

May 23, 1961

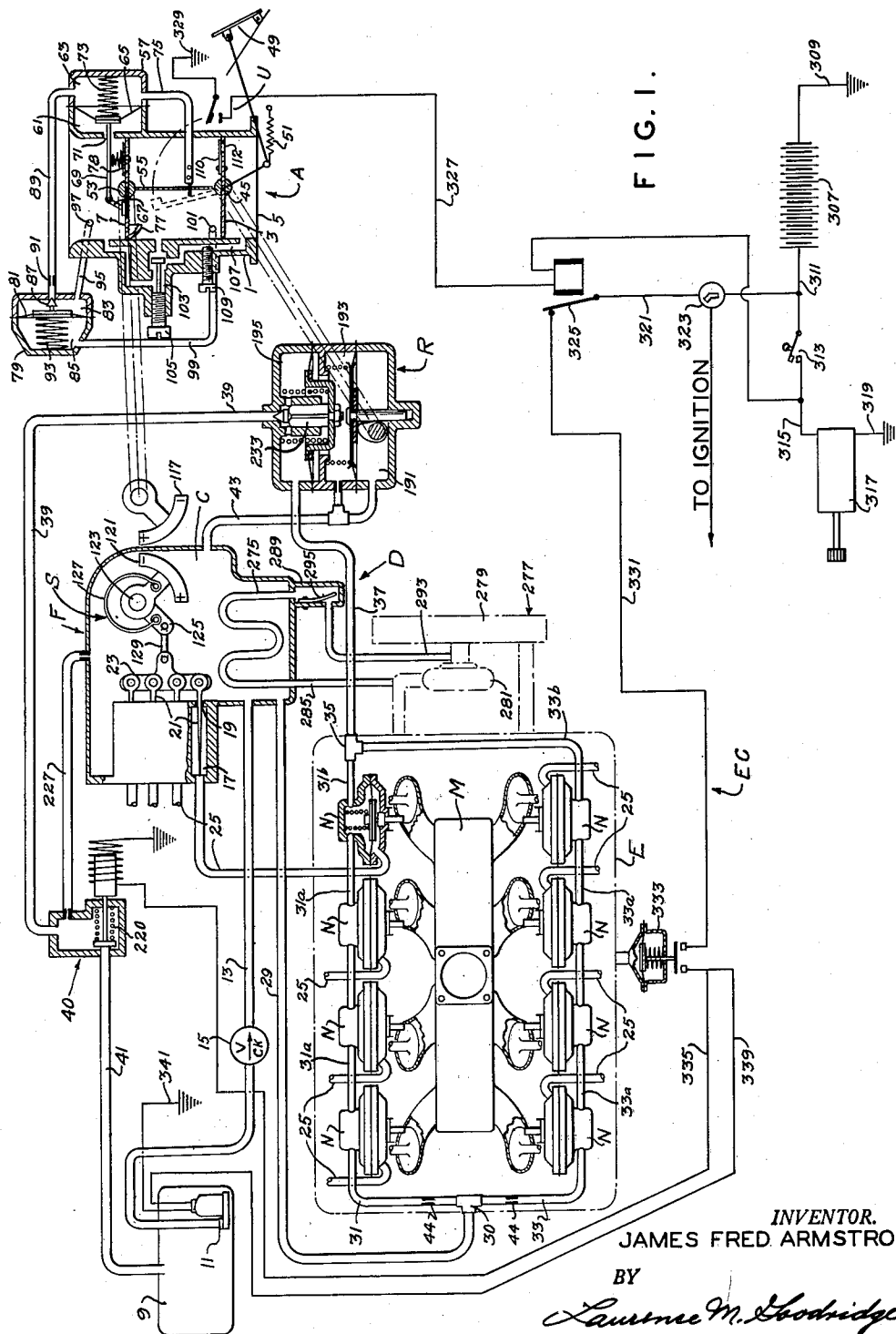
J. F. ARMSTRONG

2,985,160

FUEL INJECTION SYSTEM

Filed March 2, 1959

4 Sheets-Sheet 1



J. F. ARMSTRONG

FUEL INJECTION SYSTEM

4 Sheets-Sheet 2



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4 Sheets-Sheet 3

FIG. 5.

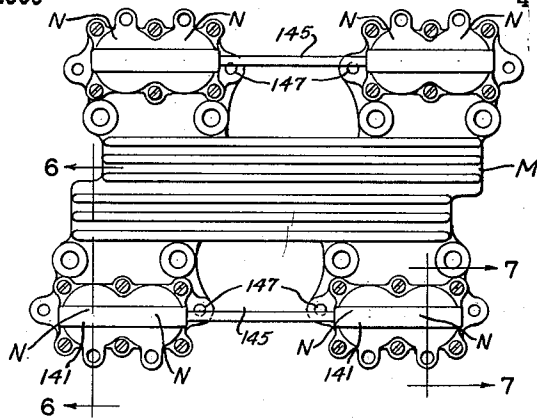
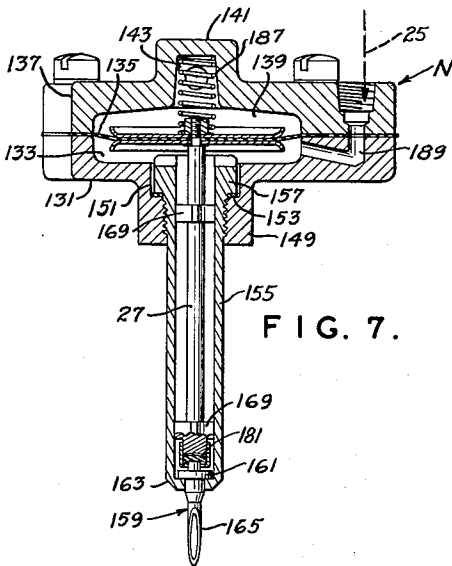


FIG. 7.

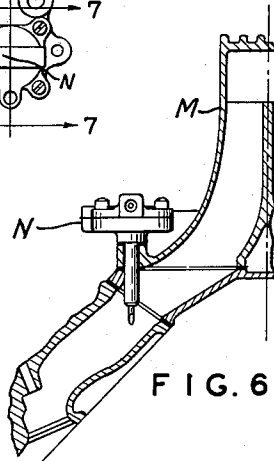


FIG. 6.

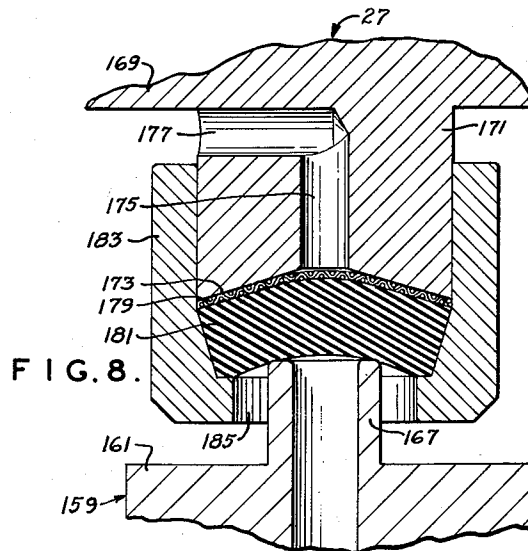


FIG. 8.

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2,985,160

FUEL INJECTION SYSTEM

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22 Claims. (Cl. 123—119)

This invention relates to fuel injection systems for internal combustion engines, and more particularly to continuous flow systems of this class adapted for port injection, in which the fuel is pressurized, measured under pressure in accordance with engine requirements, and distributed under pressure to points adjacent the intake valves of the several cylinders or combustion chambers of the engine.

