

- [54] **FUEL INJECTION APPARATUS IN AN
INTERNAL COMBUSTION ENGINE**
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|-----------|---------|---------------------|------------|
| 2,995,125 | 8/1961 | Powell et al..... | 123/139 AW |
| 3,026,928 | 3/1962 | Phillips et al..... | 123/139 AW |
| 3,125,084 | 3/1964 | Hall | 123/139 AW |
| 3,168,084 | 2/1965 | Simonet..... | 123/139 AW |
| 3,286,998 | 11/1966 | Mennesson | 123/139 AW |
| 3,288,445 | 11/1966 | Mennesson | 123/139 AW |
| 3,470,858 | 10/1969 | Mycroft | 123/139 AW |
| 3,669,081 | 6/1972 | Mompetit | 123/139 AW |

FOREIGN PATENTS OR APPLICATIONS

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123/140 MP, 123/140 FG, 123/140 MC
[51] **Int. Cl.**.....F02m 39/00, F02m 31/12, F02d 1/08
[58] **Field of Search**....123/139 E, 139 AW, 140 MP,
123/140 FG, 140 MC, 119 R, 32 EN, 32 AE

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|-----------|--------|-------------|-----------|
| 1,228,832 | 3/1960 | France..... | 123/139 E |
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[56] **References Cited**

