pump is accurately divided into increments in response to the speed of rotation of the engine and thus in response to the individual demands of the individual cylinders. Variable volume pressure responsive means in the form of an accumulator is provided in order to preclude the buildup of excess pressures and the consequent operational failures which might ensue therefrom. The accumulator also provides for a con-

stant and uniform discharge pressure for the individual increments which are discharged to individual injection nozzles from which the increment is sprayed outwardly with a substantially instantaneous pressure drop and without frictional drag or the adhesion of fuel particles to the injection nozzle structure. The spray pattern is one calculated to be highly efficient in the dispersion of the fuel particles in a combustion supporting medium so as to promote rapid and complete combustion thereof. While the present system is here disclosed in detail as to the structural elements involved and as to the method steps carried out, it will of course be understood that the disclosure of the invention is by way of illustration and that in the practice of the invention the various elements thereof may be altered both as to individual construction and operation and as to their interrelation and combination within the spirit and scope of the invention. It is also understood that numerous changes, modifications and the full use of equivalents may be resorted to without departure from the spirit or scope of the claims appended hereto.

I claim:

1. A fluid injection system including a fluid fuel supply, at least one fuel injection nozzle, a fluid delivery line from said supply to said nozzle, metering means in said line for controlling the rate of fluid flow from said supply to said nozzle, and variable-volume pressure-responsive means in communication with said line and biased to maintain constant pressure above a predetermined minimum for maintaining stable pressure conditions throughout said system.

2. A fuel injection system for multicylinder spark ignition type internal combustion engines, including a fuel supply, a plurality of fuel injection nozzles, a fluid delivery line from said supply to said nozzles, fuel metering means in said line between said supply and said nozzles, a distributor in said line between said metering means and said nozzles, and variable-volume pressure-responsive pressure energy and fuel storage means in communication with said line upstream from said distributor and biased to maintain constant pressure above a predetermined minimum and said line between said metering means and said nozzles for precluding the build-up of excessive pressures in said line and for storing energy for the discharge of fluid to said nozzles.

3. A fuel supply system for internal combustion engines including a fuel tank, a supply pump for delivering fuel from said tank to a metering pump, a metering pump receiving fuel from said supply pump, a distributor connected with said metering pump to receive fuel therefrom, and to deliver such fuel in successive timed individual increments, a plurality of fuel injection nozzles, means to deliver fuel from said distributor to said nozzles, and means effective between said metering pump and said distributor in said system for storing fuel at a pressure above a predetermined minimum between successive deliveries by said distributor.

4. A fuel supply system for internal combustion engines including a fuel supply means for delivering fuel to a metering pump, a metering pump receiving fuel from said supply means, a distributor connected with said metering pump to receive fuel therefrom and to deliver such fuel in successive timed individual increments, a plurality of fuel injection nozzles, means to deliver fuel from said distributor to said nozzles, and means in said system for storing fuel between the delivery of the successive increments by said distributor, said distributor including a variable-volume pressure-responsive accumulator having constant volume below a predetermined minimum and for maintaining constant pressure above a predetermined minimum and communicating with the metering pump for storing fuel and absorbing pressure energy between the delivery of successive increments by said distributor.

5. In a system for supplying fuel to a multicylinder high-speed spark-ignition type internal combustion engine, a fuel pump, means for operating said pump to pump fuel fuel at a volume responsive to engine demands for fuel as represented by engine speed and intake manifold pressure, and means including a pressure responsive variable displacement device biased to maintain constant pressure above a predetermined minimum for delivering fuel from said pump to said engine.

6. In a system for supplying fuel to a multicylinder high-speed spark-ignition type, internal combustion engine, a fuel pump, means for operating said pump to pump fuel at a volume responsive to engine demands for fuel as represented by intake manifold pressure modified by engine speed and ambient atmospheric conditions, and means including a pressure responsive variable displacement device biased to maintain constant pressure above a predetermined minimum for delivering fuel from said pump to said engine.

7. A method of supplying fuel for internal combustion engines which includes the steps of providing fuel in quantity sufficient to meet the varying demands for fuel by the engine, metering the fuel in response to such varying demands, releasing the metered fuel at intervals, storing the metered fuel between releases, and delivering all of the stored fuel to the engine for each release.

