Dec. 9, 1958 J. O. SARTO 2,863,433

LOW PRESSURE FUEL INJECTION SYSTEM

Filed Oct. 6, 1954 5 Sheets-Sheet 1

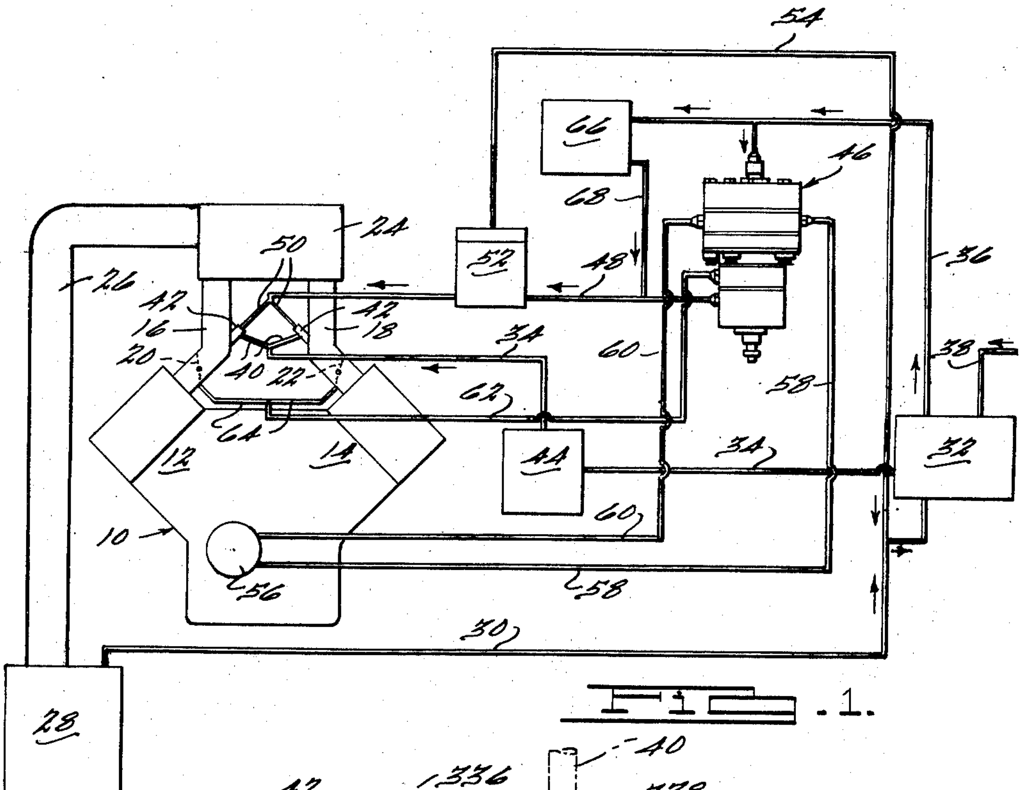

FIG. 1.

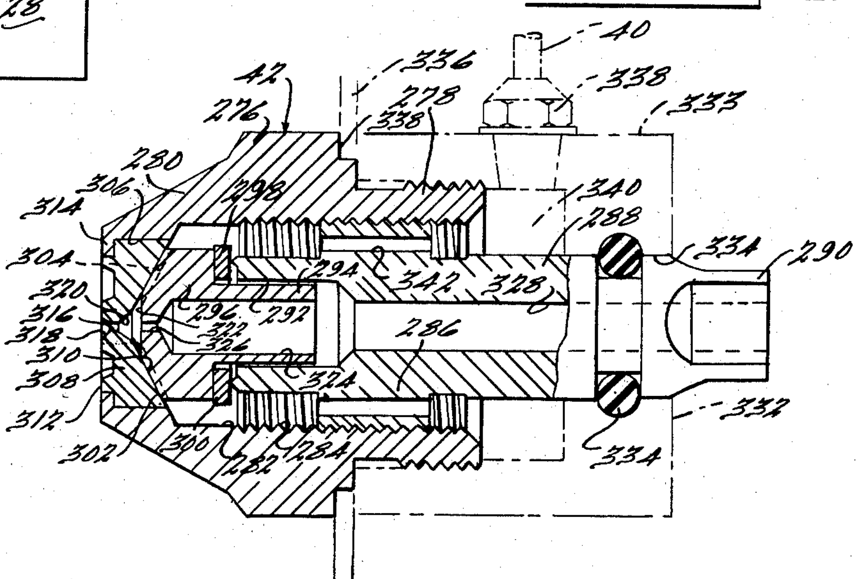

FIG. 2.

INVENTOR.
Torma O. Sarto
BY
Harness and Harris
ATTORNEYS.

Dec. 9, 1958 J. O. SARTO 2,863,433

LOW PRESSURE FUEL INJECTION SYSTEM

Filed Oct. 6, 1954 5 Sheets-Sheet 2

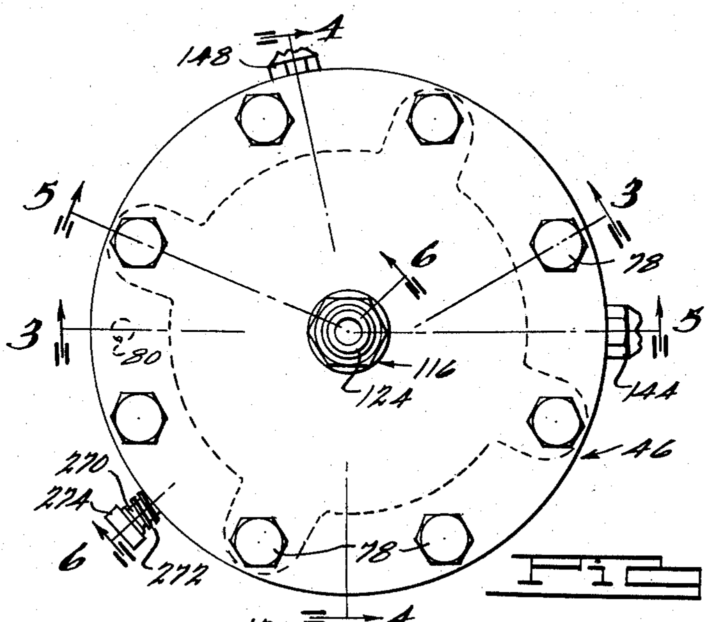

FIG. 2.

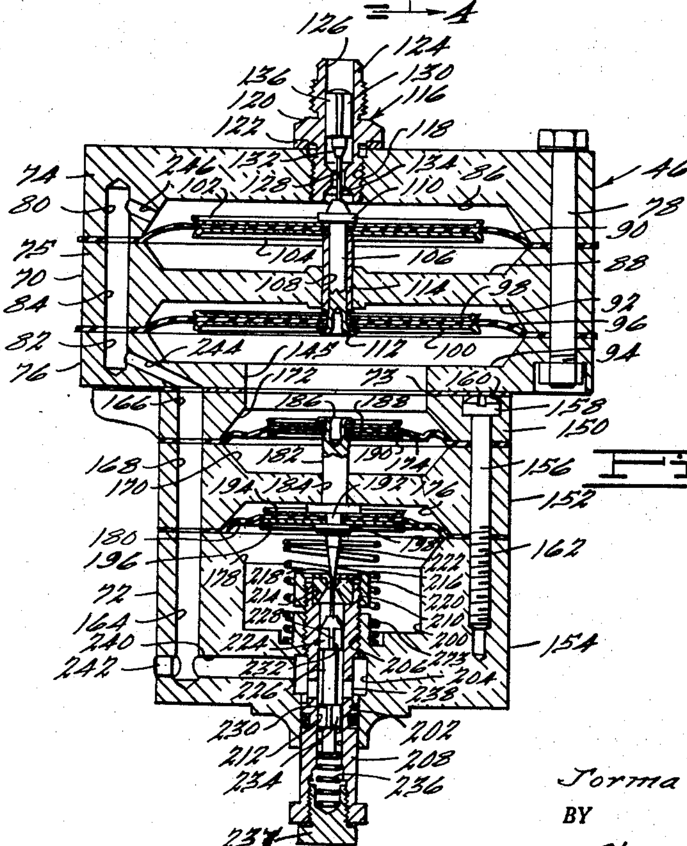

FIG. 3.

INVENTOR.
Jorma O. Sarto
BY
Harness and Harris
ATTORNEYS.

LOW PRESSURE FUEL INJECTION SYSTEM

Filed Oct. 6, 1954 5 Sheets-Sheet 3

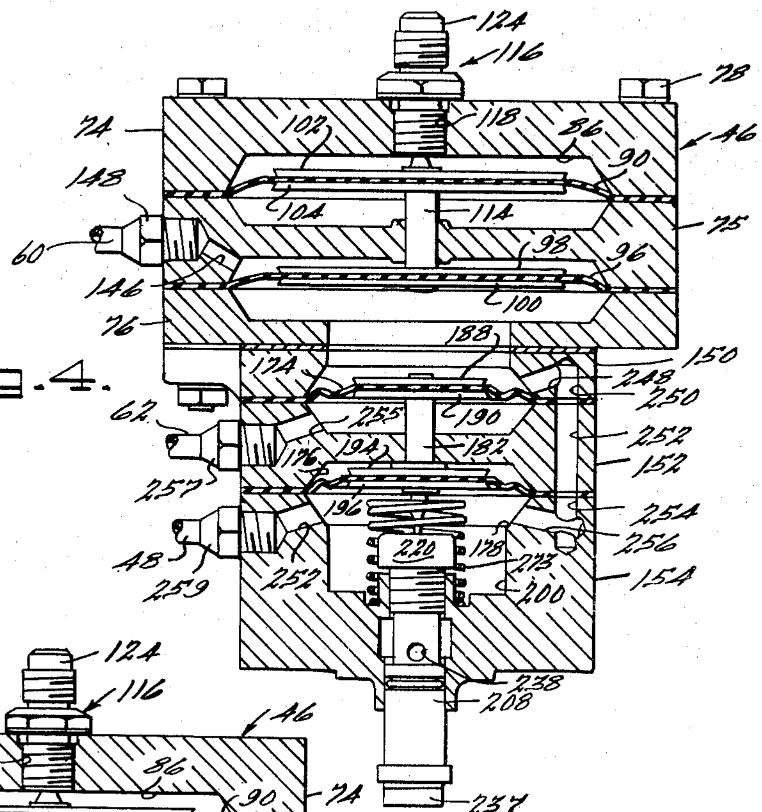

FIG. 4.