The invention is particularly concerned with a continuous-flow fuel injection system of a type having a fuel metering means for metering fuel to the engine in accordance with engine requirements as reflected by the rate of flow of air to the engine. This fuel metering means receives fuel from a source of fuel under pressure and delivers it to the engine at a rate proportional to the rate of flow of air to the engine. The metering means is of the variable-area orifice type, and the rate of flow therethrough is a function of orifice area and pressure differential upstream and downstream thereof. Provision is made for maintaining this pressure differential substantially constant, so that the rate of flow of fuel is substantially completely a function of orifice area. This is accomplished by providing pressure responsive nozzles fed by the metering means, and a datum pressure system for supplying control of datum pressure for controlling the nozzles. The datum pressure system receives fuel from the source and has a pressure regulator therein adapted to maintain a substantially constant differential between the source pressure and the datum pressure despite variations in the source pressure. In the operation of the fuel injection system, there is a continuous low rate flow of fuel from the source through the datum pressure system (including the datum pressure regulator).

In a fuel injection system of the class described, there is a problem of providing for relief of excessive gas (in the sense of air) pressure such as may occur in the datum system as, for example, because of heating of fuel in the datum system. Unless such excessive pressure is relieved, the flow of fuel to the engine may be thrown out of proper proportion to the air, or cut off completely.

Accordingly, it is an object of this invention to provide a fuel injection system of the class described in which provision is made for immediately relieving excessive pressure in the datum pressure system in a simplified manner to avoid uncontrolled pressure in the datum pressure system.

In general, this object is attained by providing the datum pressure regulator downstream from the nozzles, the regulator having a single datum fuel outlet and the datum system being adapted for free return flow of fuel from said outlet when the engine is in operation, and the regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through the datum outlet. With this arrangement, the regulator valve responds to excessive pressure in the datum system to relieve the system of

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the excess of pressure, without any necessity for an additional pressure relief valve or the like.

Another object of this invention is the provision of improved and simplified means for accomplishing enrichment of air-fuel mixture on acceleration, this means involving control of the datum pressure regulator to vary the datum pressure on acceleration in such manner as to open the nozzles wider for momentarily increased fuel delivery.

Another object of the invention is the provision of an improved nozzle construction, adapted for tightly sealing against leakage of fuel when closed, having a long life, and adapted to prevent the formation of droplets at a low rate of fuel flow (as when the engine is idling), and which is economical to manufacture.

Other objects and features will be in part apparent and in part pointed out hereinafter.

The invention accordingly comprises the construction hereinafter described, the scope of the invention being indicated in the following claims.

In the accompanying drawings, in which one of various possible embodiments of the invention is illustrated,

Fig. 1 is a schematic showing of a fuel injection system of this invention, illustrating various parts of the system in the positions assumed when the engine is off;

Fig. 2 is a plan view, with parts broken away and shown in section, of an assembly of an air metering unit, a fuel metering chamber, and a datum pressure regulator of the system;

Fig. 3 is a view in elevation of one side of the Fig. 2 assembly;

Fig. 4 is a view in elevation of the opposite side of the Fig. 2 assembly;

Fig. 5 is a plan view of the engine intake manifold;

Fig. 6 is a vertical section taken on line 6—6 of Fig. 5;

Fig. 7 is a vertical section of a nozzle of the system taken on line 7—7 of Fig. 5;

Fig. 8 is a greatly enlarged fragment of Fig. 7;

Fig. 9 is a section of a datum pressure regulator of the system taken on line 9—9 of Fig. 2;

Fig. 10 is a section taken on line 10—10 of Fig. 9; and

Fig. 11 is a section taken on line 11—11 of Fig. 9.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

General description

Referring to Fig. 1 of the drawings, a fuel injection system of this invention is shown to comprise an air metering unit A for metering air to an engine E, and a fuel charging or delivery system F for delivering fuel to the engine at a metered rate with the proportion of air to fuel (the air-fuel ratio) appropriate to the operating requirements of the engine whatever they may be. The air metering unit A comprises a cylindrical conduit 1 with a throttle valve 3 therein adjacent its exit end 5. When the throttle valve is open and the engine is in operation, air flows through the conduit 1 at a rate dependent upon the degree of opening of the throttle valve and the speed of the engine (which is a reflection of the load on the engine). In the conduit 1 upstream from the throttle valve is an air valve 7 adapted to open when the engine is in operation to a degree related to the rate of air flow. The air valve thus serves as an instrumentality for measuring the rate of air flow through conduit 1 to the intake manifold M of the engine, conduit 1 being connected to the manifold in any suitable manner.

The fuel delivery system F delivers fuel to the engine from a fuel metering chamber C which is supplied with fuel under pressure from the fuel tank 9 of the vehicle. An electric pump 11 is provided in the tank for continu-

ously pumping fuel through a fuel line 13 to the chamber C when the engine is in operation. In line 13 is a check valve 15 for preventing flow of fuel back toward the pump. Chamber C has a plurality of outlet passages such as indicated at 17. As herein described, engine E is a V-8 engine, and eight outlet passages 17, one for each cylinder of the engine, are provided, but it will be understood that alternative arrangements in which one passage and nozzle N serves more than one cylinder may be used, as in the case of a Siamese inlet port. Fuel is adapted to flow from chamber C into each of passages 17 through an orifice 19 under control of a contoured (tapered) metering rod 21 (one for each passage 17). The metering rods 21 (eight in this instance) are all carried by a crosshead 23 for simultaneous equal movement inward and outward with respect to the orifices. Crosshead 23 is controlled by the air valve 7. The rate of flow of fuel through each orifice is a function of the position of the metering rod therefor (which establishes the effective area of the orifice) and the pressure drop across the orifice, i.e., the difference between the pressure of fuel in chamber C and the pressure downstream from the orifice. Hence, the rate of flow of fuel is a function of the rate of air flow through the air metering unit A and the pressure drop across the orifices.

Associated with each cylinder of engine E is a nozzle N adapted to inject fuel close to and in the direction of the intake valve for the cylinder. Fuel delivery lines such as indicated at 25 connect outlet passages 17 of chamber C to the respective nozzles N. There are eight nozzles N and eight fuel lines 25. Each nozzle N comprises a needle 27 (see Fig. 7) responsive to the pressure differential between fuel supplied thereto through the line 25 and the pressure in a datum pressure system D. The pressure in lines 25, and hence the pressure drop across orifices 19, is dependent upon the position of the needles 27. The datum pressure system D utilizes fuel from the chamber C as a datum pressure medium. As illustrated in Fig. 1, the datum pressure system D comprises a line 29 leading from chamber C to a T 30, from which branch lines 31 and 33 pass around both sides of the manifold M, these branch lines being connected to the datum pressure chambers of the two nozzles at one end of the engine. The datum pressure chambers of the nozzles on one side of the manifold are interconnected by lines such as indicated at 31a, and the datum pressure chambers of the nozzles at the other side of the manifold are interconnected by lines such as indicated at 33a. Lines 31b and 33b lead from the datum pressure chambers of the two nozzles at the other end of the engine to a T 35. Line 37 leads from T 35 to a datum pressure regulator R. From this pressure regulator R there is a passage 39 to the inlet of a solenoid valve 40 and a return line 41 from the outlet of the solenoid valve to the fuel tank 9. The solenoid valve, when de-energized, cuts off the return. Lines 29, 31, 33, 31a, 31b, 33a, 33b, 37, passage 39, and return 41, constitute a datum flow path from chamber C to the fuel source 9.