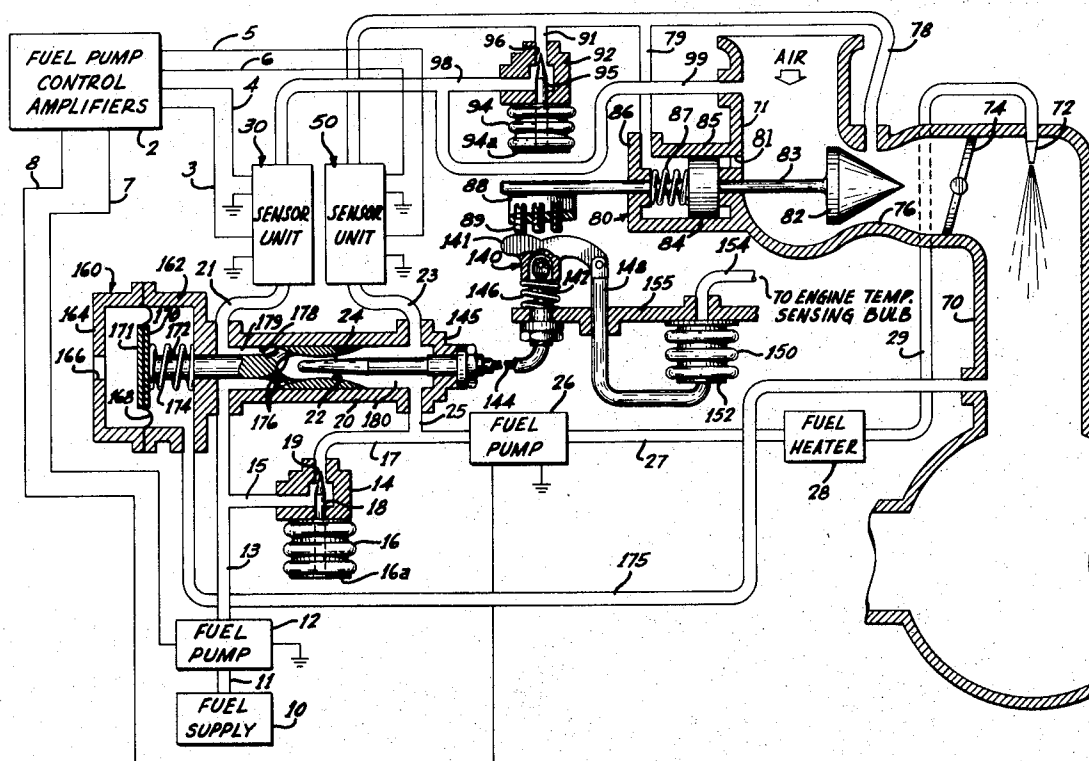
UNITED STATES PATENTS

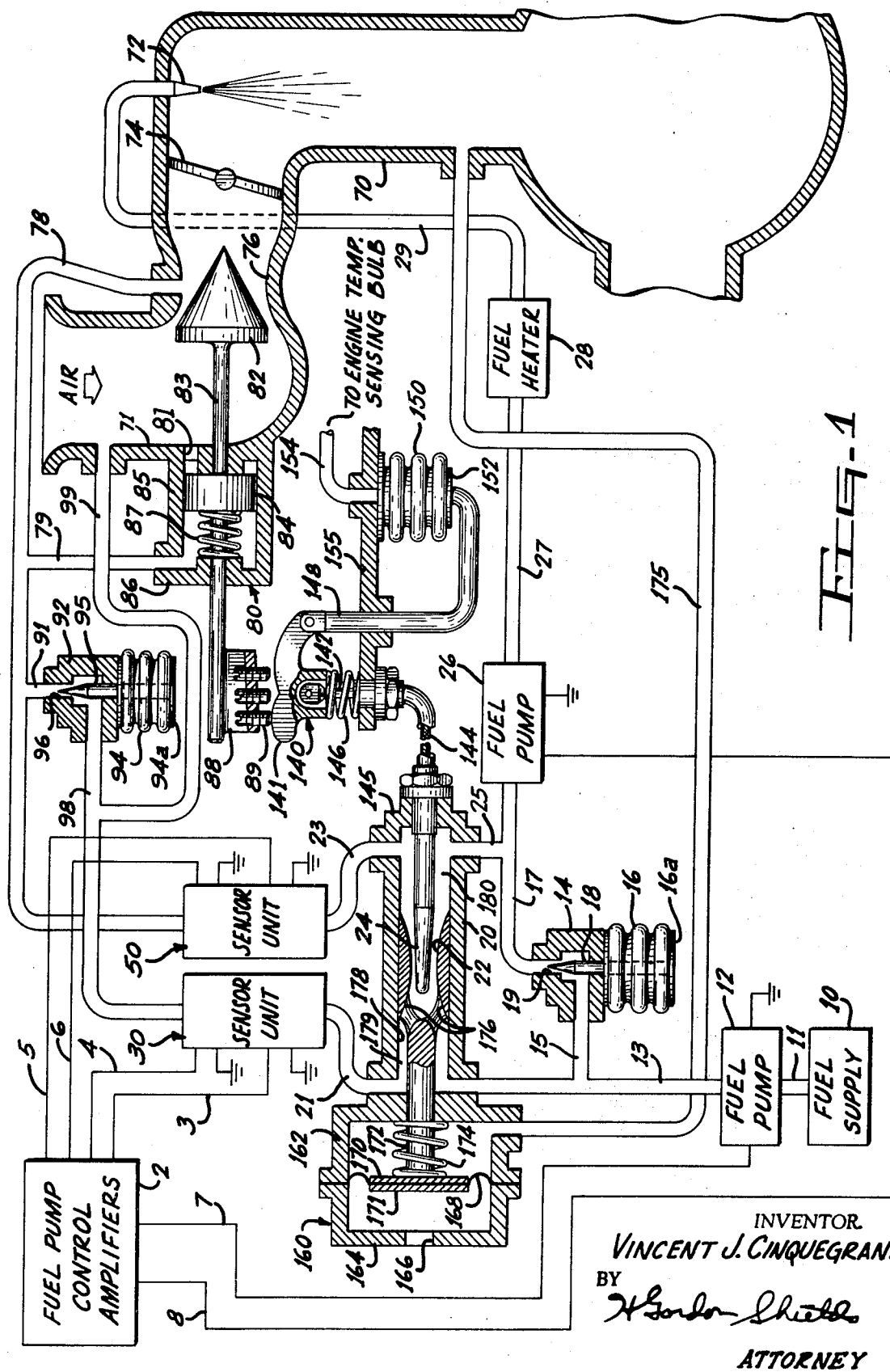
- | | | | |
|-----------|---------|----------------|------------|
| 1,835,615 | 12/1931 | Robert..... | 123/139 AW |
| 2,442,399 | 6/1948 | Chandler | 123/139 AW |
| 2,687,123 | 8/1954 | Parsons..... | 123/139 AW |

[57] ABSTRACT

Fuel metering apparatus includes a variable venturi and an air-fuel mixture ratio control system variable for a plurality of throttle settings.