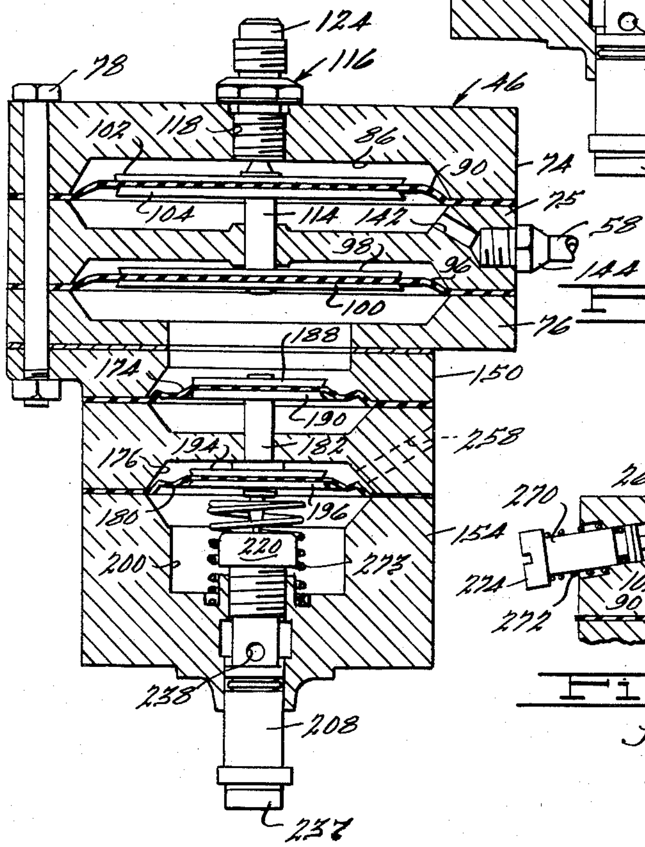

FIG. 5.

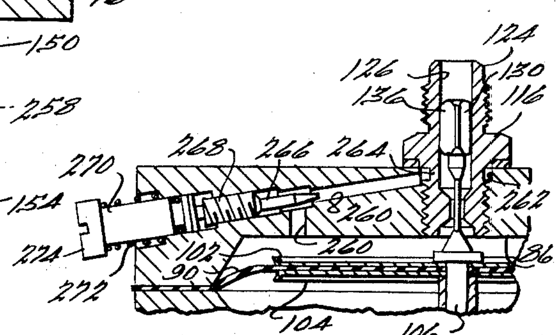

FIG. 6.

INVENTOR.
Jorma O. Sarto.
BY
Harness and Harris
ATTORNEYS.

Dec. 9, 1958 J. O. SARTO 2,863,433

LOW PRESSURE FUEL INJECTION SYSTEM

Filed Oct. 6, 1954 5 Sheets-Sheet 4

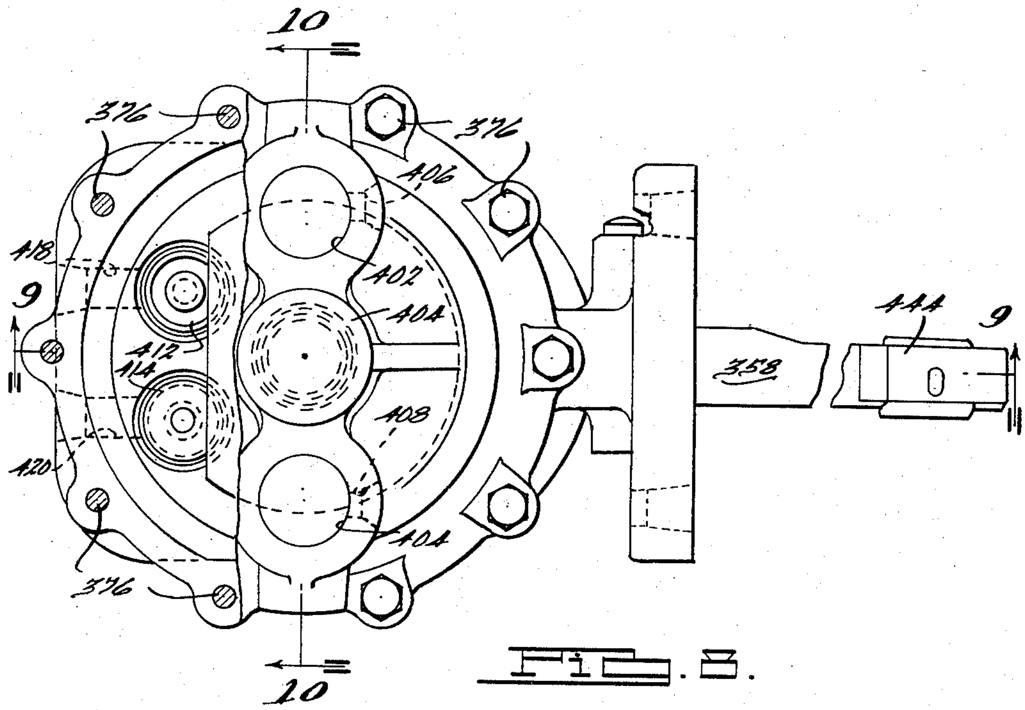

FIG. 8.

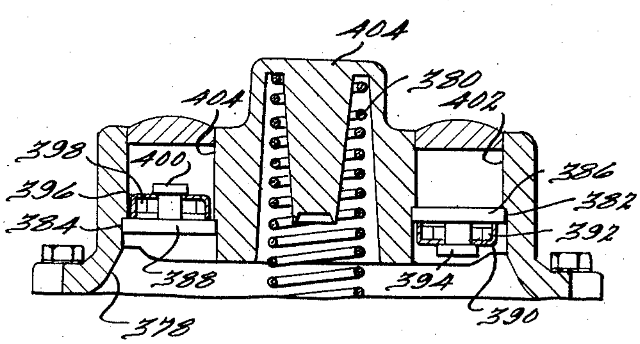

FIG. 10.

INVENTOR.
Jorma O. Sarto
BY
Harness and Harris
ATTORNEYS

LOW PRESSURE FUEL INJECTION SYSTEM

Filed Oct. 6, 1954 5 Sheets-Sheet 5

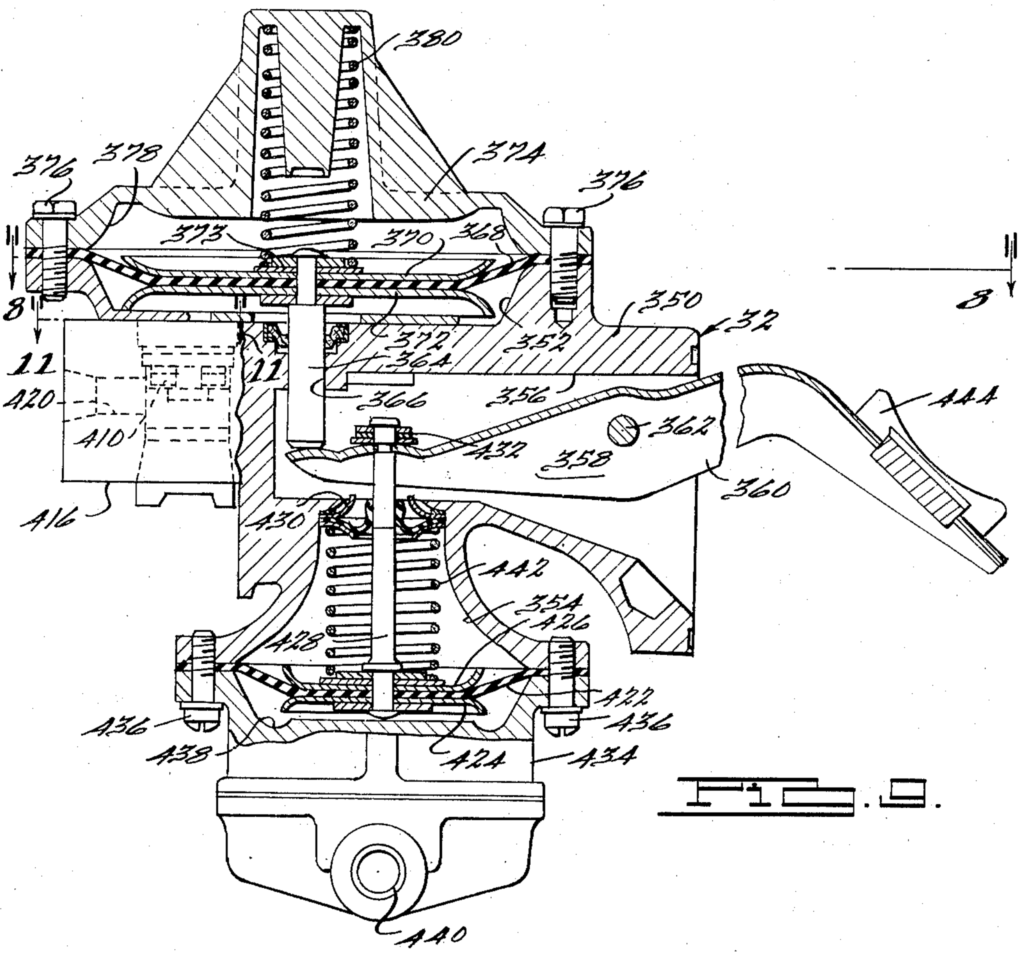

FIG. 9.

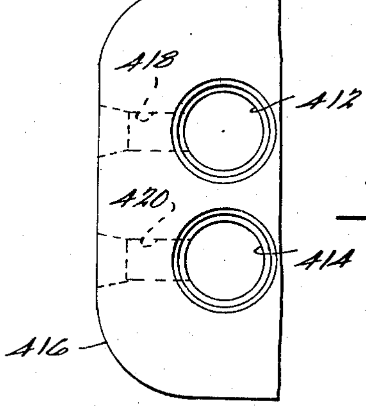

FIG. 11.

INVENTOR.
Jorma O. Sarto.
BY
Harness and Harris
ATTORNEYS

United States Patent Office

2,863,433

Patented Dec. 9, 1958

2,863,433

LOW PRESSURE FUEL INJECTION SYSTEM

Jorma O. Sarto, Walled Lake, Mich., assignor to Chrysler Corporation, Highland Park, Mich., a corporation of Delaware

Application October 6, 1954, Serial No. 460,668

38 Claims. (Cl. 123—119)

My invention relates generally to a liquid fuel combustion mechanism and more particularly to a new and improved liquid fuel control system for automatically regulating and scheduling a controlled flow of fuel to the combustion chamber of a liquid fuel combustion mechanism.

The fuel control system of my instant invention is of the fuel injection type and it is particularly adapted to be used with internal combustion, reciprocating engines although I contemplate that it is also capable of many other uses. I contemplate that the fuel injection system of my instant invention may be successfully used with spark ignition, reciprocating, automotive type engines in lieu of the conventional fuel system normally used with such spark ignition engines. This conventional system normally includes complex manifolding and a venturi type carburetor device associated with the manifolding. A venturi throat is commonly provided within the body of the carburetor device for producing a localized drop in the static pressure of the intake air, the magnitude of this static pressure drop being a function of the velocity of the intake air flow and the speed of the engine. A fuel metering device is included within the carburetor assembly and it has portions which are affected by the variations in the static pressure at the carburetor venturi to provide controlled variations in the fuel flow rate to meet varying operating fuel requirements.

Recent improvements in the internal combustion engine art have imposed greater operating requirements upon the venturi type carburetor devices. For example, the higher horsepower range and the wider operating speed range of a modern automotive engine call for a high breathing capacity and efficient carburetion over a wide range of air flow rates. This necessitates the use of various compensating devices in combination with the carburetor including multiple carburetor stages and automatic auxiliary stage actuator mechanisms. As a result of these and other refinements, the carburetor devices have become extremely complex and costly and in some instances, they are commercially unacceptable for this reason.