8. A method of supplying fuel for internal combustion engines which includes the steps of providing fuel in quantity sufficient to meet the varying demands for fuel by the engine, metering the fuel in response to such varying demands, releasing the metered fuel at intervals, storing the metered fuel between releases, delivering all of the stored fuel to the engine for each release, and maintaining a generally uniform fuel pressure throughout the metering and delivery steps.

9. A method of distributing fuel to a plurality of nozzles which comprises successively pumping fuel from a plurality of chambers into a common chamber, selectively venting said common chamber to each nozzle, and maintaining successive vent releases to any nozzle out of phase with successive fuel releases from any one of said plurality of chambers.

10. A liquid injection system which comprises a nozzle, supply means for delivering liquid under pressure to said nozzle, means for controlling flow from said supply means to said nozzle, and means adapted to accumulate liquid between the supply means and the means for controlling flow and being inoperative to receive liquid at pressures below a predetermined pressure which is substantially above the pressure at which said nozzle discharges but effective to absorb liquid from said supply means without substantially increasing the pressure of said liquid above said predetermined pressure.

11. A liquid injection system which comprises a nozzle, supply means for delivering fuel under pressure to said nozzle, control means for regulating flow from said supply means to said nozzle, and an accumulator between said supply means and said control means and adjacent to said control means and being inoperative to receive fuel at pressures below a predetermined pressure which is substantially above the pressure at which said nozzle discharges but which is effective to absorb fuel from said supply means without substantially increasing the pressure of said fuel above said predetermined pressure.

12. A fuel injection system comprising a closed system including a plurality of fuel injectors for supplying fuel to individual cylinders of an engine and providing an outlet for said system, a plural cylinder variable displacement pump connected to discharge to a common chamber and providing an inlet supply for said system, distributor means for sequentially venting said chamber to said injectors for controlling the flow of fuel to the engine, means for driving said distributor means in timed synchronism with the engine, and means for driving said pump at a variable speed which is a constant function of engine speed and which is independent of the speed of said distributor.

13. A fuel injection system comprising a closed system including a plurality of fuel injectors for supplying fuel to individual cylinders of an engine and providing an outlet for said system, a plural cylinder variable displacement pump connected to discharge to a common chamber and providing an inlet supply for said system, distributor means for sequentially venting said chamber to said injectors for controlling the flow of fuel to the engine, means for driving said distributor means in timed synchronism with the engine, and means for driving said pump at a speed not a multiple of the speed of the distributor.

14. A fuel injection system comprising a closed system including a plurality of fuel injectors for supplying fuel to individual cylinders of an engine and providing an outlet for said system, a plural cylinder variable displacement reciprocating piston pump connected to discharge to a common chamber and providing an inlet supply for said system and having an odd number of cylinders, distributor means for sequentially venting said chamber to said injectors for controlling the flow of fuel to the engine, means for driving said distributor means in timed synchronism with the engine, and means for driving said pump at a variable speed which is a constant function of engine speed and which is independent of the speed of said distributor.

15. A fuel injection system comprising a closed system including a plurality of fuel injectors for supplying fuel to individual cylinders of an engine and providing an outlet for said system, a plural cylinder variable displacement reciprocating piston pump connected to discharge to a common chamber and providing an inlet supply for said system and having an odd number of cylinders, distributor means for sequentially venting said chamber to said injectors for controlling the flow of fuel to the engine, means for driving said distributor means in timed synchronism with the ingine, and means for driving said pump at a speed not a multiple of the speed of the distributor and slower than said distributor.

16. A fuel injection system comprising a closed system including a plurality of fuel injectors for supplying fuel to individual cylinders of an engine and providing an outlet for said system, a plural cylinder variable displacement pump connected to discharge to a common chamber and providing an inlet supply for said system, distributor means for sequentially venting said chamber to said injectors for controlling the flow of fuel to the engine, means for driving said distributor means in timed synchronism with the engine, and means for driving said pump at a speed not a multiple of the speed of the distributor and slower than said distributor.

17. A fuel injection system comprising a closed system including a plurality of fuel injectors for supplying fuel to individual cylinders of an engine and providing an outlet for said system, a plural cylinder variable displacement pump connected to discharge to a common chamber and providing an inlet supply for said system, distributor means for sequentially venting said chamber to said injectors for controlling the flow of fuel to the engine, means for driving said distributor means in timed synchronism with the engine, and means for driving said pump at a speed not a multiple of the speed of the distributor and faster than said distributor.