54 Claims, 7 Drawing Figures





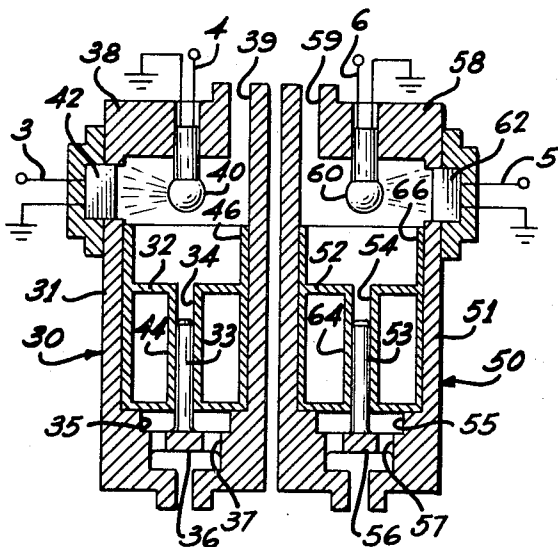


FIG. 2

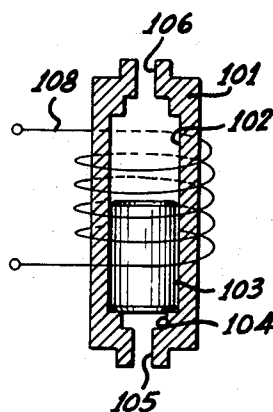


FIG. 3

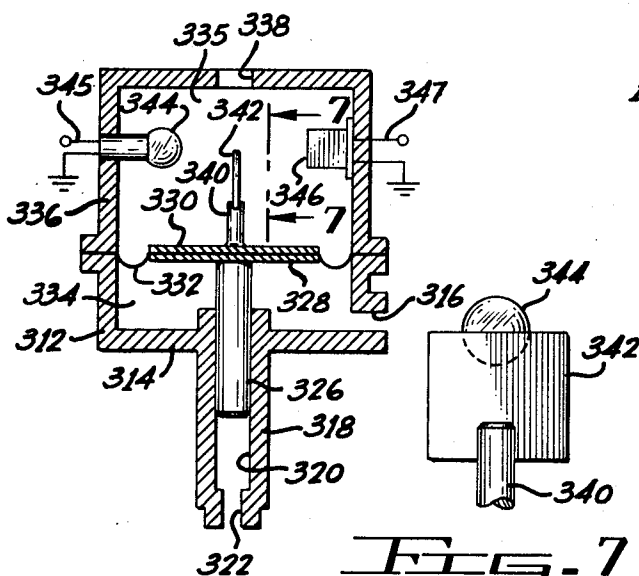


FIG. 6

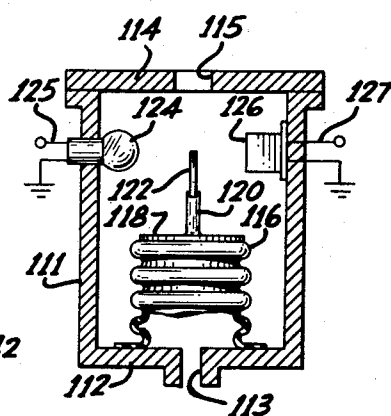


FIG. 7

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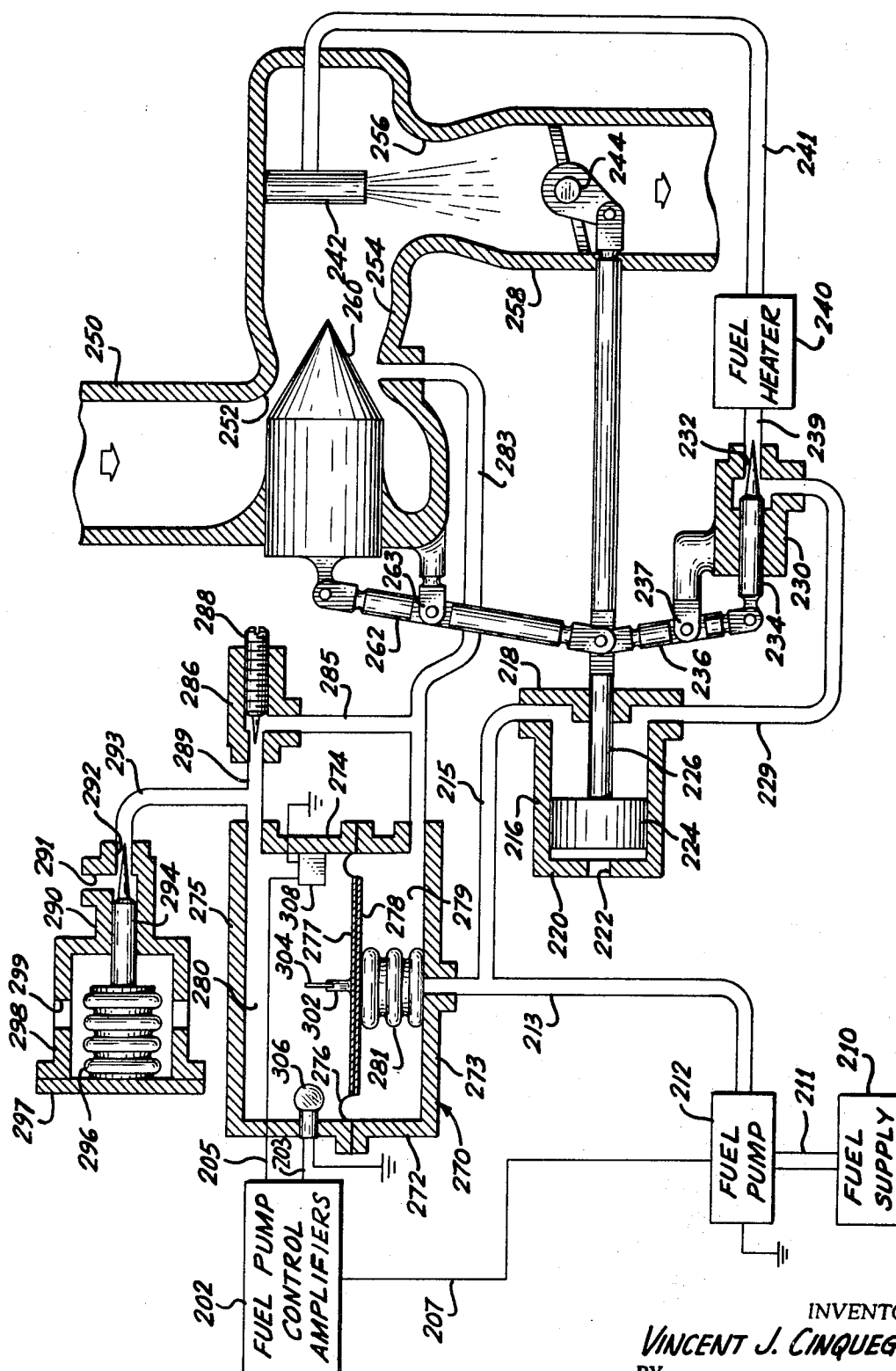


FIG-5

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FUEL INJECTION APPARATUS IN AN INTERNAL COMBUSTION ENGINE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an internal combustion engine and more particularly to apparatus for providing a mixture of fuel and air in a predetermined ratio in an internal combustion engine.