The space requirements for these complex carburetor devices are also prohibitively great for a large number of engine installations. When used with an automotive engine, such a carburetor would require a relatively high vehicle hood which is objectionable from a styling viewpoint.

In addition to the above, the limitations in the performance of the venturi type carburetors have also become increasingly apparent. For example, the presence of the throat in the carburetor device tends to restrict the flow of engine intake air and thus reduce the volumetric efficiency of the engine. Also, the carburetor device must be rather remotely positioned with respect to the individual engine cylinders and this in turn creates a difficult manifolding problem. Also, the optimum fuel mixing characteristic of the carburetor device occurs over a relatively narrow range of intake air flow velocities

and the low speed part throttle fuel economy is usually low.

In view of these and other limitations of venturi type carburetor devices, I have provided a new and improved engine fuel injection system which is particularly adapted to meet the present higher operating requirements of spark ignition, internal combustion engines. The fuel injection system of my instant invention is further characterized by its simplicity, its low operating pressures and its relatively low manufacturing cost.

The provision of an engine fuel injection system of the type referred to above being a principal object of my instant invention, another object of my invention is to provide a new and improved fuel injection system which is capable of providing uniform distribution of combustible fuel throughout the various engine cylinders.

Another object of my instant invention is to provide a fuel injection system for an internal combustion engine of the continuous flow type which is adapted to supply the engine cylinders with a combustible spray of atomized fuel.

A further object of my invention is to provide a fuel injection system as set forth in the preceding object wherein each of the individual cylinders is provided with an air atomizing nozzle for supplying a controlled spray of atomized fuel thereto.

A further object of my present invention is to provide a fuel injection system including a plurality of air atomizing nozzles associated with the engine cylinders, as above set forth, wherein the operating fuel and air pressures in the system are relatively low.

A still further object of my invention is to provide a fuel metering unit as set forth in the preceding object wherein the component elements thereof have a minimum number of critical dimensions.

A further object of my invention is to provide an automatic metering unit for regulating the supply of liquid fuel for the atomizing nozzles of the fuel injection system referred to above, said metering unit being operative in response to certain of the operating parameters of the engine with which the fuel injection system is associated to supply the fuel requirements of the latter.

A further object of my invention is to provide an improved pumping unit adapted to be used with the fuel injection system referred to above for supplying the aforementioned atomizing nozzles with a supply of both fuel and air under relatively low pressures.

Another object of my invention is to provide a new and improved low pressure fuel injection system for use with a fuel combustion apparatus, said system being capable of providing a combustible, atomized charge of fuel throughout various operating conditions of the combustion apparatus.

Another object of my invention is to provide a fuel injection system as set forth in the preceding object which is simple in construction and which is relatively trouble-free during operation.

A further object is to provide a fuel injection system as set forth in the preceding object wherein each of the individual cylinders is provided with an air atomizing nozzle for supplying a controlled spray of atomized fuel thereto.

In carrying forth the foregoing objects, I have provided a fuel injection system comprising a diaphragm type fuel and air pump and an automatic fuel metering control unit including a first fuel metering mechanism which functions to control the rate of fuel delivery in response to engine speed variations. The control unit further includes a second metering mechanism which functions to control the rate of fuel delivery in response to engine manifold vacuum pressure variations or to variations in any other load sensitive parameter. The system further comprises a tuned intake system and individual air atomizing nozzles operatively associated with each engine cylinder. Conduit structure is provided for operatively interconnecting the various interacting elements of the system and this conduit structure comprises two principal portions adapted to conduct atomizing air and liquid fuel, respectively, from the fuel and air pump to the air atomizing nozzle.

The above mentioned metering unit is interposed in the liquid fuel portion of the conduit structure and the first metering mechanism thereof comprises a first pair of actuating diaphragms and a first fuel metering element, the latter being operatively connected to the former. The second metering mechanism of the metering unit comprises another pair of actuating diaphragms and another fuel metering element operatively connected thereto, the two metering elements being disposed in a passage which is conected in series with the liquid fuel conduit portion. The liquid fuel pressure on the downstream side of each of the metering mechanisms is caused to act on one side of the first pair of diaphragms and on both sides of the other pairs of diaphragms. Also, the liquid fuel pressure downstream of the first metering element and upstream from the second metering element is caused to act on the other side of the first pair of diaphragms. Since variations in fuel pressure in the vicinity of the atomizing nozzle on the upstream side thereof will be accompanied by corresponding variations in the fuel pressure acting on opposed sides of each of the two pairs of diaphragms, the fuel pressure differential across any one pair of diaphragms will remain substantially constant and therefore the loading on the individual pairs of diaphragms will remain balanced.

According to the presently disclosed embodiment of my invention, the discharge pressure of an engine driven speed sensor pump is applied to the first pair of diaphragms to actuate the same against the opposing fuel pressure and engine manifold pressure is applied to the other pair of diaphragms to actuate the latter against an opposing spring pressure. The engine manifold pressure and the speed sensor pump pressure are caused to act on one side of the individual diaphragm while the fuel pressure acts on the other side thereof. There is therefore no problem of sealing the pressurized fuel from the working chambers which contain the speed sensor pressure and the engine manifold pressure.

For the purpose of more particularly describing these and other features of my instant invention, reference will be made to the accompanying drawings wherein:

Figure 1 is a schematic representation of the entire fuel system of my instant invention as associated with a reciprocating internal combustion engine;

Figure 2 is a top plan view of the metering unit which forms a portion of the fuel system of my instant invention and which is schematically illustrated in Figure 1;

Figure 3 is a sectional view of the metering unit shown in Figures 1 and 2 and is taken along the section line 3—3 of Figure 2;

Figure 4 is a sectional view of the metering unit shown in Figures 1 and 2 and is taken along the section line 4—4 of Figure 2;

Figure 5 is a sectional view of the metering unit shown in Figures 1 and 2 and is taken along the section line 5—5 of Figure 2;

Figure 6 is a partial sectional view of the metering unit shown in Figures 1 and 2 and is taken along the section line 6—6 of Figure 2;

Figure 7 is a sectional view of the air atomizing nozzle operatively associated with each engine cylinder as schematically illustrated in Figure 1;

Figure 8 is a plan view of a diaphragm type fuel and air pump which forms a portion of the fuel system of Figure 1;

Figure 9 is a partial sectional view of the pump of Figure 8 and is taken along the section line 9—9 of Figure 8;

Figure 10 is a partial sectional view of the upper portion of the pump of Figure 8 and is taken along section line 10—10 of Figure 8; and

Figure 11 is a sub-assembly view showing one of the pairs of air valves which are used to control a flow of air to and from the air working chambers of the pump of Figure 8 and is taken along the section line 11—11 of Figure 9.

Referring first to the fuel control system as illustrated in Figure 1, a spark ignition, reciprocating, internal combustion engine is shown at **10** and it includes a plurality of engine cylinders situated in the upper portions **12** and **14** of the engine block. Intake manifold conduit structures are shown at **16** and **18** and they are adapted to communicate with the engine cylinders in the engine block portions **12** and **14**, respectively. A throttle valve may be mounted within the manifold conduit associated with each cylinder to control the delivery of the combustible charge to each cylinder, two of these valves being shown schematically at **20** and **22** in the manifold conduit structures **16** and **18**, respectively.

Each of the manifold conduit structures communicates with a common surge tank, shown at **24**, which receives intake air from a suitable conduit **26** and distributes the same evenly among the various manifold conduit structures. The intake conduit **26** is effective to interconnect the surge tank **24** and an intake air filter **28**, the filter **28** forming a part of the engine intake system. Another air delivery conduit **30** extends from the air filter **28** to the air intake side of the fuel and air pumping unit shown at **32**.

The fuel and air pumping unit **32** comprises separate fuel and air working chambers and each of the working chambers are provided with separate delivery conduits, the air working chamber having an air delivery conduit **34** and the fuel working chamber having a fuel delivery conduit **36**. The air working chamber is supplied with low pressure intake air by the aforementioned air conduit **30** and the fuel working chamber is supplied with liquid fuel from a suitable fuel storage tank, not shown, by means of a fuel supply conduit **38**. The air delivery conduit **34** communicates with branch air passages **40** in the vicinity of the manifold conduit structures **16** and **18**, each of the branch passages **40** communicating with a separate one of a plurality of air atomizing nozzles shown generally at **42**. The nozzles **42** are suitably fixed within the manifold conduit structures **16** and **18**. An air surge chamber **44** is interposed in the air line **34** and is effective to dampen undesirable surging or pulsating pressure variations at the downstream end of the air conduit **34**.

The fuel delivery conduit **36** is connected to the upper portion of a fuel metering unit shown generally at **46**. The fuel delivered by the fuel and air pumping unit **32** passes through the fuel delivery conduit **36** and the fuel metering unit **46** and then into fuel conduit **48** which extends to a plurality of branch fuel passages **50**, the individual ones of the branch passages **50** being connected to separate ones of the atomizing nozzles **42** as shown. A vapor trap **52** may be provided within the fuel conduit **48** for the purpose of removing any vaporized portion of the fuel before it enters the atomizing nozzles **42**. Vaporized fuel may pass from the vapor trap **52** through a suitable conduit **54** connected to the air supply conduit **30**, the vapor thereby being transferred to the intake side of the air working chamber of the fuel and air pumping unit **32**.

An engine driven speed sensor pump is shown at **56** and a pair of fluid passages **58** and **60** interconnect the speed sensor pump **56** with the upper portion of the fuel metering unit **46**, the conduit **58** being connected to the high pressure side of the speed sensor pump **56** and the conduit **60** being connected to the low pressure side.

A vacuum pressure conduit 62 interconnects the lower portion of the fuel metering unit 46 with branch vacuum passages 64, each of the passages 64 communicating with individual ones of the manifold conduit structures on the downstream side of the associated throttle valves, two of which are shown at 20 and 22 as previously described. The speed sensor pump is effective to provide the fuel metering unit 46 with an engine speed signal for initiating fuel metering adjustments to compensate for varying fuel requirements of the engine as the engine speed varies over the operating speed range. The vacuum passage 62 and the branch passages 64 provide the fuel metering unit 46 with an engine load signal to initiate metering adjustments which will compensate for varying fuel requirements of the engine as the engine load is increased or decreased. The structural details and the mode of operation of the fuel metering unit 46 will be particularly set forth below.

An accelerator pump may be provided as indicated at 66 and it may be supplied by the fuel delivery conduit 36. A fuel discharge conduit for the acceleration pump 66 is provided at 68 and it communicates with the fuel conduit 48 thereby providing a bypass passage around the fuel metering unit 46. Acceleration pump 66 may be actuated by the engine throttle linkage mechanism, not shown, in the conventional manner. Similar acceleration pumps are provided on most automotive type venturi carburetors and they are effective to provide an instantaneous charge of liquid fuel to facilitate acceleration and starting of the engine. Reference may be had to the copending application of T. M. Ball, Serial No. 378,001, and now Patent No. 2,757,914 granted Aug. 7, 1956, for a description of one form of accelerator pumping mechanism which would be acceptable for these purposes. This copending application is assigned to the assignee of my instant invention.