Regulator R is interconnected with chamber C as indicated at 43. As will be made clear, regulator R functions to maintain a substantially constant pressure drop across orifices 19, despite variations in fuel pressure in chamber C, so that the rate of flow of fuel through nozzles N is dependent substantially entirely upon the position of the metering rods 21, hence dependent upon the rate of air flow through air metering unit A. Regulator R also acts in response to opening of the throttle, as will be made clear, to reduce the datum pressure to deliver additional fuel through nozzles N for acceleration and, conversely, acts in response to release of the throttle to raise the datum pressure and reduce or cut off the flow of fuel through nozzles N to obtain satisfactory engine operation when decelerating with a closed throttle. In normal operation, fuel flows continuously at a low rate in the datum pressure system from chamber C through the

datum pressure chambers of nozzles N to the regulator R, and from the regulator R back to the fuel tank 9. This tends to keep the system purged of air and accumulated vapors. The low rate of flow is established by restrictions 44 in branch lines 31 and 33 upstream from nozzles N. It is emphasized that restrictions 44 are upstream and the regulator R is downstream from the nozzles. This is an important feature of the invention.

Incorporated in the fuel injection system of this invention is a starting mixture enrichment system generally indicated at S. As will be made clear, this system acts to vary the phase of the metering rods 21 relative to the air measuring valve 7 in such manner as to provide for mixture enrichment when the engine is cold, bringing the metering rods to a normal phase position relative to valve 7 as the engine warms up. A fast idle control such as indicated at FI (Fig. 4) is provided. The electrical components of the system are connected in an electrical circuit generally indicated at EC, this circuit including a throttle operated unloading switch U for clearing the engine of excess fuel when necessary.

The air metering unit

The throttle valve 3 is fixed on a throttle shaft 45 extending across the conduit 1 adjacent its exit end 5 (its lower end as viewed in Figs. 1, 3 and 4). At this end of the conduit 1 is a flange 47 whereby it may be attached to the intake manifold of the engine. As appears in Fig. 1, the throttle valve is manually operated by the usual accelerator pedal 49 of the vehicle, being biased toward closed position by a return spring 51. The air valve 7 is balanced butterfly valve, fixed on a shaft 53 (Figs. 1 and 2) extending across the conduit 1 parallel to and upstream from the throttle valve shaft 45. The space in conduit 1 between the shafts 45 and 53 is divided by a slotted partition 55 extending lengthwise of the conduit in the plane of the shafts. On the conduit 1 is a servo-motor 57 for actuating the air valve 7. This servo-motor comprises a casing divided into an inner chamber 61 and an outer chamber 63 by a diaphragm 65. Air valve 7 has an upwardly extending bracket 67 which is connected by a link 69 to the diaphragm, the link extending through a hole 71 in the wall of conduit 1. A spring 73 in the outer chamber 63 of the servo-motor biases the diaphragm in the direction to close the air valve 7. A pitot tube 75 has one end reaching into conduit 1 on one side of the partition 55 and its other end connected to the outer chamber 63 of the servo-motor. The air valve 7 has a deflector or spoiler 77 on its under side at its leading edge. The air valve 7 is also provided with a spring loaded relief valve 78 on its upstream side. It will be observed that the diaphragm is subject substantially to atmospheric pressure on its side toward chamber 61 (open via hole 71) and, when the throttle valve is opened, to a lower pressure on its side toward chamber 63 due to the pitot tube. The pressure differential causes the air valve 7 to open against the bias of the spring 73. The amount of opening is proportional to the pressure differential, hence proportional to the rate of air flow.

Mounted on the conduit 1 is a vacuum operated air bleed motor 79, which may be referred to as an economizer, for modulating the action of servo-motor 57 to provide a leaner mixture in the part throttle range than in the full throttle range. Motor 79 comprises a casing divided by a diaphragm 81 into two chambers 83 and 85. In chamber 83 diaphragm 81 carries a valve 87 adapted to engage a valve seat at the entrance to a tube 89 which connects chamber 83 and the outer chamber 63 of the servo-motor 57. There is a restriction 91 at the entrance of tube 89. A spring 93 in chamber 85 biases the diaphragm in the direction to move valve 87 to closed position engaging its seat and blocking tube 89. Chamber 83 is connected as indicated at 95 with a port 97 in the wall of conduit 1 located upstream from the leading edge of the air valve 7. Chamber 85 is connected as indi-

cated at 99 with a port 101 in the wall of conduit 1 located adjacent the edge of the throttle upstream from the position of the leading edge of the throttle valve 3 when the latter is closed to the idle range. In the part throttle range of operation, port 97 is upstream from the air valve 7 and port 101 is downstream of the opening edge of the throttle valve 3. Diaphragm 81 then holds valve 87 open so that a restricted amount of air bleeds from the port 97 through chamber 83 and tube 89 to the chamber 63 of the servo-motor 57 to modulate the suction in chamber 63 caused by the pitot tube 75. This reduces the amount of opening of the air valve 7 that would otherwise be caused, and has the effect of reducing the rate of flow of fuel to provide a proper mixture for part throttle road load operation. In the nearly full throttle range of operation, however, both ports 97 and 101 are downstream from the air valve 7 and throttle valve 3, respectively. A relatively high vacuum is thereupon drawn in chamber 83 of the economizer 79, with the result of reducing the bleeding of air to the servo-motor 57, thereby eliminating or substantially eliminating the effect of the economizer on the servo-motor. In the wide open throttle position, due to the small difference in pressure between 101 and 97, spring 93 is sufficiently strong to position valve 87 firmly on its seat, and cut off the bleed action to the chamber 63.

The conduit 1 has an air by-pass passage 103 which extends around the edge of the air valve 7 when the latter is in a nearly closed position. Flow of air through this by-pass is controlled by a metering screw 105. By adjustment of this screw, it is possible to vary the position of the air valve 7, and hence metering rods 21, etc., in the low range of engine speeds (in the idle range and slightly above). This provides a fuel mixture control in the low range of engine speeds. When air valve 7 opens beyond the upper port to this passage, the by-pass is out of operation. Conduit 1 also has an air by-pass 107 extending around throttle valve 3. Flow of air through this by-pass is controlled by a metering screw 109. This by-pass provides for flow of air for idling around the throttle valve when the latter is closed, the flow being adjustable by means of screw 109 to control the engine idling speed. Throttle valve 3 is provided with a thermostatic strip 110 covering opening 112 in the valve. When the air passing through conduit 1 reaches a predetermined temperature range, opening 112 is uncovered to permit a small portion of the air to pass through the throttle valve.