18. A fuel injection system comprising a closed system including a plurality of fuel injectors for supplying fuel to individual cylinders of an engine and providing an outlet for said system, a plural cylinder variable displacement reciprocating piston pump connected to discharge to a common chamber and providing an inlet supply for said system and having an odd number of cylinders, distributor means for sequentially venting said chamber to said injectors for controlling the flow of fuel to the engine, means for driving said distributor means in timed synchronism with the engine, and means for driving said pump at a speed not a multiple of the speed of the distributor and faster than said distributor.

19. A liquid injection system having supply means for feeding liquid under pressure, injector means for receiving said liquid, liquid flow control means between said supply means and said injector means for selectively releasing liquid to the injector, and an accumulator between the flow control means and the supply means preloaded to receive liquid only at pressures substantially above the injector discharge pressure and effective to discharge all of the liquid received therein between flow releases to the injector before the flow control means stops said flow releases.

20. A liquid injection system having a metering pump for supplying liquid under pressure, an injector for receiving said liquid, a distributor for intermittently releasing liquid received from the pump to the injector, and an accumulator between the pump and the distributor preloaded to temporarily absorb liquid only at pressures substantially above the injector discharge pressure and operable to discharge said liquid thus absorbed prior to closing of the distributor.

21. A fuel injection system which comprises a nozzle having a predetermined release pressure, supply means for delivering metered quantities of liquid under pressure to said nozzle, distributor means for selectively venting said supply means to said nozzle, an expansible pressure accumulator chamber between said supply means and distributor opening to receive fluid at pressures above said release pressure from said supply means and to discharge all of its fluid to the nozzle at pressures above said release pressure while said distributor vents said supply means to the nozzle.

22. A mechanism for distributing fuel to a plurality of fuel injection nozzles comprising a fuel pump having a plurality of chambers, a common chamber receiving fuel from each of said pump chambers and means for selectively venting said common chamber to each nozzle, said fuel pump and venting means maintaining successive vent releases to any nozzle out of phase with successive fuel releases from any one of said plurality of chambers.

23. A mechanism for distributing fuel to a plurality of fuel injection nozzles comprising a fuel pump having a plurality of chambers with reciprocating plungers, a common chamber receiving fuel from each of said pump chambers, and a rotary distributor having a number of releases for each rotation for selectively venting said common chamber to each nozzles, said distributor and fuel pump maintaining successive releases to any nozzle out of phase with successive fuel releases from any one of said plurality of chambers.

24. A mechanism for distributing fuel to a plurality of fuel injection nozzles in accordance with claim 23 wherein the number of pump chambers is different than the number of distributor releases and not a multiple thereof.

25. A fuel supply system for a fuel injection engine comprising a distributor for releasing fuel to individual injectors at periodic uniform intervals, means for driving the distributor at a speed to release fuel for each fuel intake stroke of an engine, a reciprocating variable delivery fuel pump having a pulsating output connected to deliver fuel to the distributor, and means for driving said pump at a speed so that the phase of the pulsations of the pump changes with respect to the phase of releases of the distributor so that the releases occur at different times with respect to the pulsations so that a rich or starved delivery of fuel will not continually occur at the same injector and the same engine cylinder.

26. A fuel supply system for a fuel injection engine comprising a distributor for releasing fuel to individual injectors at periodic uniform intervals, means for driving the distributor at a speed to release fuel for each fuel intake stroke of an engine, a reciprocating variable delivery fuel pump having a pulsating output connected to

delivery fuel to the distributor, and means driving said fuel pump at an engine speed which cannot be expressed exactly in whole numbers so that the phase of the pulsations of the pump change with respect to the phase of releases of the distributor so that the releases occur at different times with respect to the pulsations and so that a rich or starved delivery of fuel will not continually occur at the same injector and at the same engine cylinder.

27. A fuel delivery system for an engine fuel injection arrangement comprising a variable volume positive displacement fuel metering pump, a distributor connected to receive fuel from the pump and intermittently at periodic

intervals releasing fuel to engine fuel injectors, an accumulator chamber connected between the pump and distributor for accumulating fuel between distributor releases, and means resiliently ejecting fuel from the accumulator chamber with said ejecting means having a natural frequency in excess of the distributor exciting frequency.

References Cited in the file of this patent

UNITED STATES PATENTS

1,617,567	Blanchard	Feb. 15, 1927
2,720,344	Isreeli et al.	Oct. 11, 1955
2,967,520	Morris et al.	Jan. 10, 1961