Referring next to Figures 2, 3, 4, 5, and 6, it is seen that the fuel metering unit 46 comprises two principal portions. The first portion, shown at 70, may be identified as a speed sensing unit, and the other portion, shown at 72, may be identified as a load sensing unit. By preference the load sensing unit 72 is bolted in concentric relationship with respect to the speed sensing unit 70 as shown to form a composite integral assembly, a jacket member 73 being interposed between the mating surfaces of the individual units. The speed sensing unit 70 comprises three concentrically disposed housing portions 74, 75, and 76 which may be secured in axially stacked relationship by means of bolts 78 as shown. Openings 80 and 82 may be formed in the housing portions 74 and 76, respectively, and they are adapted to communicate with a through passage 84 formed in the housing portion 75.

The juxtaposed surfaces of the housing portions 74 and 75 may be provided with centrally disposed recesses 86 and 88, respectively, to form a pair of fluid working chambers. A flexible diaphragm 90 may extend across the recesses 86 and 88 and may be secured about its periphery between the adjacent surfaces of housing portions 74 and 75.

The juxtaposed surfaces of the housing portions 75 and 76 may similarly be recessed as shown at 92 and 94. Another flexible diaphragm 96 may be disposed across the recess 92 and 94 and may be secured about its periphery between the adjacent surfaces of the housing portions 75 and 76. A pair of backup plates 98 and 100 is situated on the opposed sides of the diaphragm 96 and similar backup plates 102 and 104 are situated on the opposed sides of the diaphragm 90. A connecting stem member 106 extends through a central aperture 108 formed in the housing portion 75 and it includes a shoulder portion 110 on the upper end thereof against which the backup plate 102 is seated. The lower end of the member 106 may be peened over, as shown at 112, for the purpose of retaining the backup plate 100. The member 106 is received within a bushing 114 which is slidably disposed in the housing aperture 108 and which serves as a spacer element for retaining the backup plates 98, 100, 102, and 104 in a fixed, spaced relationship, the diaphragms 90 and 92 thereby being permitted to operate in tandem as a unitary assembly.

A fitting 116 is threadably received in a threaded opening 118 formed in the housing portion 74. An annular shoulder 120 is formed on the fitting 116 and a suitable closure element 122 is interposed between the shoulder element 120 and the top of the housing portion 74 to provide a fluid tight connection. The fitting 116 further comprises an externally threaded stem portion 124 which may be centrally bored as shown at 126. A fluid flow restricting orifice 128 is formed at the base of the centrally bored opening 126 and it provides restricted communication between fuel delivery conduit 36 and the chamber 86 above the flexible diaphragm 90. The fluid delivery conduit 36 may be secured to the stem portion 124 of the fitting 116 in a conventional manner. A metering element 130 is slidably received in bored opening 126 and it is provided with an extension 132 which is adapted to progressively restrict the orifice 128. A pin 134 may be carried by and formed integrally with the aforementioned connecting member 106 and is extended through the orifice 128, the diameter of the pin 134 being substantially less than the diameter of the orifice 128. Upon movement of the diaphragms 90 and 96 in a vertical direction, the pin 134 is effective to lift the metering element 130 to provide for an increased flow of fuel from the fuel delivery conduit 36 into the chamber 86 above the diaphragm 90. The sides of the metering element 130 may be provided with flat portions 136 to permit the free passage of liquid fuel through the bored opening 126.

As best seen in Figure 5, the chamber 88 on the lower side of the diaphragm 90 is connected to the fluid conduit 58 extending from the high pressure side of the speed sensor pump 56 through a branch passage 142 extending laterally through the side of the housing portion 75, a suitable fitting 144 being provided to accommodate a fluid tight connection at this point.

As best seen in Figure 4, the fluid conduit 60 extending from the low pressure side of the speed sensor pump 56 is connected to the chamber on the upper side of the diaphragm 96 through a branch passage 146 formed transversely through a wall of the housing portion 75, a suitable fitting 148 being provided to accommodate a fluid tight connection at this point.

The engine load sensor unit 72 comprises three housing portions 150, 152, and 154 which are situated in concentric, axially stacked relationship as shown, and which are secured together by means of bolts 156. The head portion 158 of the bolt 156 is preferably received within a recess 160 formed in the upper surface of the housing portion 150 and the lower housing portion 154 may be provided with suitable threads for receiving the threaded portion 162 of the bolts 156. The lower housing portion 154 may be provided with a bored opening 164 and the housing portions 150 and 152 may be provided with through passages 166 and 168 which may be axially aligned with the bored opening 164 to form one continuous passage through the load sensor unit 72.

The upper surface of the housing portion 152 and the juxtaposed lower surface of the housing portion 150 are recessed, as shown at 170 and 172 respectively, to define an upper and a lower chamber. The chamber 122 of the load sensor unit is in fluid communication with the chamber 94 of the speed sensor unit through an opening 145 as shown. A flexible diaphragm 174 is disposed across the recesses 170 and 172 for the purpose of separating the upper and lower chambers and it may be secured at its periphery between the adjacent surfaces of the housing portions 150 and 152. The lower surface of the housing portion 152 and the upper surface of the housing portion 154 may be recessed, as shown at 176 and 178 respectively, to define another pair of upper and lower chambers which may be separated by a flexible diaphragm 180. The diaphragm 180 may be secured about its periphery between the adjacent surfaces of the housing portions 152 and 154. A stem 182 is slidably received through a central opening 184 formed in the housing portion 152. The upper end of the stem 182 is provided with a reduced diameter portion 186 which may be received through a pair of diaphragm backup plates 188 and 190 situated on either side of the flexible diaphragm 174. The outer end of the reduced diameter portion 186 may be peened over for the purpose of securing in place the diaphragm assembly comprising the backup plates 188 and 190 and the diaphragm 174. The lower end of the shaft 182 is provided with a reduced diameter portion 192 which may be received through diaphragm backup plates 194 and 196 situated on either side of the flexible diaphragm 180. A shoulder member 198 is secured to the end of the reduced diameter portion 192 for securing in place the diaphragm assembly consisting of the backup plates 194 and 196 and the diaphragm 180. The chamber 178 formed on the lower side of the diaphragm 180 includes a well 200 and a central opening 202 is formed in the lower wall of the housing portion 154 between the well 200 and the exterior of the load sensor unit 72. A peripheral cavity is formed about the interior wall of the opening 202 and the inward portion of the opening 202 is threaded as shown at 206.

A metering mechanism for the load sensor unit 72, as best seen in Figure 3, comprises an elongated substantially cylindrical body portion 208 which may be threadably received in the opening 202 formed in the housing portion 154, the upper end of the body portion 208 being threaded as shown at 210. An opening 212 extends axially through the housing portion 208 and it communicates at the upper end thereof with an enlarged diameter portion 214 within which is received an orifice element 216. The orifice element 216 is formed with a precalibrated orifice 218 and it is held in position by means of a cap member 220 which is threadably received on the upper end of the body portion 208. A tapered metering rod 222 extends through the orifice 218 and it is adapted to contact the shoulder member 198 carried by the vertically movable stem 182. The metering rod 222 is provided with a progressively increasing transverse dimension and is effective to progressively restrict the orifice 218 upon movement thereof in an axial direction. The metering pin 222 is carried by a movable metering element 224 which is slidably received within the opening 212. The metering element 224 comprises a reduced diameter portion 226 and two axially spaced bearing portions 228 and 230, the latter portion being formed with flat side surfaces 232 and 234, respectively, to permit the passage of fluid through the opening 212. The metering element 224 is biased in an upward direction by a spring 236 which is received within the lower portion of the opening 212 and which is seated on a closure member 237 threadably received in the lower end of the housing portion 208. A spring element 237 is interposed between the backup plate 196 of the lower diaphragm assembly and the lower surface of the well 200 for the purpose of normally biasing the diaphragms 174 and 180 in an upward direction.

The housing portion 208 is provided with transversely extending ports 238 which interconnect the peripheral recess 204 in the housing portion 154 with the central opening 212 formed in the body portion 208 of the metering mechanism. The peripheral recess 204 also communicates with a branch passage 240 formed in the housing portion 154 and the passage 240 in turn communicates with the opening 164, as shown in Figure 3. By preference, the passage 240 may be formed by a drilling operation in which the drilling tool is inserted radially inward from the side of the housing portion 154 and a plug 242 may be inserted in the end of the passage 240 after the drilling operation is completed.

The passage 166 formed in the housing portion 150 of the load sensor unit 72 communicates with the opening 82 in the housing portion 76 of the speed sensor unit 70 through a branch passage 244 and the opening 80 formed in the housing portion 74 of the speed sensor unit 70 communicates with the fluid chamber 86 above the flexible diaphragm 90 through a passage 246. The chamber 86 is therefore in fluid communication with the peripheral recess 204 formed in the housing portion 154 of the load sensor unit 72.

As best seen in Figure 4, the fluid chamber 178 below the flexible diaphragm 180 is in fluid communication with the fluid chamber 172 above the flexible diaphragm 174 through passages 248 and 250 formed in the housing portion 150 of the load sensor unit 72, through passage 252 formed in the housing portion 152 and through passages 254 and 256 formed in the housing portion 154. Also the fluid chamber 170 below the flexible diaphragm 174 is in fluid communication with the vacuum line 62. Also the fluid chamber 170 below the flexible diaphragm 174 communicates with the vacuum line 62 through a side passage 255 formed in the housing portion 152 of the load sensor unit 72, the vacuum line 62 communicating with the intake manifold conduit structure for the engine as previously described. Also the fluid chamber 178 below the flexible diaphragm 180 communicates with the fuel conduit 48 through the side passage 252 formed in the housing portion 154 of the load sensor unit 72, the fuel conduit communicating with the atomizing nozzles 42 as previously described. Suitable fittings 257 and 259 may be provided for accommodating a fluid tight connection between the load sensor unit 72 and each of the conduits 62 and 48 respectively.

As best seen in Figure 5, the fuel chamber 176 above the flexible diaphragm 180 communicates with the exterior of the metering unit 46 through a vent passage 258.

Referring next to Figure 6, a bypass passage 260 is formed in the upper wall of the housing portion 74 of the speed sensor unit 70 and it communicates at one end thereof with the opening 126 formed in the stem 124 of the fitting 116. A groove 262 and a port 264 may be provided in the fitting 116, as shown to effect this fluid communication. An adjustable metering pin 266 is positioned within the bypass passage 260, as shown, and it includes a threaded body portion 268 and a shank portion 270, the latter extending externally of the housing portion 74. A spring 272 is interposed between a head 274 of the shank portion 270 and the housing portion 74 to maintain the metering pin 266 at a constant setting. The metering pin 266 may be manually adjusted to provide a controlled bypass flow of fuel from the opening 126 of the fitting 116 to the chamber 86.