The fuel metering chamber

As appears in Fig. 2, the fuel metering chamber C is associated with the conduit 1, comprising a casing 111 which may be formed as an integral part on conduit 1 and a closure plate 113 for the casing. Casing 111 is located on the side of conduit 1 at one end of the air valve shaft 53. At this end of the air valve shaft 53, conduit 1 has a recess 115 accommodating a magnetic coupling member 117 fixed on the end of the air valve shaft. A thin plate 119 of nonmagnetic material closes this recess, sealing off chamber C from the recess. The magnetic coupling member 117 is active upon a driven magnetic coupling member 121 in the chamber C rotatable on a stud 123 carried by plate 119. A lever 125 is pivoted on the stud 123 and coupled to the driven magnetic coupling member 121 by a thermostatic member 127 (Fig. 1). This thermostatic member constitutes an element of the starting mixture enrichment system S, as will be made clear. For purposes of immediate explanation, the lever 125 and coupling member 121 may be regarded as locked together. A link 129 connects the lever and the crosshead 23 which carries the metering rods 21. The arrangement is such that, upon rotation of the air valve 7 and the air valve shaft 53, the driven magnetic coupling member 121 rotates in unison with the driving magnetic coupling member 117 on air valve shaft 53 to move the crosshead 23 and the metering rods 21 in

amount proportional to the rotation of the air valve 7. Magnetic coupling members 117 and 121 provide a friction-free leakproof connection for transmitting the torque developed by the air valve 7 to the metering rods 21 to move them in proportion to the rotation of the air valve, and in direction corresponding to the direction of rotation of the air valve. Reference has already been made to the outlet passages 17 and orifices 19 of the fuel metering chamber C.

The nozzles

As appears in Fig. 5, the injector nozzles N are clustered in groups of two, so that, as a matter of practice, there are four nozzle clusters on the intake manifold M of the engine. Eight individual nozzles N appear in the diagrammatic representation of Fig. 1 for simplicity of illustration. As shown, each nozzle cluster comprises a body 131 formed to provide two shallow circular recesses 133 located side-by-side for the pair of nozzles in the cluster. Only one of these recesses appears in Fig. 7. A diaphragm 135 is clamped on the body 131 of each cluster by a head 137. This head is similarly formed to provide two shallow circular recesses 139 located side-by-side, which mate with recesses 133. Again, only one of these recesses 139 appears in Fig. 7. As to each nozzle N, recess 133 constitutes a charging fuel chamber and recess 139 constitutes a datum pressure chamber. The head 137 has an internally recessed rib 141 extending lengthwise thereof. This provides a passage 143 connecting the two datum pressure chambers 139 of the cluster. Fuel connections may be made between the ends of these ribs to provide for the interconnection of the datum pressure chambers of all the nozzles N in the system (corresponding to the connections such as indicated at 31, 31a, 31b, 33, 33a and 33b in Fig. 1). Fig. 5 shows interconnections at 145 between the forward and rearward clusters of each bank of four cylinders of the engine. The body 131 and head 137 are formed with bolt holes 147 for the reception of bolts for attaching them to the manifold M.

For each of the two nozzles N in a cluster, the base 131 of the cluster has an outwardly (downwardly) projecting tubular boss 149 coaxial with the recesses or chambers 133, 139. The hole through this boss is enlarged at its inner end providing a recess 151 and an inwardly facing annular shoulder 153. Each nozzle N comprises a nozzle tube 155 threaded in the hole in the boss and projecting out (downward) from the boss. The nozzle tube has a head 157 at its inner (upper) end received in the recess 151 and seating against shoulder 153 for sealing purposes. Fixed in the outer (lower) end of the nozzle tube is a combination nozzle tip and valve seat member 159. This comprises a short tube having an annular external flange 161 which is press fitted into the turned flange 163 at the outer (lower) end of the nozzle tube 155. The outer end of tip 159 is cut off at an angle as indicated at 165. The inner end portion of the tip 159 extends inward from flange 161 and provides a needle seat 167 (Fig. 8).

Each nozzle N includes the needle 27 having its inner (upper) end attached to the diaphragm 135, the needle extending slidably in the nozzle tube 155. The diameter of the needle is less than the internal diameter of the nozzle tube, to provide an annular space around the needle for flow of fuel through the tube to tip 159, and the needle is held centered in the tube by upper and lower radial projections 169 on the needle which slide on the internal surface of the nozzle tube. At its outer (lower) end, the needle has an enlarged portion 171. This portion has a conically concave face 173 at its outer end. It also has an axial passage 175 leading inward from the face and a passage 177 extending radially outward from the upper end of passage 175. Seated against face 173 is a piece of wire mesh 179, and seated against the wire mesh is a disk 181 of fuel-resistant rubber or the like.

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The wire mesh 179 and rubber disk 181 are held against the face 173 by a cap 183 press fitted on the needle enlargement 171. The cap has an opening 185 for receiving the inner end portion 167 of nozzle tip 159. The cap terminates short of the radial passage 177, this passage and passage 175 being provided to vent air from under the disk 181 in the assembly of the wire mesh, disk and cap on the needle enlargement 171. The rubber disk 181 is initially a flat disk held in a bowed condition under compression against the face 173 by the cap 183, which places the lower working surface under compression to constitute a resilient tip for the needle engageable with the inner end 167 of the nozzle tip (which constitutes a seat for the needle) to provide a tight seal to prevent leakage when the needle is closed. The rubber face of the valve, being compressed, resists the shearing forces of seat engagement. The screen is used to provide for some slight swelling of the rubber composition between the interstices thereof. With the arrangement shown, when the needle is retracted and the rubber disk is clear of the seat 167, fuel flows upward around the seat 167, and thence around into the nozzle tip and down and out of the nozzle tip. This tends to avoid the formation of droplets at low rates of flow as during engine idling which would cause engine idle roughness.

As to each nozzle N, the needle 27 is biased downward by a spring 187 toward its closed position wherein the rubber disk 181 at the lower end of the needle engages the needle seat 167. For each nozzle, there is a passage 189 through the base 131 and the head 137 and communicating with the lower recess or chamber 133. To this passage is connected the respective fuel delivery line 25. Accordingly, the needle 27 is subject to the downward force of spring 187 and datum pressure in recess or chamber 139 tending to drive it downward and close it, and an upward force due to charging fuel pressure in the lower recess or chamber 133 tending to drive it upward and open it. The charging pressure being sufficient to overcome the force of the spring 187 and the datum pressure, diaphragm 135 is moved upward to unseat the needle 27 from needle seat 167 for flow of fuel from chamber 133 out of the nozzle. Upon an increase in datum pressure, diaphragm 135 flexes downward to move the needle 27 closer to its seat 167, thereby to increase the back pressure in the nozzle charging fuel chamber 133, and vice versa.

The datum pressure regulator

As appears in Figs. 2 and 3, the datum pressure regulator R is associated with the fuel metering chamber C, being connected thereto by the connection or fitting 43. The regulator is formed to provide first, second and third expansible chambers 191, 193 and 195 in tandem (see Figs. 9 and 11). The first chamber 191, which is the bottom chamber of the three, is provided by a cup-shaped base 197 closed at the top by a diaphragm 199 clamped against the rim of the base by a ring 201. The second or intermediate chamber 193 is constituted by the space within the ring 201, being closed at the bottom by diaphragm 199, and at the top by a second diaphragm 203, the latter being clamped against the top of the ring by a head 205. The third or upper chamber 195 is constituted by a recess in the bottom of the head, closed at the bottom by the second diaphragm 203. The head overhangs the base and ring, and carries the solenoid valve 40.