2. Description of the Prior Art

Fuel injection systems are generally concerned with the delivery of a mixture of fuel and air in the proper ratio into a chamber where combustion, the ignition of the fuel and air mixture, takes place. The sequential delivery of a proper quantity, and of a proper or predetermined ratio, of fuel and air into a plurality of combustion chambers or cylinders in an internal combustion engine has been a primary objective for fuel injection systems since soon after the invention of the internal combustion engine.

There are two primary means for forming a combustible charge, namely, carburetion and fuel injection. In carburetion charge forming, a quantity of fuel is mixed with a quantity of air in a predetermined ratio according to air flow, and the fuel-air mixture is then introduced into a manifold, or a plurality of manifolds from where the atomized fuel-air mixture or charge is drawn into the individual cylinders. Due to the design configurations of the manifolds, the inertia of the fuel molecules as compared to the air molecules, and the various distances from the carburetor to the individual cylinders, the charge taken into each of the cylinders usually varies both quantitatively and qualitatively. That is, the total volume of the charge varies from cylinder to cylinder and the fuel-air ratio varies from cylinder to cylinder. Moreover, since the metering of the fuel is determined by air flow, the fuel and air ratios are usually not correct over a wide range of speed and load conditions.

Fuel injection charge forming provides for the direct injection of a predetermined quantity of fuel to a quantity of air into a manifold at or adjacent to a cylinder, thus insuring substantially equal quantities of fuel and air in substantially the same ratio at each cylinder. The metering of the fuel in a fuel injection system is usually governed or controlled by some parameter or parameters other than air flow.

A problem of prior art fuel injection systems has been the provision of means for varying the fuel-air ratio accurately over a wide range of operating conditions demanded of an engine. For example, an engine is required to operate at an idling speed and at various other speed and load conditions and under various acceleration and deceleration requirements. There are optimum or desired fuel-air ratios for various operating speeds, and there may be an optimum or a minimum amount of air required to properly atomize the fuel for proper combustion for the various operating speed and load conditions of the engine.

The various embodiments of the present invention, as disclosed and claimed herein, provide for the proper fuel air ratios under a wide range of speed and load conditions imposed on an internal combustion engine.

SUMMARY OF THE INVENTION

This invention comprises fuel injection apparatus for an internal combustion engine. A variable venturi provides for the volumetric control of air into the engine and also for the metering of fuel through a fuel metering system into the engine. The fuel-air ratio is predeterminably variable for a plurality of throttle settings, permitting the fuel metering system to provide fuel to the engine in accordance with operating demands of the engine and volumetrically for best engine efficiency.

Included among the objects of the present invention are the following:

to provide a new and useful fuel injection system for an internal combustion engine;

to provide new and useful apparatus for metering fuel;

to provide new and useful variable venturi apparatus for controlling the flow of air in an internal combustion engine;

to provide new and useful apparatus for injecting fuel in an internal combustion engine;

to provide new and useful apparatus for controlling the flow of fuel in an internal combustion engine;

to provide new and useful apparatus for controlling the flow of air in an internal combustion engine; and

to provide new and useful apparatus for controlling the air-fuel ratio in an internal combustion engine.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic representation of an embodiment of the fuel injection apparatus of the present invention;

FIG. 2 is a schematic sectional illustrating an embodiment of fuel metering apparatus of the present invention;

FIG. 3 is another embodiment of fuel metering apparatus of the present invention;

FIG. 4 is another embodiment of fuel metering apparatus of the present invention;

FIG. 5 is a schematic representation illustrating another embodiment of the fuel injection system of the present invention;

FIG. 6 is another embodiment of fuel metering apparatus used in the present invention; and

FIG. 7 is a view taken along 7—7 of FIG. 6.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 discloses an embodiment of the fuel injection system which comprises the present invention. Broadly speaking, the fuel injection system comprises a fuel metering system, a variable orifice system which cooperates with the fuel metering system, and a variable venturi system for providing a variable amount of air according to the needs of the engine.

Fuel for the system originates with a fuel supply 10 and from the fuel supply it flows through a conduit 11 to a variable speed fuel pump 12. The control of the speed of the fuel pump, by fuel pump control amplifiers 10, is accomplished by a fuel metering system which includes sensor units 30 and 50 and fuel pump control amplifiers 2. From the fuel pump 10, the fuel flows through conduit 13 to variable orifice housing 20,

which includes a pair of chamber 179 and 180, and an orifice 22 which separates the chambers. From the variable orifice housing 20, the fuel flows through another conduit 25 to a second fuel pump 26, which is again a variable speed fuel pump, controlled by the fuel metering system, and through conduit 27 to fuel heater 28, and then through conduit 29 for delivery to a fuel nozzle 72 within intake manifold 70 downstream or below the throttle 74.