As best seen in Figure 7, the nozzle 42 comprises a main body portion 276 having an extension 278 and a conically formed nose 280. An axially extending portion 282 is formed in the body portion 276 and is provided with internal threads 284 to accommodate the externally threaded nozzle element 286. The nozzle element 286 extends rearwardly, as shown at 288, and is provided with a fluid fitting 290 which may be suitably connected to the branch fuel passages 50 communicating with the fuel passage 48, as previously described. The forward portion of the nozzle element 286 is centrally bored, as shown at 292, for the purpose of receiving a shank 294 of an adaptor element 296. A radial shoulder 298 is formed about the adaptor element 296 and a spacer element 300 is situated between the nozzle element 286 and the shoulder 298. The forward end of the adaptor 296 is formed with a substantial conical face 302 having a plurality of grooves 304 which extend from the center of the conical face 302 to the portion of the opening 282 surrounding the adaptor element 296. The forward end of the nozzle nose 280 is provided with a circular opening 306 of reduced diameter which receives a circular nozzle element 308 having a concave conical lateral surface 310 against which the conical surface 302 of the adaptor element 296 is positioned. The other lateral side of the nozzle element 308 is provided with an annular pilot shoulder 312 which is positioned against an internally directed flange 314 at the forward end of the nose 280. A central orifice 316 is formed in the nozzle element 308 and is countersunk as shown at 318 and 320.

A flat surface 322 formed on the conical adaptor element and the central portion of the conical surface 310 of the nozzle element 308 define a swirl chamber which is effective to mix liquid fuel with atomizing air to produce an atomized spray of liquid fuel which is ejected outwardly through the orifice 316. This swirl chamber communicates with a hollow interior 324 of the adaptor element 296 through a passage 326. The hollow interior 324 communicates with a longitudinal central opening 328 formed in the extension 288 of the nozzle element 286. The branch passages 50 of the fuel line 48, as shown in Figure 1, may be connected to the fitting 290 on the extension 288 for the purpose of providing the nozzle 42 with a supply of liquid fuel.

A suitable casing 330 may be threadably received on the externally threaded extension 278 of the nozzle body 276, as shown in Figure 7 by means of phantom lines. The casing 330 may include a closure wall portion 332 having an axial opening 334 through which the extension 288 of the nozzle element 286 may be received. A suitable seal may be provided between the adjacent surfaces of the extension 288 and the closure wall 332 as shown at 334. A portion of the engine manifold wall through which the nozzle body portion 276 is received is shown by means of phantom lines at 336. The casing 330 and a peripheral shoulder 338 on the body portion 276 are disposed at opposite sides of the manifold wall 336 thereby securing the nozzle assembly in place. A fitting 338 may be provided, as shown, within the wall of the casing 330 for providing communication between branch air conduits 40 and the interior 340 of the casing 330. The portion of the opening 282 surrounding the adaptor element 296 within the nozzle body portion 276 communicates with the interior 230 of the casing 330 through axially extending passages 342 formed in the nozzle element 286.

The fuel and air pumping unit 32 is shown in more particular detail in Figures 8 through 11 and it comprises a main body portion 350 having a first working chamber 352 formed at the upper portion thereof and a spring chamber 354 formed at the lower portion. A transversely extending side opening 356 is provided, as shown, and it is adapted to receive an arm 358 of a pump actuator lever 360. The lever 360 is pivoted at 362 within the opening 356 and the arm 358 is adapted to contact a central shaft or stem 364 which is slidably received within a vertically disposed opening 366 in the housing body portion 350. The upper end of the stem 364 is secured to an air diaphragm assembly comprising a flexible diaphragm member 368 and a pair of diaphragm backup plates 370 and 372 disposed on either side of the diaphragm member 368. A washer element 373 is adapted to be retained on the upper end of the shaft 364 by means of a press fit thereby preventing axial movement of the lements of the diaphragm assembly.

A housing cap member 374 may be secured to the housing body portion 350 by suitable bolts 376 and it may be formed with a second air working chamber 378, the diaphragm member 364 being secured about its periphery between the adjacent surfaces of the housing cap portion 374 and the housing body portion 350. A spring 380 is interposed between the air diaphragm assembly and the housing cap portion 374 and is effective to bias the diaphragm assembly and the stem 364 in a downward direction.

The housing cap portion 374 is provided with a pair of air valves 382 and 384, as shown in Figure 10, which comprise apertured discs 386 and 388, respectively. The air valve 386 further includes a cage 390 within which a movable valve disc 392 is housed. A pin 394 is secured to the disc 386 and is effective to retain the cage 390 in place. The air valve 384 is similarly provided with a cage 396, a movable valve washer 398 and a retaining pin 400.

The valve 386 is disposed within an air inlet passage 402 and the valve 384 is disposed within an air outlet passage 404. These passages 402 and 404 extend from the air working chamber 378 and communicate with branch inlet and outlet passages 406 and 408, as shown in Figure 8, which in turn communicate with the common air delivery conduit 34.

The air working chamber 352 is similarly provided with inlet and outlet air valves, one of which is shown in phantom at 410 in Figure 9. These additional valves are disposed in air inlet and outlet passages 412 and 414 which are formed in an auxiliary casting 416, as shown in Figure 11. The air passages 412 and 414 communicate with branch air passages 418 and 420, respectively, which communicate with the common air delivery conduit 34 as shown in Figure 1. The casting 316 may be secured to the housing body portion 350 in any suitable manner.

A fuel diaphragm assembly is formed across the spring chamber 354 in the housing body portion 350 and it comprises a flexible fuel diaphragm 422 and diaphragm backup plates 424 and 426. The diaphragm stem 428 is secured to the fuel diaphragm assembly and extends vertically through a sealed opening 430 into the opening 356. The upper end of the stem 428 is attached to the arm 358 of the lever 360 by a lost motion connection, as shown at 432.

A lower casting 434 is secured to the bottom side of the housing body portion 350 by means of suitable bolts 436 and the fuel diaphragm 422 is secured about its periphery between the adjacent surfaces of the lower casting 434 and the housing body portion 350. A fuel working chamber 438 is formed in the lower casting 434 below the fuel diaphragm 422 and it communicates with a fuel outlet passage 440 through a fuel outlet valve, not shown. The fuel chamber 438 also communicates with a fuel inlet port through a suitable inlet fuel valve, not shown. The inlet and outlet valves for the fuel chamber 438 may be similar in construction to the above described air valves 382 and 384. The outlet port 440 communicates with the previously described fuel delivery conduit 36 and the inlet port communicates with the previously described fuel conduit 30.

A spring 442 is interposed between the fuel diaphragm and the upper portion of the spring chamber 354 and it is effective to normally bias the fuel diaphragm assembly in a downward direction to provide a working stroke for the latter.

The lever 360 is provided with a cam follower element 444 which may be adapted to contact a mating cam element formed on the camshaft of the internal combustion engine 10.

The operation of my invention is as follows:

The engine 10 is supplied with intake air through the intake air duct 26, the surge tank 24 being effective to evenly distribute the air among the individual manifold conduits communicating with the various engine cylinders. The throttle valves associated with each of the individual manifold conduits may be actuated by means of a conventional throttle linkage mechanism.

During the operation of the engine, the engine crankshaft is effective to oscillate the lever 360 of the fuel-air pump 32 thereby positively actuating the air diaphragm assembly and the fuel diaphragm assembly in a vertically upward direction against the opposing forces of the air spring 380 and the fuel spring 442 respectively. As the air diaphragm assembly is moved vertically, high pressure air is discharged through the air outlet valve 384 to the air conduit 34 and air is supplied simultaneously to the air working chamber 352 through the air inlet valve associated with the air inlet passage 410. When the upward stroke of the air diaphragm assembly is terminated, the air spring 380 is effective to pump air from the air working chamber 352 through the air outlet valve associated with the air outlet passage 414 while the air working chamber 378 is being supplied with a fresh charge of low pressure air through the air inlet valve 382.

It is thus apparent that the air pumping portion of the fuel-air pump 32 is double-acting and the length of the working stroke is dependent upon the pressure which exists in the working chamber 352. When the pressure in the working chamber 352 is increased to a value which is sufficient to partially compress the air spring 380, the air diaphragm assembly will not be returned to its lowest position and only partial working strokes will thereafter be effected. This variable displacement feature adapts the fuel-air pumping unit to supply air at a substantially constant pressure which is independent of engine speed.

The fuel diaphragm assembly is similarly actuated by the lever 360 as it is oscillated about its pivot 362. As the diaphragm stem 428 is lifted vertically by the arm 358, fuel is admitted through the fluid fuel inlet valve into the working chamber 438 and as the stem 428 is moved vertically downward under the influence of the fuel spring 442, fuel is discharged from the working chamber 438 through the fuel outlet valve. The fuel pressure delivered by the fuel pumping portion of the fuel-air pump 42 is substantially constant by virtue of the substantially constant force exerted by the fuel spring 442. The downward working stroke of the stem 428 of the fuel diaphragm assembly is independent of the lever 360 by virtue of the lost motion connection provided at 432. It will be readily observed that the variable displacement feature above described with reference to the air pumping portion of the fuel-air pump 32 applies equally well to the fuel pumping portion thereof since the pressure of the fuel within the working chamber 438 following one working stroke will determine the length of the following working stroke.

Atomizing air is delivered by the fuel-air pump 32 to the nozzles 42 through the conduit 34 and surge chamber 44 and through branch passages 40 as previously described. The air then enters the interior of casing 330, as shown in Figure 7, through fitting 338 and passes through axially extending passages 342 to the space surrounding the nozzle adaptor element 296. The air then passes through the grooves 304 toward the central nozzle axis and then enters the swirl chamber adjacent the orifice 316.

As the fuel-air pump 32 delivers liquid fuel to the fuel metering unit 46 through the fuel conduit 36 as above described, the fuel passes from conduit 36 through the fitting 116 into the fluid chamber 86 of the speed sensor unit 70. The fuel then passes through passages 246, 80, 84, 82, 244, 166, 168, 72, 240 and then into the recess 204 formed in the housing portion 154 of the load sensor 72. The fluid then passes through ports 238 into the interior opening 212 in the body portion 208 of the load sensor metering mechanism. The fluid is then directed in a vertically upward direction through the central opening 212. The fuel passes through the orifice 218 and enters the fluid chamber 178 below the flexible diaphragm 180.

In passing through the elongated opening 212, the fuel approaches a substantially steady state which is free of localized turbulence. Accordingly, the metering characteristics of the orifice 218 is not subjected to undesirable variations during operation.

The metered fuel then passes from the fluid chamber 178 to the fuel delivery line 48 through the passage 252. The fuel reaches each of the individual nozzles 42 through branch passages 50 and it is then conducted through the nozzle elements 286 and adaptor 296 to the above-described swirl chamber, the hollow interior of the adaptor 296 communicating with the swirl chamber through orifice 326 as previously mentioned. The fuel is atomized in the swirl chamber and the atomized fuel and air mixture is discharged into the associated engine combustion chamber through the discharge orifice 316 of each nozzle.

Upon an increase in engine speed, the engine driven speed sensor pump 56 is effective to increase the magnitude of the pressure in fluid chamber 88 with respect to the magnitude of the pressure in fluid chamber 92. Therefore, the force acting in an upward direction on coupled diaphragms 90 and 96 becomes greater than the downward force acting thereon. The metering element is then lifted vertically in the passage 126 by the rod 134 and the restriction at the orifice 128 is accordingly lessened. This permits an increased quantity of fuel to enter the fluid chamber 86 and the flow of fuel to the nozzle 42 is correspondingly increased to meet the increased fuel consumption requirements of the engine.