Return passage 39 is formed as a horizontal passage in the head 205 extending from an outlet 207 coaxial with the two diaphragms to a recess 209 extending upward from the bottom of the overhanging portion of the head. The head is formed with a valve seat 211 for the solenoid valve which extends downward in the recess 209. The solenoid of the valve 40 is in a case 211 having a neck 213 threaded in the recess 209. The plunger 215 of the solenoid has a resilient valve member 217 at its upper end engageable with the valve seat 211 when the solenoid is

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de-energized to cut off flow through an outlet passage 219 provided in the head extending through the valve seat. The plunger is biased by a spring 220 (see Fig. 1) in the direction (upward as viewed in Figs. 9 and 10) for engagement of valve member 217 with seat 211. When the solenoid is energized, the valve member is withdrawn from the seat. The outer end of the outlet passage 219 is threaded as indicated at 221 in Fig. 10 for connection of the aforementioned fuel return line 41 leading back to the fuel tank 9. The head 205 has a threaded lateral inlet port 223 (see Fig. 11) for connection of the aforementioned datum line 37, this port leading into the upper regulator chamber 195. At its outer end, the head has a threaded port 225 leading to recess 209 for connection of a vapor vent line 227 (see Fig. 1) leading from fuel metering chamber C for carrying off vapor from chamber C when the solenoid valve 40 is open.

A tubular valve guide and seat member 229 (Figs. 9-11) has a reduced upper end portion threaded in the outlet 207, and extends downward in the upper regulator chamber 195. The upper diaphragm 203 carries a cup 231. A needle valve 233 has its lower end secured to the bottom of the cup 231 and extends upward in member 229, being slidable therein. A spring 235 surrounding member 229 biases the upper diaphragm 203 and needle valve 233 downward in the opening direction. The needle valve 233 is thus subject to the downward force of spring 235 and pressure in the upper regulator chamber 195 tending to open it, and to the pressure in the intermediate regulator chamber 193 tending to close it. The lower diaphragm 199 is biased downward by a spring 237 reacting from an internal shoulder 239 formed in the ring 201. A fluted guide pin 241 has its upper end fixed to the center of the lower diaphragm 199 and extends downward in a tubular guide 243 which is threaded in the bottom of the cup-shaped regulator base 197. The guide pin 241 is slidable in the tubular guide 243. A bushing 245 (Fig. 11) is threaded in an opening 247 in the annular wall of the cup-shaped regulator base 197 with its axis parallel to the axis of the throttle shaft 3. A shaft 249 is rotatable in the bushing. Packing to prevent leakage around the shaft is indicated at 251, and this is a plastic washer having a low coefficient of friction ("Teflon") placed against the movable surface, and a plastic washer (rubber) placed against the stationary surface. At its inner end in the lower regulator chamber, shaft 249 carries a cam 253 engageable by a wear plate 255 on the underside of the lower diaphragm 199. An arm 257 (Fig. 2) is fixed to the outer end of the shaft 249. A link 259 connects this arm to an arm 261 on the throttle shaft (Figs. 2-4). The arrangement is such that when the throttle valve 3 is closed, cam 253 occupies a position holding the lower diaphragm 199 in a raised position. When the throttle valve 3 is opened, cam 253 is rotated clockwise as viewed in Fig. 9, allowing the lower diaphragm 199 to flex downward. A spring 261, a torsion spring in compression, is provided for biasing the shaft 249 and cam 253 to rotate counterclockwise toward the raised-diaphragm position of the cam, and to provide for keeping the seal 251 under compression. This dual function eliminates sliding friction between the parts. The ring 201 has a radial nipple 263 which is externally threaded for reception of a coupling nut 265 to couple the regulator to the fitting 266. The nipple 263 has a horizontal passage 267 receiving fuel from chamber C via fitting 266. From the inner end of this horizontal passage there is a port having a restriction 269 leading into the intermediate regulator chamber 193. There is also a downwardly extending opening 271 communicating with a passage 273 formed in the annular wall of the cup-shaped regulator base 197 communicating with the lower regulator chamber 191. Thus, the lower and intermediate regulator chambers 191 and 193 are in communication with the fuel metering chamber C, with communication to the intermediate chamber 193 restricted at 269.

The starting mixture enrichment system

The starting mixture enrichment system S (Fig. 1) comprises the aforementioned thermostatic member 127 and a heat-exchange pipe 275 for circulating coolant (water) from the cooling system 277 of engine E through the fuel metering chamber C. The radiator of the cooling system is indicated at 279 in Fig. 1, and the pump for circulating coolant is indicated at 281. The closure plate 113 (Fig. 3) of chamber C has an inlet port 283 to which is connected a pipe 285 leading from the cooling system 277 on the outlet side of pump 281. Pipe 275 extends in chamber C through a tortuous course from inlet port 283 to an outlet port 287 in closure plate 113. The outlet port 287 opens into a valve housing 289 mounted on the closure plate 113. This housing 289 has an outlet port 291 to which is connected a return pipe 293 leading back to the cooling system on the inlet side of the pump 281. In the housing 289 is a thermostatic valve 295 which, when cold, is bent away from port 291 and which, as it is heated by the coolant (which becomes hotter and hotter as the engine warms up) bends toward port 291, ultimately closing off the latter when the engine has reached operating temperature to reduce the circulation of coolant through the heat-exchange pipe 275 and maintain an even fuel temperature in chamber 111.

When the engine is cold, the coolant is cold and the fuel in chamber C is cold. Accordingly, the thermostatic member 127 is cold. When this thermostatic member is cold, it holds the lever 125 at a certain angle relative to the magnetic coupling member 121. As the engine warms up, the coolant warms up. Due to the circulation of the warmed up coolant through the heat-exchange pipe 275 in chamber C, the fuel in chamber C is heated and the thermostatic member 127 is heated. As the thermostatic member 127 is heated, its shape changes in such a way as to change the angle of lever 125 relative to coupling member 121. Since the lever 125 controls the position of crosshead 23 and metering rods 21, the heating of the thermostatic member 127 results in a change in the position of the metering rods. The arrangement is such that, for a given position of the coupling member 121 (such as the position it assumes at idle), the metering rods 21 occupy a more drawn-out position when the engine is cold than they occupy when the engine is warm, thereby providing for mixture enrichment when the engine is cold. This also would be true at any rate of air flow and engine speed.

The fast idle control

The fast idle control FI (Fig. 4) comprises a fast idle cam 297 pivoted at 299 on the conduit 1. This cam is controlled by a thermostatic member 301 in a housing 303. The thermostatic member is responsive to engine temperature. Arm 261 on the throttle shaft 45 carries a screw 305 engageable with the cam to determine the throttle opening at idle in accordance with the position of the cam as determined by engine temperature.

The electrical circuit and unloader

At 307 (Fig. 1) is indicated the battery of the vehicle. One terminal of the battery is grounded as indicated at 309. A line 311 extends from the other terminal of the battery to one terminal of starting switch 313. A line 315 extends from the other terminal of the starting switch to one terminal of the starting motor 317 for engine E, the other terminal of the motor being grounded as indicated at 319. A line 321 including ignition switch 323 extends from line 311 to one terminal of a normally closed relay 325. The coil of the relay is connected in a line 327 extending from one terminal of the unloader switch U to line 315. The other terminal of the unloader switch is grounded as indicated at 329. The unloader switch U is normally open, being closed

when the accelerator pedal 49 is pushed to open the throttle valve 3 wide. A line 331 extends from the other terminal of relay 325 to one terminal of an oil pressure switch 333. This switch is normally open, being closed by engine oil pressure when the engine is in operation. A line 335 extends from the other terminal of the oil pressure switch to the solenoid 40, which is grounded as indicated at 337. Another line 339 extends from the other terminal of the oil pressure switch to the motor of the electric fuel pump 11, which is grounded as indicated at 341.