A fuel conduit 15 branches from fuel conduit 13 and provides a bypass of the variable orifice housing 20. The fuel flows from conduit 15 through a valve body 14 and through orifice 19 into conduit 17 and to the junction of conduit 17 with conduit 25 prior to flowing through the second fuel pump 26. Within valve housing 14 is a needle valve 18 which is moved in and out of orifice 19 according to movement of bellows 16. The bellows 16 is a sealed unit which is secured at one end to valve body 14. The other end of the bellows moves according to the fluctuations in the temperature and pressure of the ambient air. Needle valve 18 is secured to the movable wall of bellows 16 and its position within orifice 19 accordingly varies with the movement of the bellows and in accordance with fluctuation in the temperature and pressure of the ambient air. The needle valve 18 comprises a tapered needle valve and the size of the orifice accordingly varies with the position of the needle valve 18 within the orifice 19.

Variable orifice housing 20 includes a pair of conduits 21 and 23 communicating with chamber 179 and 180, respectively, within the orifice housing on opposite sides of the orifice 22, which will be described in detail below. The orifice 22, movable within housing 20, divides the interior of the housing into the two chambers, 179 and 180. Sensor unit 30 receives a flow of fuel through conduit 21 and sensor unit 50 receives a flow of fuel through conduit 23. The flow of fuel from chamber 179 to sensor unit 30 and from chamber 180 to sensor unit 50 is proportional to the fuel flow across the orifice 22. This flow is directly related to the pressure differential across the orifice as manifested within sensor units 30 and 50. The sensor units 30 and 50 are shown in block form in FIG. 1 and are disclosed in detail in FIG. 2.

Sensor units 30 and 50 are of substantially the same size and are substantially the same with respect to their design. However, they function just the opposite from each other with respect to the sensing of the fuel flowing therein and to the control of the fuel output of the pumps 12 and 26 to which they are respectively connected. Sensor unit 30 is electrically connected to fuel pump control amplifiers 2 by connectors 3 and 4 and sensor unit 50 is similarly electrically connected to the fuel pump control amplifiers 2 by connectors 5 and 6. The amplifiers for the two units are similar in design but, as will be explained more in detail later, function opposite from each other with respect to the balancing of the fuel flow across orifice 22 and within the sensor units and of the fuel pumps to which the metering units are electronically connected and which they control. The fuel flow in the sensor unit 30, and therefore the sensor unit 30 and amplifiers in fuel pump control amplifiers 2 control the output of fuel pump 12 and the fuel flowing in the sensor unit 50, and accordingly, the unit itself and its amplifiers, is electronically connected to and controls the output of fuel pump 26.

Both sensor units 30 and 50 communicate with the interior of the variable orifice housing 20. Since the sensor units are on opposite sides of the orifice within the housing 20, and since the sensor units are directly above the housing and are of substantially the same size and same height, the flow of fuel within the sensing units is an indication of the fuel flowing across the orifice. Since the fuel flow across the orifice can be measured or can be indicated by the sensing units, it is accordingly possible to control the fuel flow through the orifice according to the fuel flow within the sensor units. This is accomplished by having sensor unit 30 electronically associated with fuel pump 12. The speed of fuel pump 12 is responsive to the amount of fuel flowing through the fuel pump and to chamber 179 of the variable orifice housing 20. Similarly, the speed of fuel pump 26 is responsive to the amount of the fuel flowing through the pump from the chamber 180 of the housing 20 and on to the nozzle 72 within the intake manifold 70. Under steady state conditions, or conditions of substantial equilibrium with respect to speed and load on the engine, both fuel pump 12 and fuel pump 26 would be flowing the same amount of fuel. However, upon demand from the engine either with respect to load or with respect to speed, and accordingly whether accelerating or decelerating, the fuel pumps would at least momentarily be out of balance with respect to their individual outputs according to the fuel flow across the orifice as indicated by the fuel flow to the sensor units 30 and 50. This will be explained in detail with reference to FIG. 2.

In FIG. 2 the sensor unit 30 includes a housing 31 which is preferably cylindrical in configuration. Within the housing is a float 32, the position of which within the housing 31 depends on the amount of fuel flowing into the housing by way of conduit 21 from chamber 179 of orifice housing 20. The float 32 moves up and down, according to the fuel within the housing, on guide rod 33 which is located within a central bore 34 of the float. The float 32, at its lower position, as shown in FIG. 2, rests on interior shoulder 35 on the bottom portion of the housing 31. The lower wall 36 of the housing 31 is situated below the shoulder 35 and it includes a plurality of orifices 37 through which fuel flows from conduit 21 to the interior of the housing 31. Guide rod 33 is secured to lower end wall 36. The housing 31 is closed at its top by upper end wall 38. Disposed through an aperture in the upper end wall 38 is a light source 40. Light sensitive means, such as photo cell 42, are located adjacent light source 40 through an aperture in the housing 31. The float 32 includes a float cavity 44 on the interior thereof, and it also includes a top flange 46. The top flange extends above the body of the float in the manner of an inverted piston skirt. The float 32 is not in a tight fitting relationship with respect to the interior of the housing 31, but for accuracy and ease of movement of the float according to the flow of the fuel within the housing, it is in a rather loose or sloppy fitting relationship with respect to the interior of the housing 31.