When the engine load is increased, the engine throttle valves are moved to a more fully opened position and the engine intake manifold vacuum is reduced. The vacuum existing in chamber 170 therefore decreases by virtue of the connection with the intake manifold provided by the vacuum line 62 and branch conduits 64. The spring 237 therefore biases the coupled diaphragms 180 and 174 in a vertically upward direction and this in turn permits the spring 236 to move the tapered metering rod 222 vertically upward thus reducing the degree of fluid restriction provided by the orifice 218. This decrease in the fluid restriction is accompanied by an increase in the flow of fuel to the nozzles 42 thereby accommodating the increased fuel consumption requirements due to the increased engine load.

When the engine speed and engine load are both changed simultaneously, the metering mechanism associated with the speed and load sensor units are effective to make independent appropriate adjustments, as above described, and the total metered flow passing through the metering unit to the nozzle will be of a correct magnitude so that the fuel requirements of the engine are effectively met under any operating condition.

The coupled diaphragms 90 and 96 of the speed sensor unit 70 are subjected to fuel pressure which creates a force that opposes and balances the force produced by the pressure differential across the speed sensor pump 56, the fuel pressure acting on the upper surface of diaphragm 90 being greater than the pressure of the metered fuel acting on the lower surface of diaphragm 96. As the engine speed changes, the corresponding variation in pressure differential across the speed sensor pump 56 causes an unbalance in the forces acting on the coupled diaphragms 90 and 96 thereby causing compensating adjustments of the metering element 136. After the coupled diaphragms have assumed a new balanced position, the fuel pressure existing in the chamber 86 will be higher or lower depending upon whether or not the metering element 136 is moved vertically upward or downward. This change in fuel pressure in chamber 86 will not be accompanied by an equal change in the fuel pressure in fluid chamber 94 because the pressure drop across metering orifice 218 will be greater if the rate of flow of fuel through the metering unit increases or will be smaller if the rate of fuel flow through orifice 218 increases, the pressure in chamber 94 being equal to the metered fuel pressure in chambers 178 and 172. Therefore, the metering element 136 of the speed sensor unit 70 will assume a definite stabilized position for any given set of operating conditions for the engine 10.

The position of the metering pin 222 is not affected by changes in the magnitude of the fuel pressure in any of the fluid chambers of the metering unit because, as readily observed from the drawings, the pressure acting on the upper surface of the diaphragm **174** is equal to the pressure acting on the lower surface of the diaphragm **180**.

If it is assumed that the engine load changes while the engine speed remains constant, the metering pin **222** will make appropriate adjustments in the rate of fuel flow as previously described. However, if the metering pin **222** moves vertically upward or downward upon a change in engine load to provide for a change in the rate of fuel supply, the pressure within the fluid chambers **178**, **172** and **94** will not change since the change in back pressure at the orifice **218** is transmitted back to the speed sensor unit and causes a change in the pressure ratio across the speed sensor diagraphms. This in turn adjusts the metering element **130** until the pressure differential across the speed sensor diaphragms is again restored. The flow of fuel past the orifice **128** will be increased or decreased depending upon whether the adjustment of the metering element **130** is vertically upward or downward. Although the pressure drop across the metering orifice **218** is a function of the rate of flow of fluid passing therethrough, the metering pin **222** is calibrated so that the effect of the change in the effective area of the metering orifice will substantially compensate and counteract the effect of the change in the rate of flow through the orifice **218**. Thus, although the flow of fuel through the orifice **218** may be changed upon a variation in load, the pressure drop thereacross remains substantially constant by virtue of the corresponding change in the effective area of the orifice which is produced as the metering pin **222** moves upwardly.

If the flow of fuel to the nozzle **42** is changed under a given set of operating conditions to such an extent that the back pressure on the nozzle is changed, a corresponding change in pressure takes place in the chambers **178**, **172**, **94**, and **86**. Therefore, the pressure differential across the coupled diaphragms **90** and **96** and across the coupled diaphragms **174** and **180** will remain constant although the aboslute pressure may change. The metering characteristics of the speed sensor unit and the load sensor unit are therefore not affected by variations in fuel pressure in the vicinity of the nozzles.

If the engine speed changes without a corresponding change in engine load, an appropriate adjustment in the speed sensor metering element **130** will take place as above described. This will in turn cause an increase in the flow of fuel through the load sensor unit to the nozzles, and the back pressure on the upstream side of the nozzles will increase. This modified back pressure also exists in chamber **172** thereby tending to urge the diaphragm **174** in a downward direction, as viewed in the drawings, to supplement the biasing force produced by reason of the engine speed signal. The accompanying adjustment of the metering element **130** which occurs by reason of this supplementary biasing force tends to restore the pressure differential across the diaphragms **90** and **96** and across the load sensor orifice thereby compensating for the increase in back pressure on the upstream side of the nozzle. It is thus seen that the speed sensor unit is effective to meet the changed fuel requirements accompanying a change in speed and that it is insensitive to changes in the back pressure in the system. Therefore any condition which might give rise to a change in back pressure such as a faulty nozzle or a plugged fuel passage extending to one or more of the nozzle orifices, will not cause a change in the metering characteristics of the metering units.

By way of further explanation of the above feature, it is emphasized that the loading on the movable portions of the speed sensor mechanism will remain substantially constant regardless of the position of the speed sensor metering element providing the engine speed remains constant. Furthermore, the design of the metering element for the load sensor is such that the pressure drop thereacross will at all times remain constant regardless of the position of the same as above explained, by reason of the increased fuel flow which is accommodated by the speed sensor as load adjustments are made. It therefore follows that the load sensor and the speed sensor mutually cooperate to schedule a flow of fuel through the nozzles so that the fuel rate directly reflects the engine fuel demands. Stated in another way, a change in fuel metering rate by the load sensor due to a change in engine load will be sensed by the speed sensor, and the latter automatically makes compensating adjustments so that the net change in fuel delivery is precisely that which is demanded by the engine by reason of its changed load. Similarly, the load sensor senses changes in the speed sensor setting due to changes in engine speed, and it functions to make automatic self-compensating adjustments, the net change in fuel delivery being equal to that which the engine requires by reason of the changed engine speed.

The chamber **176** is vented to atmosphere, as previously described, thereby accommodating the exit and the entry of air displaced by the diaphragm **180** as the latter is vertically adjusted.

By preference, I have formed the diaphragms for the speed sensor unit with relatively large diameters in order to increase the sensitivity of the unit and to make a relatively small pressure range for the speed sensor pump possible.

It is apparent that no serious sealing problem is encountered with the presently disclosed metering unit since the liquid fuel is separated at all times from the speed sensor and vacuum chambers by means of a flexible diaphragm.

I contemplate that other types of speed sensor pressure sources may be provided in lieu of the speed sensor pump **56**. For example, the high pressure conduit **58** and the low pressure conduit **60** may be connected respectively to the high pressure side and the low pressure side of the engine coolant pump for the engine, the coolant pump pressure differential being a function of the square of the engine speed.

By preference, the metering rod for the metering mechanism of the load sensor unit is actuated in response to manifold vacuum, as above described. However, I contemplate that other means may also be provided for actuating the metering pin to vary the rate of fuel delivery. For example, a suitable connection between the engine throttle and the metering pin may be provided for the purpose of actuating the latter in response to throttle movement. Also, a suitable exhaust manifold temperature responsive actuator means may be provided for adjustably positioning the metering pin in the desired position as the engine load varies.

I have designed the presently disclosed fuel system to operate at very low pressure. The fuel and air pumping unit is effective to maintain a substantially constant discharge pressure of about 15 or 20 p. s. i. and the fuel pressures which exist in the vicinity of the nozzles may be as low as 3 to 5 p. s. i. The nozzles are effective to provide substantially complete atomizing of the liquid fuel at these low pressures throughout the entire operating range of the engine.

The provision of an independent nozzle for each engine cylinder and the location of the individual nozzles in proximate relationship with respect to the engine cylinders makes possible an immediate response of the engine to sudden changes in throttle position and it also assures better fuel distribution.

The individual intake manifold conduits for each of the engine cylinders may be adapted to provide a tuned air induction system which will produce a power peak in the mid speed range of the engine. The length of the individual manifold conduits may be varied as desired, depending upon the power characteristics which are required.

I have disclosed the speed sensor unit and the load sensor unit as part of a unitary assembly. However, I contemplate that the load sensor unit and the speed sensor unit may comprise individual and separate units in which the chamber 172 of the load sensor unit is connected to the chamber 94 of the speed sensor unit by means of a suitable fluid conduit.

What I claim and desire to secure by United States Letters Patent is:

1. In a fuel injection system for an internal combustion engine, said engine having a plurality of engine cylinders and individual manifold conduits communicating with each cylinder; a plurality of air atomizing nozzles, individual ones of said nozzles having discharge portions communicating with each of said manifold conduits, a fuel and air pumping unit, first conduit means for conducting fuel from said pumping unit to said nozzles, second conduit means for conducting atomizing air from said pumping unit to said nozzles, and a fuel metering mechanism disposed in said first conduit means for regulating the rate of flow of fuel from said pumping unit to said nozzles, said metering mechanism being operative in response to variations in certain of the operating parameters of said engine to provide a controlled flow of fuel to said nozzles to compensate for corresponding variations in the fuel requirements of the engine.

2. In a fuel injection system for a liquid fuel combustion apparatus, said combustion apparatus having a plurality of fuel combustion chambers, and individual manifold conduits communicating with each combustion chamber; a plurality of air atomizing nozzles, individual ones of said nozzles having discharge portions communicating with each of said manifold conduits, a fuel and air pumping unit, first conduit means for conducting fuel from said pumping unit to said nozzles, second conduit means for conducting atomizing air from said pumping unit to said nozzles, and a fuel metering mechanism disposed in said first conduit means for regulating the rate of flow of fuel from said pumping unit to said nozzles, said metering mechanism being operative in response to variations in certain of the operating parameters of said combustion apparatus to provide a controlled flow of fuel to said nozzles to compensate for corresponding variations in the fuel requirements of the combustion apparatus.

3. In a fuel injection system for an internal combustion engine, said engine having a plurality of engine cylinders and individual manifold conduits communicating with each cylinder; a plurality of air atomizing nozzles, individual ones of said nozzles having discharge portions communicating with each of said manifold conduits, a fuel and air pumping unit, first conduit means for conducting fuel from said pumping unit to said nozzles, second conduit means for conducting atomizing air from said pumping unit to said nozzles, a fuel metering mechanism disposed in said first conduit means for regulating the rate of flow of fuel from said pumping unit to said nozzles, an engine speed sensor means, first conduit structure connecting one portion of said metering mechanism with said speed sensor means, and other conduit structure connecting the manifold conduits for said cylinders with another portion of said metering mechanism, said metering unit being responsive to variations in engine speed and manifold vacuum pressure to provide a controlled flow of fuel to said nozzle to compensate for corresponding variations in the fuel requirements of the engine.

4. In a fuel injection system for an internal combustion engine, said engine having a plurality of engine cylinders and intake manifold structure communicating with said cylinders, a plurality of air atomizing nozzles, individual ones of said nozzles having discharge portions communicating with said minfold structure, separate ones of said nozzles being disposed closely adjacent each of said cylinders, a fuel and air pumping unit, first conduit means for conducting fuel from said pumping unit to said nozzles, second conduit means for conducting atomizing air from said pumping unit to said nozzles, a fuel metering mechanism disposed in said first conduit means for regulating the rate of flow of fuel from said pumping unit to said nozzles, an engine speed sensor means, first conduit structure connecting one portion of said metering mechanism with said speed senor means, and other conduit structure connecting the manifold structure for said cylinders with another portion of said metering mechanism, said metering mechanism being responsive to variations in engine speed and engine load to provide a controlled flow of fuel to said nozzles to compensate for corresponding variations in the fuel requirements of the engine.