Operation

To start the engine E, ignition switch 323 is closed and starting switch 313 is closed to energize the starting motor 317 to crank the engine E. Relay 325 being normally closed as appears in Fig. 1, and oil pressure being developed to close the oil pressure switch 333, the electric pump 11 is energized to pump fuel to fuel metering chamber C and solenoid valve 40 is energized to open. With fuel being delivered by pump, chamber C is maintained full of fuel under pressure. Fuel also fills the datum pressure chambers 139 of nozzles N and the upper, intermediate and lower chambers 191, 193 and 195 of the datum pressure regulator R. Fuel for the engine E is delivered from chamber C through the orifices 19 and lines 25 to the charging fuel chambers 133 of nozzles N.

Regulator R is adapted to maintain a predetermined pressure differential between the charging pressure (i.e., the pressure in fuel metering chamber C) and the datum pressure (i.e., the pressure in chambers 139 of nozzles N), with the datum pressure lower than the charging pressure during all normal rates of flow. This pressure differential may be about $\frac{1}{2}$ p.s.i., for example, and it is maintained except during rotation of the cam 253, at which times it is reduced or raised (depending upon which way the cam rotates), as will be made clear. The regulator R acts in accordance with variations in the pressure in chamber C to maintain the stated pressure differential as follows: Upon a decrease in charging pressure in chamber C, the pressure in regulator chambers 191 and 193 drops. Diaphragm 203 thereupon moves downward to move the regulator valve 233 farther away from its seat. This allows fuel to escape more readily from chamber 195 and datum line 37 so as to drop the datum pressure an amount equal to the drop in charging pressure, whereby the difference between charging pressure and datum pressure remains the same. Upon an increase in charging pressure in chamber C, the pressure in regulator chambers 191 and 193 increases. Diaphragm 203 thereupon moves upward to move the valve 233 closer to its seat. This increases the datum pressure an amount equal to the increase in charging pressure so that the difference between charging pressure and datum pressure remains the same. Thus, the regulator R reduces the charging pressure by a predetermined amount ($\frac{1}{2}$ p.s.i., for example) to convert it to datum pressure.

As to each nozzle N, the nozzle diaphragm 135 is subject on one side to charging pressure in chamber 133 tending to move the nozzle needle 27 away from its seat 167, and subject on the other side to datum pressure in chamber 139 and the force of the nozzle spring 187 tending to move the nozzle needle toward its seat. With the charging pressure high enough to overcome the closing force on the nozzle needle 27 due to the datum pressure and spring 187, the needle is unseated, and fuel is discharged through the tip 159 of the nozzle. The rate of flow of fuel through a nozzle is dependent upon the position of the metering rod 21 related to that particular nozzle in relation to the metering rod orifice 19 and the pressure drop across the orifice. As long as the pressure differential between charging pressure and datum pressure remains substantially constant, the pres-

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sure drop across orifice 19 remains substantially constant, being equal to the stated pressure differential plus the pressure created by the nozzle spring 187 (which is a low rate spring). Thus, the pressure drop across orifice 19 is normally maintained substantially constant, and variations in the rate of flow of charging fuel are caused solely by moving the metering rods 21 in or out, the farther in the rods, the lower the rate of flow, and vice versa.

The position of the metering rods 21 is dependent upon the position of air valve 7 and the temperature of thermostatic member 127. The position of the air valve is dependent upon the rate of air flow through the conduit 1. The temperature of thermostatic member 127 is dependent upon the temperature of engine E. Assuming that the engine is fully warmed up, the effect of temperature on the position of the rods may be disregarded, and it will be observed that with the air valve 7 closed, the metering rods 21 will occupy an advanced position wherein the effective area of each orifice 19 (the annular area around the rod within the orifice) is a minimum, for flow of charging fuel at a minimum rate corresponding to the rate of flow of air to the engine. As the air valve 7 opens with increase in the rate of air flow, the metering rods 21 are withdrawn an amount proportional to the opening of the air valve to increase the rate of flow of charging fuel proportionately to the increase in the rate of air flow. In the part throttle range, the opening of the air valve 7 is attenuated by the economizer 79 to attenuate the withdrawal of the metering rods to provide a lower rate of flow of charging fuel than would occur without such attenuation, so as to deliver an economy mixture of air and fuel to the engine. In the full throttle range of operation, wherein the air valve 7 has opened to the point where port 97 is downstream from the air valve, the attenuating effect of the economizer 79 is decreased, and the metering rods 21 are withdrawn to the point of providing the necessary rate of flow of charging fuel in relation to the rate of flow of air to deliver a richer mixture. A full rich mixture for power is delivered when manifold pressure increases to close valve 87.

On starting a cold engine, valve 87 is closed to provide a richer mixture, and during starting and engine warm-up, the thermostatic member 127 functions to provide for enrichment of the mixture by changing the phase of the metering rods 21 relative to the magnetic coupling member 121 and the air valve 7. As the engine warms up, the modulation of metering rod position by the thermostatic member 127 is lessened, and, once the engine has fully warmed up, the thermostatic member has no further effect.

On acceleration (pushing down the pedal 49), cam 253 is rotated clockwise as viewed in Fig. 9. The lower diaphragm 199 of regulator R is subject on both sides to charging pressure (regulator chambers 191 and 193 being in communication with fuel metering chamber C) and additionally subject to the downward force of spring 237. Accordingly, spring 237 drives the lower diaphragm 199 downward, forcing fuel out of chamber 191. Restriction 269 acts momentarily to prevent the fuel forced out of chamber 191 from entering chamber 193, most of the fuel being forced back to chamber C and increasing the pressure in chamber C. The pressure in the intermediate regulator chamber 193 is lowered, and the upper regulator diaphragm 203 is driven downward. This pulls valve 233 farther away from its seat, thereby reducing the datum pressure. Upon the drop in datum pressure in the nozzle datum pressure chambers 139, the nozzle diaphragms 135 respond to move the nozzle needles 27 farther away from their seats. This drops the pressure in the charging fuel chambers 133 of the nozzles. Thus, the pressure drop across metering orifices 19 is increased. As a result of this increase in the pressure drop across the orifices, charging fuel is delivered at a higher rate

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than it otherwise would have been delivered. This provides for momentary mixture enrichment on acceleration. The action on deceleration is the reverse, cam 253 then rotating counterclockwise and driving the lower regulator diaphragm 199 upward. Because of restriction 269, this results in increase of pressure in chamber 193, and the upper regulator diaphragm 203 moves upward to move the regulator valve 233 nearer its seat. This increases the datum pressure, and the nozzle diaphragms 135 respond to move the nozzle needles 27 closer to their seats. This decreases the rate of delivery of charging fuel. When the cam 253 comes to rest after the accelerating or decelerating movement of the pedal 49, the pressure on opposite sides of the lower regulator diaphragm 199 equalizes, no matter what position the cam 253 may be in, and the equilibrium of the regulator R is restored so that it resumes functioning to maintain the substantially constant pressure differential between charging and datum pressure.

For unloading (i.e., clearing the engine of excess fuel), the pedal 49 is pushed all the way in, thereby closing the unloader switch U. This completes a circuit for the coil of relay 325, and the latter opens. This deenergizes the electric pump 11 and the solenoid valve 40. The solenoid valve closes, thereby holding pressure in the datum system. With the pump cut off and increased pressure in the datum system, nozzles N close to cut off delivery of charging fuel to the engine. The engine is cranked by closing the starting switch 313, and this clears the engine of excess fuel.