In operation, the light source 40 is illuminated by an appropriate current through conductor 4 and the fuel pump control amplifiers whenever the ignition switch of the internal combustion engine is turned on. The light sensitive means or photocell 42 is responsive to the illumination produced by the light source 40 for the

determination of a voltage output therefrom. As fuel flow from variable orifice housing 20 through conduit 21 to the interior of the sensor unit housing 31 increases, the float rises within the interior of the housing. As the float rises, the skirt or flange 46 is disposed between the light source 40 and the light sensitive means or photo cell 42, thus depriving the photo cell of a portion of the illumination from the light source. The extent to which the photo cell is deprived of illumination varies according to the position of the float and of the flange 46 thereof. As the flange 46 is raised in height, thus depriving the photo cell of illumination, the voltage output from the photocell 42 decreases. This decreasing output voltage is sensed by the fuel pump control amplifiers through conductor 3 and a signal is transmitted to fuel pump 12 through conductor 7 (see FIG. 1) causing the fuel pump to decrease its speed and consequently its output. As the fuel flow to the interior of the housing decreases, the float 32 will move down within the housing, thus removing the flange 46 from between the light source and the light sensitive means 42, which increases the output voltage of the light sensitive photo cell 42. The increasing voltage from the photo cell in turn signals the fuel pump 12 to increase its speed and accordingly to increase its output.

The operation of sensor unit 50 is just the reverse, while the construction is substantially identical. Sensor unit 50 includes a housing 51 with a float 52 located on the interior of the housing in a loose fitting relationship thereto. The float 52 is located within the housing and floats on the fuel which flows to the housing from conduit 23 from chamber 180 in the interior of the variable orifice housing 20. A guide pin 53 is located within a central bore 54 of the float 52. A cavity 64 is located on the interior of the float 52. An interior lower shoulder 55 is located at the bottom of the housing adjacent a lower wall 56. The lower wall 56 includes a plurality of apertures 57 which communicate with the interior of the housing 51. An upper wall 58 includes a light source 60 extending through an aperture in the upper wall and a light sensitive means or photo cell 62 is located adjacent the light source 60 through an aperture in the housing 51. The float 52 includes an upper flange or skirt 66 which, depending on the location of the float within the housing 51, decreases the illumination from the light source 60 to the light sensitive means 62. Light source 60 receives power through conductor 6. Conductor 6 provides power for light source 60.

In operation, the position or location of the float 52 within the housing 51 is determined by the flow of the fuel from chamber 180 in the variable orifice housing 20 through conduit 23 and through the apertures 57 of the lower housing wall 36 to the interior of the housing 31. As the flow of fuel within the housing increases, the float 52 is lifted on the guide rod 53 and the flange 66 is disposed between the light source 40 and the photo cell 62. As the skirt of flange 66 moves upwardly and extends between the light source and the photo cell, the decreasing voltage output of the photo cell causes the speed of fuel pump 26 to increase. Conversely, as the fuel flow across orifice 22 and within the housing 51 decreases, and the float accordingly is lowered within the housing, more light from the light source 40 strikes

the photo cell 62 as the flange 66 is lowered and the voltage output from the photo cell through conductor 4 to the fuel pump control amplifiers 2 increases. The increased output results in a signal through conductor 8 to the fuel pump 26 to decrease its output.

When the level of the fuel within the housings 31 and 51 is the same, the output of the fuel pumps, resulting from them operating at about the same speed, is substantially the same and the system is in equilibrium. At such time as there is an increase or a decrease in the demand for the fuel from the engine, the two metering units will be in a state of imbalance, resulting in a change in the respective outputs of the fuel pumps, until such time as the system is once again in equilibrium. A state of equilibrium with respect to the output of the fuel pumps can exist at any output from a very low output to a very high output, and such state is determined by the demand of the engine.

Reference will again be made to FIG. 1. From fuel pump 26 the fuel flows to fuel heater 28 by way of conduit 27. The heater 28 may be of any design, but is preferably fueled from a source separate and apart from the engine itself. That is, rather than to use exhaust gases as the heat source for the fuel heater or preheater, it is preferable to have a separate heating source or element, which could be electrical, but is preferably either a butane or propane type heater. The purpose of the heater 28 is to heat the fuel flowing therethrough to the extent that the fuel is substantially vaporized prior to delivery to fuel nozzle 72 via conduit 29. The nozzle 72, as previously mentioned, is located within intake manifold 70 downstream from or below throttle 74.

The vaporization of the fuel by the heater 28 insures proper mixture with the air flowing through the intake manifold prior to delivery of the fuel and air mixture into the cylinders and also reduces the amount of unburned gases and other pollutants from the engine. With the fuel at its full extent of vaporization prior to delivery into the intake manifold, the fuel is assured of combustion to a greater extent than with fuel entering into the intake manifold in either a partial state of vaporization or in a liquid or a fuel droplet state.

Above the throttle, or upstream, with respect to air flow, from the throttle 74, and within intake manifold 70, is a venturi 76. A vacuum line 78 senses the pressure or the extent of the vacuum at the throat of the venturi and provides a means for transmitting the pressure or vacuum of the venturi to other parts of the fuel injection system. The vacuum line or conduit 78 extends between the throat of the venturi to sensor unit 50 where it introduces the vacuum or the low pressure within the housing 51 above the float 52 through aperture 59. The pressure existing within the housing 51 is thus the pressure or the vacuum which exists at the throat of the venturi 76. The low pressure or vacuum within the housing 51 affects the level of the fuel within the housing and therefore correspondingly affects the height or location of the float within the housing. Thus the flow of fuel from chamber 179 to chamber 180 across the orifice 22 is directly affected by the vacuum at the venturi 76.