5. In a fuel injection system for a fuel combustion apparatus, said combustion apparatus having a driven power output member and having a plurality of fuel combustion chambers with intake manifold structure communicating with said combustion chamber; a plurality of air atomizing nozzles, individual ones of said nozzles having discharge portions communicating with said manifold structure, separate ones of said nozzles being disposed closely adjacent each of said combustion chambers, a fuel and air pumping unit, first conduit means for conducting fuel from said pumping unit to said nozzles, second conduit means for conducting atomizing air from said pumping unit to said nozzles, a fuel metering mechanism disposed in said first conduit means for regulating the rate of flow of fuel from said pumping unit to said nozzles, an engine speed sensor means, first conduit structure connecting one portion of said metering mechanism with said speed sensor means, and other conduit structure connecting the manifold structure for said combustion chambers with another portion of said metering mechanism, said metering mechanism being responsive to variations in the driven speed of said power output member and to the magnitude of the output load to provide a controlled flow of fuel to said nozzles to compensate for corresponding variations in the fuel requirements of the combustion apparatus.

6. The combination as set forth in claim 4 wherein said manifold structure includes a plurality of throttle valves for controlling the passage of intake air to said cylinders and wherein said first conduit means comprises an accelerator pump means for bypassing said metering unit, said accelerator pump means being operatively connected to said throttle valves and adapted to be actuated upon movement of said throttle valves to supply said nozzles with an immediate charge of fuel, said engine thereby responding immediately upon a sudden change in throttle position.

7. The combination as set forth in claim 4 wherein said second conduit means includes a surge chamber for reducing pulsating air pressure variations in the vicinity of said nozzles.

8. In a fuel injection system for an internal combustion engine having intake manifold structure and having at least one air atomizing fuel nozzle disposed in said manifold structure, a fuel delivery conduit and an air delivery conduit each communicating with said atomizing fuel nozzle; a metering mechanism disposed in said fuel delivery conduit comprising an engine speed sensor portion and an engine output load sensor portion, a first control means for providing an engine speed signal and a second control means for providing an engine load signal, said first control means including conduit structure connected with said speed sensor portion and said second control means including conduit structure connected with said sensor portion, each of said sensor portions including a fuel flow restricting means disposed in and forming a portion of said fuel delivery conduit, said speed sensor portion being adapted to control the rate of fuel delivery to said fuel nozzle in response to variation in engine speed and said load sensor portion being adapted to control the rate of fuel delivery to said fuel nozzle in response to variations in engine output load.

9. In a fuel injection system for an internal combustion engine having an intake manifold structure and having

at least one air atomizing fuel nozzle disposed in said manifold structure; a fuel delivery conduit and an air delivery conduit communicating with said atomizing fuel nozzle, a metering system disposed in said fuel delivery conduit, said metering system including at least one fuel metering orifice disposed in and forming a portion of said fuel delivery conduit, and control means for adjusting the effective area of said orifice to control the flow of fuel through said fuel delivery conduit, said control means being operative in response to variations in at least one of the operating parameters for said engine.

10. In a fuel injection system for an internal combustion engine having an intake manifold structure and having a plurality of air atomizing fuel nozzles disposed in said manifold structure, a fuel delivery conduit and an air delivery conduit communicating with said air atomizing fuel nozzle; a metering system disposed in said fuel delivery conduit, said metering system including two fuel metering orifices disposed in and forming a portion of said fuel delivery conduit, a first control means for adjusting the effective area of one of said orifices and a second control means for adjusting the effective area of the other of said orifices, said first control means being operative in response to variations in engine speed and said second control means being operative in response to variations in engine load.

11. The combination as set forth in claim 10 wherein said second control means is operative in response to variations in engine manifold pressure.

12. The combination as set forth in claim 10 wherein said first control means includes an engine driven speed sensor pump, a diaphragm actuator mechanism including a movable diaphragm member, an orifice restricting element adapted to be actuated by said diaphragm member, and conduit structure connecting one side of said diaphragm member to the high pressure side of said speed sensor pump and connecting the opposite side of said diaphragm member to the low pressure side of said speed sensor pump.

13. The combination as set forth in claim 10 wherein said first control means includes an engine driven speed sensor pump, a diaphragm actuator mechanism, an orifice restricting element adapted to be adjusted by said diaphragm member, and conduit structure interconnecting said diaphragm actuator mechanism and said speed sensor pump to provide for the actuation of the former.

14. The combination as set forth in claim 10 wherein said second control means includes a movable diaphragm member, said diaphragm member partly defining a vacuum pressure chamber, an orifice restricting element adapted to be actuated by said diaphragm member, and conduit structure interconnecting said pressure chamber and said manifold structure.

15. A control unit for use in combination with a fuel injection system, a housing, a first pair of coupled diaphragms, each diaphragm of said first pair separately defining in part a first and a second pressure chamber and a third and a fourth pressure chamber respectively on opposed sides thereof, a second pair of coupled diaphragms, each diaphragm of said second pair separately defining in part a fifth and a sixth pressure chamber and a seventh and an eighth pressure chamber respectively on opposed sides thereof, a fuel inlet passage in said first chamber, a first flow restricting orifice communicating with said first chamber, a metering element disposed in proximate relationship with respect to said first flow restricting orifice and adapted to be moved relative to said orifice by said first pair of coupled diaphragms, a fluid passage connecting said first and said eighth chamber, a second flow restricting orifice in said fluid passage, another metering element disposed in proximate relationship with respect to said second flow restricting orifice and adapted to be moved relative to said orifice by said second pair of diaphragms, and a fuel outlet passage in said eighth chamber, said fourth chamber, said fifth chamber and said eighth chamber being in fluid communication.

16. In a fuel injection system for an internal combustion engine having an intake manifold, at least one air atomizing fuel nozzle secured to said manifold, fuel and air delivery conduits communicating with said nozzle, a speed sensor pump drivably connected to said engine, and a metering unit disposed in said fuel delivery conduit; said metering unit comprising a housing, a first pair of coupled diaphragms, each diaphragm of said first pair separately defining in part a first and a second pressure chamber and a third and a fourth pressure chamber respectively on opposed sides thereof, a second pair of coupled diaphragms, each diaphragm of said second pair separately defining in part a fifth and a sixth pressure chamber and a seventh and an eighth pressure chamber respectively on opposed sides thereof, a fuel inlet passage in said first chamber communicating with said fuel delivery conduit, a first fuel metering mechanism comprising a first flow restricting orifice providing communication between said first chamber and said inlet passage, a metering element disposed in proximate relationship with respect to said first flow restricting orifice and adapted to be moved relative to said orifice by said first pair of coupled diaphragms, a fluid passage connecting said first and said eighth chamber, another fuel metering mechanism including a second flow restricting orifice in said fluid passage, another metering element disposed in proximate relationship with respect to said second flow restricting orifice and adapted to be moved relative to said orifice by said second pair of diaphragms, a fuel outlet passage in said eighth chamber, said fourth chamber, said fifth chamber and said eighth chamber being in fluid communication, conduit means interconnecting said sixth chamber and said intake manifold, and other conduit means for connecting said second and said third chamber with the high pressure side and the low pressure side of said speed sensor pump respectively, the seventh chamber being vented to the atmosphere.

17. In a fuel injection system for an internal combustion engine having an intake manifold, at least one air atomizing fuel nozzle secured to said manifold, fuel and air delivery conduits communicating with said nozzle, a speed sensor pump drivably connected to said engine, and a metering unit disposed in said fuel delivery conduit; said metering unit comprising a housing, a plurality of pressure chambers in said housing, a first diaphragm means having portions disposed in at least one of said pressure chambers, a first fuel metering mechanism in said housing providing communication between said fuel delivery conduit and said one chamber, conduit means for subjecting said first diaphragm means to speed sensor pump pressure to bias the same in one direction, diaphragm means being biased in the opposite direction by fuel pressure thereby balancing the force produced by the speed sensor pump pressure, a second diaphragm means in said housing having portions disposed in at least one other of said plurality of pressure chambers, passage means connecting said one and said other pressure chambers, a second fuel metering mechanism disposed in said passage means, a fluid outlet connection providing communication between said other pressure chamber and said fuel delivery conduit, other conduit means for subjecting said second diaphragm means to manifold pressure for biasing the same in one direction, spring means for biasing said second diaphragm means in the opposite direction, said first metering mechanism including a first fuel metering orifice and a first metering element for progressively restricting said first orifice, said first metering element being adapted to be controlled and moved relative to said first metering orifice by said first diaphragm means, said second metering mechanism including a second fuel metering orifice and a second metering element for progressively restricting said second orifice, said second metering element being adapted to be contacted and

moved relative to said second metering orifice by said second diaphragm means.

18. The combination as set forth in claim 17 wherein passage means are provided for subjecting either of opposed sides of said second diaphragm means and one side of said first diaphragm means to the fuel pressure existing on the downstream side of said second metering mechanism, the other side of said first diaphragm being subjected to the fuel pressure existing in said one chamber.

19. The combination as set forth in claim 17 wherein said second metering mechanism includes a metering assembly comprising a body portion, a central passage formed in said body portion communicating with said passage means, said second metering orifice being formed at one end of said central passage, said second metering element being slidably disposed in said opening, means for biasing said second metering element toward said second diaphragm, a tapered pin formed on said metering element and extending through said second metering orifice, the pressure drop across said second metering orifice remaining substantially constant as said tapered pin is moved relative to said second metering orifice.

20. The combination as set forth in claim 16 wherein said first chamber is further provided with a bypass passage means interconnecting the same with said fuel inlet passage, said bypass passage means including a manually adjustable flow restricting element to control the rate of bypass fuel flow.

21. A fuel metering device for providing a controlled flow of fuel from a fuel passage to a fuel chamber comprising a body portion, a flow metering passage formed in said body portion, a calibrated metering orifice formed in one portion of said metering passage for accommodating a controlled flow from said fuel passage to said fuel chamber, a fuel metering element having a guide portion slidably disposed in said metering passage on the upstream side of said orifice, said metering element including an elongated tapered pin positioned on the upstream side of said orifice and extending through the same, and spring means for biasing said metering element toward said orifice, said fuel passage communicating with said metering passage at an axially spaced distance from said metering orifice.

22. The combination as set forth in claim 21 wherein the transverse dimension of said tapered pin is greater on the downstream side of said orifice than on the upstream side thereof.

23. A fuel metering device for providing a controlled flow of fuel from a fuel passage to a fuel chamber comprising a body portion, a flow metering passage formed in said body portion, a fuel metering element slidably disposed in said metering passage, a calibrated metering orifice formed in said metering passage for accommodating a controlled flow from said metering passage to said fuel chamber, said metering element including an elongated tapered pin extending through said orifice, spring means for biasing said metering element toward said orifice, said fuel passage communicating with said metering passage at an axially spaced distance from said metering orifice, the transverse dimension of said tapered pin being greater on the downstream side of said orifice than on the upstream side thereof, and means for moving said metering pin relative to said metering orifice to provide a controlled flow of fuel through said orifice, the pressure drop across said orifice being substantially constant for all positions of said metering pin.