If heat should cause expansion of fuel in the datum system with resultant increase of pressure in the datum system, the pressure drives the upper regulator diaphragm 203 downward, thereby opening up the regulator valve 233 to relieve the excess pressure via passage 39 and return line 41 (the solenoid valve 40 being open). It will be observed that with solenoid valve 40 open, there is no restriction in the datum system downstream from the regulator R such as would inhibit relief of excess pressure.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative, and not in a limiting sense.

I claim:

1. In a fuel injection system for an internal combustion engine, a source of fuel under pressure, a fuel delivery system for delivering fuel from said source to an outlet at the engine, a datum pressure system connected to receive fuel from said source and having a regulator therein for regulating the pressure in said datum system and adapted to maintain a substantially constant differential between source pressure and datum pressure, and pressure responsive means for controlling the pressure at said outlet connected into the datum pressure system between said source and said regulator, said regulator having a single datum fuel outlet, said datum pressure system being adapted for free return of fuel from said datum fuel outlet when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

2. In a fuel injection system for an internal combustion engine, a fuel tank, a fuel delivery system including a pump for supplying fuel under pressure from the tank to an outlet at the engine, a datum pressure system having an inlet for receiving datum fuel under pressure from the pump and a return to the tank, flow limiting means in said datum pressure system, a pressure regulator in said datum pressure system downstream from

said flow limiting means adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, and pressure responsive means for controlling the pressure at said outlet connected into the datum pressure system between said flow limiting means and said regulator, said regulator having a single datum fuel outlet, said datum pressure system being adapted freely to return fuel from said datum outlet to the tank when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

3. In a fuel injection system for an internal combustion engine, a fuel tank, a fuel delivery system including a pump for supplying fuel under pressure from the tank to a nozzle at the engine, said nozzle including pressure responsive means for controlling the discharge therefrom, a datum pressure system having an inlet for receiving datum fuel under pressure from the pump and a return to the tank, a restriction in said datum pressure system, a pressure regulator in said datum pressure system downstream from said flow limiting means adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, the pressure responsive means of said nozzle being connected into the datum pressure system between said restriction and said regulator, and means for cutting off flow of datum fuel from the regulator to the tank in response to stopping the engine, said regulator having a single datum fuel outlet, said datum pressure system being adapted freely to return fuel from said datum outlet to the tank when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

4. In a fuel injection system for an internal combustion engine, a source of fuel under pressure, a fuel delivery system for delivering fuel from said source to an outlet at the engine, a datum pressure system connected to receive fuel from said source and having a pressure regulator therein adapted to maintain a substantially constant differential between source pressure and datum pressure, said fuel delivery system comprising means for metering fuel from said source to said outlet and means responsive to the difference between the pressure in the delivery system downstream from said metering means and the datum pressure for controlling said downstream delivery pressure and adapted to maintain a substantially constant differential between said source pressure and said downstream delivery pressure, said controlling means being connected into the datum pressure system between said source and said regulator, said regulator having a single datum fuel outlet, said datum pressure system being adapted for free return of fuel from said datum outlet when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

5. In a fuel injection system for an internal combustion engine, a fuel delivery system including a pump for supplying fuel under pressure to an outlet at the engine, a datum pressure system connected to said pump, a pressure regulator in said datum pressure system adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, said fuel delivery system comprising means for metering fuel to said outlet and means responsive to the difference between the pressure in the delivery system downstream from said metering means and the datum pressure for controlling said downstream delivery pressure and adapted to maintain a substantially constant differential between pump supply pressure and said downstream delivery pressure, said controlling means being connected into said datum pressure system upstream from said regulator, said regulator having a single datum fuel outlet, said datum system being

adapted for free return of fuel from said datum outlet when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

6. In a fuel injection system for an internal combustion engine, a fuel tank, a fuel delivery system including a pump for supplying fuel under pressure from the tank to an outlet at the engine, a datum pressure system having an inlet for receiving datum fuel under pressure from the pump and a return to the tank, flow limiting means in said datum system, a pressure regulator in the datum system adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, said fuel delivery system comprising means for metering fuel to said outlet and means responsive to the difference between the pressure in the delivery system downstream from said metering means and the datum pressure for controlling said downstream delivery pressure and adapted to maintain a substantially constant differential between pump supply pressure and said downstream delivery pressure, said controlling means being connected into the datum pressure system between said flow limiting means and said regulator, said regulator having a single datum fuel outlet, said datum pressure system being adapted freely to return fuel from said datum outlet to the tank when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

7. In a fuel injection system for an internal combustion engine, a fuel tank, a fuel delivery system including a pump for supplying fuel under pressure to a nozzle for delivering fuel from said source to an outlet at the engine, said nozzle including pressure responsive means for controlling the discharge therefrom, a datum pressure system having an inlet for receiving datum fuel under pressure from the pump and a return to the tank, a restriction in said datum system, a pressure regulator in said datum system downstream from said restriction adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, said fuel delivery system comprising means for metering fuel to the nozzles, said pressure responsive means of said nozzle being responsive to the difference between the pressure in the delivery system at the nozzle and the datum pressure for controlling the pressure at the nozzle and adapted to maintain a substantially constant differential between pump supply pressure and the pressure at the nozzle, said pressure responsive means of the nozzle including a datum pressure chamber connected into the datum pressure system between said restriction and said regulator, said regulator having a single datum fuel outlet, said datum pressure system being adapted freely to return fuel from said datum outlet to the tank when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

8. In a fuel injection system for an internal combustion engine, throttle means for controlling the flow of air to the engine, means for measuring the flow of air to the engine, a source of fuel under pressure, a fuel delivery system for delivering fuel from said source to an outlet at the engine, a datum pressure system connected to receive fuel from said source and having a regulator therein for regulating the pressure in said datum system, said fuel delivery system including fuel metering means for metering fuel from said source to said outlet, means controlled by said air flow measuring means for controlling said fuel metering means, pressure responsive means for controlling the pressure at said outlet connected into said datum system, and means controlled by said throttle means for actuating said regulator to vary the datum pressure in response to movement of said throttle means.

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9. In a fuel injection system as set forth in claim 8, said regulator comprising first, second, and third expandable chambers, the first being in communication with said source, the second being in restricted communication with said source and said first chamber, the third having a datum inlet and outlet, a first pressure responsive element separating the first and second chambers, said throttle controlled means being operable on said first pressure responsive element, a second pressure responsive element separating the second and third chambers, and a valve controlled by said second pressure responsive element for controlling the flow from said datum inlet to said datum outlet.

10. In a fuel injection system as set forth in claim 9, said first pressure responsive element being biased in one direction by a spring, and said throttle controlled means comprising a cam engageable by said first pressure responsive element, said cam being movable in one direction to allow for movement of said first pressure responsive element in said one direction by the spring and said cam being movable in the opposite direction to move said first pressure responsive element in the opposite direction against the spring bias.

11. In a fuel injection system for an internal combustion engine, throttle means for controlling the flow of air to the engine, means for measuring the flow of air to the engine, a source of fuel under pressure, a fuel delivery system for delivering fuel from said source to an outlet at the engine, a datum pressure system connected to receive fuel from said source and having a regulator therein for regulating the pressure in said datum system and adapted to maintain a substantially constant differential between source pressure and datum pressure, said fuel delivery system including means for metering fuel from said source to said outlet, means controlled by said air flow measuring means for controlling said fuel metering means, pressure responsive means for controlling the pressure at said outlet connected into the datum pressure system between said source and said regulator, and means controlled by said throttle means for actuating said regulator to vary the datum pressure in response to movement of said throttle means.