A conduit 79 branches from conduit 78 for delivery within variable venturi system 80. The variable venturi system 80 includes a venturi piston 82, which is of a

generally conical configuration, and it extends into the venturi 76. The venturi piston 82 is fastened to a piston rod 83 which extends through a wall of the intake manifold 70 and into a cylinder or housing 85. Within the housing or cylinder 85 is an actuating piston 84 secured to the piston rod 83. The head of the cylinder or housing 85 comprises an end wall 86 with an aperture or bore extending therethrough in which the piston rod 83 moves. The lower end wall of the cylinder or housing 85 is the wall of the intake manifold 70. Exterior of the cylinder head or end wall 86 and fastened to the piston rod 83 is a cam plate 88 which includes a plurality of adjustable cam screws 89 extending therethrough. The cam screws may be adjusted as desired and as the piston rod 86 moves, the plate and screws move therewith. If desired, a fixed cam could be used instead of the adjustable screws. The vacuum lines 78 and 79 introduce the vacuum pressure from the throat of the venturi to the interior of the cylinder or housing 85 above the actuating piston 84. It will thus be seen that the movement of piston 84, and accordingly of piston rod 83 secured thereto and venturi piston 82 also secured to rod 83, depends on the vacuum at the throat of the venturi. When the vacuum at the throat of the venturi increases, this vacuum or low pressure is transmitted to cylinder 85 by conduits 78 and 79 and serves to draw the piston 84 to the left, as shown in FIG. 1, which in turn withdraws venturi piston 82 out of the venturi. With the venturi piston withdrawn from the venturi, more air flows around the piston and through the venturi and on into the intake manifold for delivery to the cylinders after mixing with the atomized fuel delivered through nozzle 72. As the engine demands fuel and air, the manifestation of that demand by means of air flow through the venturi 76 is transmitted to the variable venturi system which in turn provides for the precise metering of the air according to the demands of the engine. When the air flow through the venturi decreases, the pressure increases, that is, the vacuum decreases, and pressure within cylinder 85 increases and piston 84 is biased by compression spring 87 to move the piston rod and the venturi piston into the throat of the venturi. Air enters above the venturi via air intake chamber 71, which may include an air filter. Cylinder 85 is vented to the chamber 71 through opening 81 below piston 84.

Another conduit 91 branches from vacuum conduit 78 and connects with a valve body 92. The valve body 92 has attached thereto a sealed bellows unit 94. The bellows unit, while sealed at one wall to the valve body 92, includes a lower movable wall to which is secured, on the interior of the bellows, a tapered needle valve 95. The needle valve extends into an orifice 96 within the valve body 92 and thus the position of the needle valve 95 within the orifice 96 controls or governs the vacuum pressure therethrough.

A conduit 98 extends from the valve body 92 below the orifice 96 and connects with a conduit 99 which extends from the air intake chamber 71 upstream from both the throttle and the variable venturi to the sensor unit 30 above the float therein. Since the air conduit 99 is upstream or above the throttle and the variable venturi, the air flowing through the conduit is at substantially atmospheric pressure. The atmospheric pressure thus flowing to the sensor unit 30 provides a balance or

reference for the flow of fuel within the sensor unit, and thus the conduit 99 may be termed a balance tube or line.

The air at substantially atmospheric pressure flowing in the balance line 99 is modulated by the engine vacuum through conduit 78, branch conduit 91, the valve body 92, with its bellows and needle valve, and conduit 98. The bellows unit 94 is responsive to atmospheric pressure and temperature with respect to its expansion or contraction. When the temperature of the atmospheric air is warm, the sealed bellows unit 94 expands and withdraws the tapered needle valve 95 from the orifice 96, which allows vacuum pressure from the throat of the venturi 76 through vacuum line 78 and conduit 91 and conduit 98 to be bled into atmospheric air conduit 99. This in turn modulates the air above the float 32 in sensor unit 30. This modulation of the atmospheric air pressure within sensor unit 30 provides a lower pressure area within the unit and thus serves to decrease the flow of fuel between the sensor units across the orifice 22 by decreasing the pressure differential within the sensor units. This is accomplished by the raising of the float and the skirt 46 within the unit 30 which causes a decrease in the light reaching the photo cell 42 from light source 40. This results in the decrease of the output from the photo cell which in turn results in the decrease in the output of the fuel pump 12. When the atmospheric air temperature is cold, the reverse takes place. That is, the bellows contract and the needle valve seals off the orifice which prevents vacuum from conduit 78 from reaching conduit 99 and accordingly provides only atmospheric air pressure within sensor unit 30.

The flow of fuel across the orifice 22, and hence the flow of fuel to nozzle 72, is directly related to the pressure differential across the orifice as manifested by the pressure differential across or between the sensor units 30 and 50. With air at atmospheric pressure, modulated by engine vacuum at sensor 30, and with air at the pressure of the intake manifold vacuum at sensor 50, there is a sufficient differential to cause a flow of fuel across the orifice 22 between the sensors. The flow of fuel is detected by the sensor units and the fuel pump control amplifiers 2 which in turn signal the fuel pumps 12 and 26 to increase or decrease their output.