24. In a fuel injection system for an internal combustion engine, said engine having a plurality of engine cylinders, manifold structure having individual conduit portions communicating with each engine cylinder for supplying the same with a combustible charge, a separate fuel and air atomizing nozzle disposed in each conduit portion, fuel and air pumping means for supplying said nozzles with liquid fuel and air, said nozzles being effective to produce an atomized spray of liquid fuel, control means for regulating the rate of fuel delivery to said nozzles, and throttle valve means including portions disposed in each conduit portion for regulating the delivery of the combustible charge for each engine cylinder.

25. In a fuel system for a liquid fuel combustion apparatus having at least one fuel combustion chamber and at least one induction manifold conduit for accommodating the flow of a fuel and air combustible mixture to said combustion chamber, a throttle valve mounted in said conduit for controlling the rate of delivery of said combustible mixture, an air atomizing liquid fuel nozzle having an ejection portion communication with said conduit on the upstream side of said throttle valve, and conduit means having one portion for supplying said nozzle with liquid fuel and another portion for supplying said nozzle with fuel atomizing air.

26. In a fuel system for a liquid fuel combustion apparatus having at least one fuel combustion chamber and at least one induction manifold conduit for accommodating the flow of a fuel and air combustible mixture to said combustion chamber, a throttle valve mounted in said conduit for controlling the rate of delivery of said combustible mixture, an air atomizing liquid fuel nozzle having an ejection portion communicating with said conduit on the upstream side of said throttle valve, conduit means having one portion for supplying said nozzle with liquid fuel and another portion for supplying said nozzle with fuel atomizing air, and means for regulating the rate of delivery of liquid fuel in response to variations in at least one operating parameter of said combustion apparatus.

27. In a fuel system for a liquid fuel combustion apparatus having at least one fuel combustion chamber and at least one induction manifold conduit for accommodating the flow of a fuel and air combustible mixture to said combustion chamber, a throttle valve mounted in said conduit for controlling the rate of delivery of said combustible mixture, an air atomizing liquid fuel nozzle having an ejection portion communication with said conduit on the upstream side of said throttle valve, conduit means having one portion for supplying said nozzle with liquid fuel and another portion for supplying said nozzle with fuel atomizing air, and regulator valve means for regulating the rate of delivery of liquid fuel through said one conduit portion including a flow restricting valve opening forming a part of said one conduit portion, a flow metering valve registering with said opening to vary the degree of restriction of the latter, and means for adjustably positioning said flow metering valve with respect to said valve opening in response to variations in an operating parameter of said combustion apparatus.

28. The combination as set forth in claim 27 wherein said regulator valve means further includes a second valve opening situated in and forming a part of said one conduit portion in series with said first-named valve opening, a second flow metering valve registering with said second metering opening, and means for adjustably positioning said flow metering valve with respect to said second opening in response to variations in another operating parameter of said combustion apparatus.

29. In a fuel system for an internal combustion engine having an intake manifold, a liquid fuel nozzle having an ejection portion communicating with said intake manifold, a liquid fuel conduit communicating with said nozzle for supplying the same with liquid fuel, a regulator valve means including a pair of metering orifices situated in series and forming a part of said liquid fuel conduit, a first metering element registering with one of said orifices and a second metering element registering with the other of said orifices, engine load sensitive means for adjustably positioning said first metering element with respect to said one orifice and engine speed sensitive means for adjustably positioning said second metering element with respect to said other orifice.

30. In a fuel system for an internal combustion engine having an intake manifold, an air atomizing liquid fuel nozzle having an ejection portion communicating with said intake manifold, conduit means including a liquid fuel conduit portion communicating with said nozzle for supplying the same with liquid fuel and an air conduit portion for supplying said nozzle with fuel atomizing air, a regulator valve means including a pair of metering valve openings situated in series in and forming a part of said liquid fuel conduit portion, a first valve element registering with one of said openings and a second valve element registering with the other of said openings, engine load sensitive means for adjustably positioning said first valve element with respect to said one orifice and engine speed sensitive means for adjustably positioning said second valve element with respect to said other valve opening, said second valve element being upstream from said first valve element.

31. In a fuel system for an internal combustion engine having a fuel combustion chamber and an intake manifold conduit for accommodating the delivery of a combustible mixture to said combustion chamber, an air atomizing liquid fuel nozzle having an ejection portion situated in said manifold conduit, a throttle valve mounted in said manifold conduit on the downstream side of said nozzle, conduit means including a first portion for supplying said nozzle with liquid fuel and a second portion for supplying said nozzle with fuel atomizing air, regulator valve means including first and second fuel metering valve openings situated in series in said conduit portion, a first and a second valve element respectively registering with said first and said second valve openings for variably adjusting the rate of flow through the latter, and movable wall structure operatively associated and movable with said first valve element, said wall structure defining in part a first fuel chamber communicating with said first conduit portion intermediate said valve opening, said wall structure also defining in part a second fuel chamber communicating with said first conduit portion on the downstream side of said second valve opening.

32. In a fuel system for an internal combustion engine having a fuel combustion chamber and an intake manifold conduit for accommodating the delivery of a combustible mixture to said combustion chamber, an air atomizing liquid fuel nozzle having an ejection portion situated in said manifold conduit, a throttle valve mounted in said manifold conduit on the downstream side of said nozzle, conduit means including a first portion for supplying said nozzle with liquid fuel and a second portion for supplying said nozzle with fuel atomizing air, regulator valve means including first and second fuel metering valve openings situated in series in said conduit portion, a first and a second valve element respectively registering with said first and said second valve openings for variably adjusting the rate of flow through the latter, movable wall structure operatively associated and movable with said first valve element, one side of said wall structure being subjected to the fuel pressure on the downstream side of said first valve opening and the other side of said wall structure being subjected to the fuel pressure on the downstream side of said second valve opening.

33. In a fuel system for an internal combustion engine having a fuel combustion chamber and an intake manifold conduit for accommodating the delivery of a combustible mixture to said combustion chamber, an air atomizing liquid fuel nozzle having an ejection portion situated in said manifold conduit, a throttle valve mounted in said manifold conduit on the downstream side of said nozzle, conduit means including a first portion for supplying said nozzle with liquid fuel, and a second portion for supplying said nozzle with fuel atomizing air, regulator valve means including a first and a second fuel metering valve opening situated in series in the first portion of said conduit means, a first and a second valve element respectively restricting said first and said second valve openings for variably adjusting the rate of flow through the latter, engine speed sensitive means for adjustably positioning said first valve element with respect to said first valve opening, engine load sensitive means for adjustably positioning said second metering valve element with respect to said second valve opening, and movable wall structure operatively associated and movable with said first valve element, said wall structure defining in part a first fuel chamber communicating with said first portion of said conduit means intermediate said valve openings and a second fuel chamber communicating with said first portion of said conduit means on the downstream side of said second valve opening.

34. In a fuel system for a liquid fuel combustion apparatus comprising an induction manifold conduit, a liquid fuel nozzle having an ejection portion communicating with said manifold conduit, a throttle valve movably mounted in said manifold conduit on the downstream side of said nozzle, a liquid fuel conduit communicating with said nozzle for supplying the latter with liquid fuel, fuel flow regulator means in said fuel conduit comprising a first and a second valve opening forming a part of said fuel conduit, first and second valve members cooperating with said first and second valve openings respectively for variably restricting the same, means for adjustably positioning one of said valve members in response to variations in one operating parameter of said apparatus and means for adjustably positioning the other of said valve members in response to variations in another operating parameter of said apparatus, and means responsive to the pressure differential across said second valve opening for varying the position of said one valve member independently of said one operating parameter.

35. The combination as set forth in claim 34 wherein said first valve opening is upstream from said second valve opening.

36. A liquid fuel metering system for a fuel combustion apparatus comprising a fuel pressure source, a gas atomizing liquid fuel nozzle forming a part of said combustion apparatus, conduit structure interconnecting said pressure source and said nozzle, a metering mechanism interposed in said conduit structure, said metering mechanism including a pair of metering valve openings situated in series and forming a portion of said conduit structure, first and second valve elements registering with said valve opening, a movable wall defining a pair of opposed fuel chambers, said first valve element being operatively associated and movable with said movable wall and adjustably positioned thereby, one of said fuel chambers communicating with one side of the downstream valve opening and the other fuel chamber communicating with the other side of the downstream valve opening thereby subjecting said movable wall to a pressure differential for adjustably positioning the same.

37. A liquid fuel injection system for an internal combustion engine having an intake manifold structure and having a plurality of gas atomizing fuel nozzles for supplying said manifold structure with a charge of combustible fuel; a fuel delivery conduit communicating with said nozzles, a fuel metering mechanism disposed in said delivery conduit, said metering mechanism including a pair of metering valve openings situated in series and defining a part of said conduit, first movable valve structure having portions registering with one of said valve openings, second movable valve structure having portions registering with the other of said valve openings, said second valve opening being downstream from said first valve opening, control means for adjustably positioning each of said valve structures in response to variations in separate operating parameters of said engine, and means for subjecting another portion of said first valve structure to the fuel

pressure differential existing across said second valve opening.

38. In a fuel system for an internal combustion engine having intake manifold structure and having at least one gas atomizing fuel nozzle disposed in said manifold structure: a fuel delivery conduit and an air delivery conduit communicating with said air atomizing fuel nozzle, a fuel metering mechanism situated in said fuel delivery conduit for scheduling the flow of fuel to said nozzle, said metering mechanism comprising a fuel metering means with separate portions being disposed in series in said conduit for regulating the rate of fuel delivery to said engine in accordance with the engine fuel requirements, each of said separate portions being responsive to variations in separate operating parameters of said engine, and means for subjecting one of said separate portions to the fuel pressure differential existing across the other separate portion, said one separate portion being responsive to said pressure differential to complement the fuel metering effort produced by its associated operating parameter.

References Cited in the file of this patent

UNITED STATES PATENTS

1,149,322	Baker	Aug. 10, 1915
1,627,727	Charter	May 10, 1927
1,662,040	Lee	Mar. 6, 1928
1,725,066	Egersdorfer	Aug. 20, 1929
2,033,211	Tice	Mar. 10, 1936
2,117,380	Walters	May 17, 1938
2,488,250	Williams	Nov. 15, 1949
2,511,213	Leslie	June 13, 1950
2,697,007	Wille	Dec. 14, 1954

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,863,433

December 9, 1958

Jorma O. Sarto

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 19, for "conected" read -- connected --; column 5, line 64, for "recess" read -- recesses --; column 9, line 65, for "lements" read -- elements --; column 13, line 14, for "diagraphms" read -- diaphragms --; line 39, for "aboslute" read -- absolute --; column 15, line 69, for "minfold" read -- manifold --; column 20, lines 12 and 39, for "communication", in each occurrence, read -- communicating --.

Signed and sealed this 5th day of May 1959.

(SEAL)

Attest:

KARL H. AXLINE

Attesting Officer

ROBERT C. WATSON

Commissioner of Patents