12. In a fuel injection system for an internal combustion engine, throttle means for controlling the flow of air to the engine, means for measuring the flow of air to the engine, a fuel delivery system including a pump for supplying fuel under pressure to an outlet at the engine, a datum pressure system connected to said pump, a pressure regulator in datum pressure system adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, said fuel delivery system including means for metering fuel to said outlet, means controlled by said air flow measuring means for controlling said fuel metering means, pressure responsive means for controlling the pressure at said outlet connected into said datum system upstream from said regulator, and means controlled by said throttle means for actuating said regulator to vary the datum pressure in response to movement of said throttle means.

13. In a fuel injection system for an internal combustion engine, throttle means for controlling the flow of air to the engine, means for measuring the flow of air to the engine, a fuel tank, a fuel delivery system including a pump for supplying fuel under pressure from the tank to an outlet at the engine, a datum pressure system having an inlet for receiving datum fuel under pressure from the pump and a return to the tank, flow limiting means in said datum pressure system, a pressure regulator in said datum pressure system downstream from said flow limiting means adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, and pressure responsive means for controlling the pressure at said outlet connected into the datum pressure system between said flow limiting means and said regulator, said regulator having a single datum fuel outlet, said datum pressure system being adapted for free

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return of fuel from said datum outlet when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

14. In a fuel injection system for an internal combustion engine, throttle means for controlling the flow of air to the engine, means for measuring the flow of air to the engine, a fuel tank, a fuel delivery system including a pump for supplying fuel under pressure from the tank to a nozzle at the engine, said nozzle including pressure responsive means for controlling the discharge therefrom, a datum pressure system having an inlet for receiving datum fuel under pressure from the pump and a return to the tank, a restriction in said datum pressure system, a pressure regulator in said datum pressure system downstream from said flow limiting means adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, the pressure responsive means of said nozzle being connected into the datum pressure system between said restriction and said regulator, and means for cutting off flow of datum fuel from the regulator to the tank in response to stopping the engine, said regulator having a single datum fuel outlet, said datum pressure system being adapted freely to return fuel from said datum outlet to the tank when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

15. In a fuel injection system for an internal combustion engine, throttle means for controlling the flow of air to the engine, means for measuring the flow of air to the engine, a source of fuel under pressure, a fuel delivery system for delivering fuel from said source to an outlet at the engine, a datum pressure system connected to receive fuel from said source and having a pressure regulator therein adapted to maintain a substantially constant differential between source pressure and datum pressure, said fuel delivery system comprising means for metering fuel from said source to said outlet and means responsive to the difference between the pressure in the delivery system downstream from said metering means and the datum pressure for controlling said downstream delivery pressure and adapted to maintain a substantially constant differential between said source pressure and said downstream delivery pressure, said controlling means being connected into the datum pressure system between said source and said regulator, said regulator having a single datum fuel outlet, said datum pressure system being adapted for free return of fuel from said datum outlet when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

16. In a fuel injection system for an internal combustion engine, throttle means for controlling the flow of air to the engine, means for measuring the flow of air to the engine, a fuel tank, a fuel delivery system including a pump for supplying fuel under pressure from the tank to an outlet at the engine, a datum pressure system having an inlet for receiving datum fuel under pressure from the pump and a return to the tank, flow limiting means in said datum system, a pressure regulator in the datum system adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, said fuel delivery system comprising means for metering fuel to said outlet and means responsive to the difference between the pressure in the delivery system downstream from said metering means and the datum pressure for controlling said downstream delivery pressure and adapted to maintain a substantially constant differential between pump supply pressure and said downstream delivery pressure, said controlling means being connected into the datum pressure system between said flow limiting means and said regulator, said regulator having a single datum

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fuel outlet, said datum pressure system being adapted freely to return fuel from said datum outlet to the tank when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

17. In a fuel injection system for an internal combustion engine, throttle means for controlling the flow of air to the engine, means for measuring the flow of air to the engine, a fuel tank, a fuel delivery system including a pump for supplying fuel under pressure to a nozzle for delivering fuel from the engine, said nozzle including pressure responsive means for controlling the discharge therefrom, a datum pressure system having an inlet for receiving datum fuel under pressure from the pump and a return to the tank, a restriction in said datum system, a pressure regulator in said datum system downstream from said restriction adapted to maintain a substantially constant differential between pump supply pressure and datum pressure, said fuel delivery system comprising means for metering fuel to the nozzle, said pressure responsive means of said nozzle being responsive to the difference between the pressure in the delivery system at the nozzle and the datum pressure for controlling the pressure at the nozzle and adapted to maintain a substantially constant differential between pump supply pressure and the pressure at the nozzle, said pressure responsive means of the nozzle including a datum pressure chamber connected into the datum pressure system between said restriction and said regulator, said regulator having a single datum fuel outlet, said datum pressure system being adapted freely to return fuel from said datum outlet to the tank when the engine is in operation, and said regulator having a single valve responsive to differential between source pressure and datum pressure controlling the flow through said datum outlet.

18. In a fuel injection system as set forth in claim 17, said regulator comprising first, second and third expandible chambers, the first being in communication with the pump outlet, the second being in restricted communication with the pump outlet, and said first chamber, the third having a datum inlet and said datum outlet, a first pressure responsive element separating the first and second chambers, said throttle controlled means being operable on said first pressure responsive element, a second pressure responsive element separating the second and third chambers, and a valve controlled by said second pressure responsive element for controlling the flow from said datum inlet to said datum outlet.

19. In a fuel injection system as set forth in claim 18, said first pressure responsive element being biased in one direction by a spring, and said throttle controlled means

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comprising a cam engageable by said first pressure responsive element, said cam being movable in one direction to allow for movement of said first pressure responsive element in said one direction by the spring, and said cam being movable in the opposite direction to move said first pressure responsive element in the opposite direction against the spring bias.

20. In a fuel injection system as set forth in claim 17, said nozzle comprising opposed expandible chambers separated by a diaphragm, one of said chambers being a datum chamber and the other a charging fuel chamber, a tube extending from the charging fuel chamber, a needle valve attached to the diaphragm slidable in the tube, a nozzle tip at the end of the tube having an inwardly extending tubular portion, the inner end of which constitutes a valve seat, said needle valve having a resilient member at its end engageable with said seat.

21. In a fuel injection system for an internal combustion engine having throttle means for controlling the flow of air to the engine, means for measuring the flow of air to the engine, a fuel delivery system and a datum pressure system, a pressure regulator in the datum pressure system comprising first, second and third expandible chambers, the first being in communication with said delivery system, the second being in restricted communication with said delivery system and said first chamber, the third having a datum inlet and outlet, a first pressure responsive element separating the first and second chambers, throttle controlled means for moving said first pressure responsive element, a second pressure responsive element separating the second and third chambers, and a valve controlled by said second pressure responsive element for controlling the flow from said datum inlet to said datum outlet.

22. In a fuel injection system as set forth in claim 21, said first pressure responsive element being biased in the direction of said first chamber by a spring, and said throttle controlled means comprising a cam in said first chamber engageable by said first pressure responsive element, said cam being movable in one direction to allow for movement of said first pressure responsive element in the direction of said first chamber by the spring, and said cam being movable in the opposite direction to move said first pressure responsive element in the opposite direction against the spring bias.

References Cited in the file of this patent

UNITED STATES PATENTS

2,531,666	Bower	Nov. 28, 1950
2,820,673	Zubaty	Jan. 21, 1958
2,890,690	Dolza	June 16, 1959
2,893,364	Elliott et al.	July 7, 1959