The fuel pumps respond to the commands of the sensors through conductors 3 and 5 to the fuel pump control amplifiers 2 and through conductors 7 and 8 to the fuel pumps, respectively, to equalize the fuel flow. The fuel flow is responsive to air flow through venturi 76. The venturi pressure, or vacuum, therefore controls the fuel flow by controlling the pressure differential across orifice 22.

The orifice 22 is variable in two ways. The first manner of variability is that a tapered needle valve or metering rod 24 is movable within the orifice 22. The second manner in which the orifice is variable is that the orifice is itself movable within the orifice housing 20.

The tapered metering rod 24 is moved within the orifice 22 by mechanical linkage from the movement of the venturi piston 82. The piston rod 83 to which the venturi piston 82 is secured includes, as has been described, a cam plate 88 which includes a plurality of adjustable cam screws 89. As the venturi piston 82 and

the piston rod 83 move in response to the vacuum at the throat of venturi 76, there is cooperating movement with the metering rod actuation system 140. The movement of piston rod 83 moves the cam plate 88 with the adjustable screws 89 thereon against the metering rod actuation system 140 to move the tapered metering rod 24 in the orifice 22. The adjustable cam screws 89 sequentially bear against cam 141 as the rod 83 moves. The cam 141 is pivotally secured to a rod 142 which is in turn connected to a flexible shaft 144. The shaft 144 is in turn secured to the metering rod 24 through a connection 145 on one end of the variable orifice housing 20. A compression spring 146 biases the cam 141 and the rod 142 secured thereto against the adjustable screws 89. The spring 146 serves also to bias the metering rod 24 out of the orifice 22. The sequential action of the adjustable screws, as the cam plate 88 is moved by the piston rod 83, serves to move the rod 142 and the flexible shaft 144 against the bias of the spring. By adjusting the plurality of screws 89, the size of the orifice 22 is varied to richen the mixture as desired. For example, as the air flow through the orifice 76 increases, the vacuum at the throat of the venturi increases and the venturi piston 82 is withdrawn from the throat of the venturi to increase the flow of air therethrough. As the piston is withdrawn the cam plate 88 moves with the piston rod and the venturi piston and the adjustable screws 89 sequentially bear against cam 141. As shown in the drawing, as the piston rod is moved to the left to move the venturi piston out of the orifice, the bias of the spring 146 will move the cam 141 upwardly against the screws 89 to withdraw the metering rod 24 out of the orifice 22. The movement of the metering rod out of the orifice will allow more fuel to flow through the orifice 22 and through conduit 25 to fuel pump 26 and through conduit 27, through fuel heater 28, conduit 29, and through nozzle 72 into the manifold 70, thus richening the mixture in a controlled amount according to the flow of air through the manifold and in accordance with the demand of the engine.

The cam 141 is pivotally connected to the rod 142 and, due to the pivoting of the cam and to the curvature of its camming surface, the metering rod 24 is also responsive to engine temperature for adjustment into or out of the orifice 22. This actuation is accomplished by means of a bellows 150 which is in turn responsive to the temperature of the engine for its expansion or contraction. A movable wall 152 of the bellows is mechanically connected through rod 148 to the cam 141. As shown, the rod 148 is bent or configured to impart movement to the metering cam 141 directly with the movement, by expansion or contraction, of the bellows 150. The metering rod actuation system, including the cam and the rod 142, spring 146, and shaft 144, as well as the bellows 150 and the rod 148 movable thereby, are secured to a plate or bracket 155 which may be conveniently secured to any part of the engine. The bellows 150 is conveniently connected to an engine temperature sensing bulb or any other source of engine heat by an appropriate conduit or manifold 154. In operation, when the engine is cold the bellows 150 is contracted and the rod 148 pivots the cam 141 slightly causing the adjustable screws to contact the cam on a different camming surface. This causes a movement of

the shaft 144 and rod 142 to move the needle valve 24 slightly out of the orifice 22 which in turn results in a slightly richer mixture. As the engine heats up, the bellows 150 expands which results in movement of the wall 152 of the bellows and of the rod 148 connected thereto. The movement of the rod 148 again results in a change in the orientation of the cam 141 with respect to the adjustable screws 89 and in turn results in the movement of the needle valve 24 into the orifice which decreases the flow of fuel through the orifice 22 and thereby leans the fuel-air mixture.

The tapered metering rod 24 may be considered as a fuel needle valve which is responsive to both the temperature of the engine and to the flow of air in the air intake manifold according to the settings of the adjustable screws 89. The number of the screws and their individual settings may be as desired in order to compensate for the linear movement of the venturi piston in the venturi. Or, as previously indicated, a solid camming surface, contoured as desired, could be used.

The movement of the orifice 22 within the orifice housing 20 is accomplished in response to the load on the engine as manifested by the pressure inside the intake manifold 70 below the throttle plate 74. The load responsive orifice movement system 160 includes a housing 162 and a housing cover plate 164 secured thereto. An aperture 166 in the housing cover plate 164 admits air at ambient pressure inside the cover plate. A flexible diaphragm 168 is secured at its outer periphery between mating flanges on the housing 162 and the housing cover plate 164. The diaphragm 168 is clamped between a diaphragm plate 170 and a diaphragm plate 171 at a central portion of the diaphragm. The diaphragm plates 170 and 171 may be secured together, and in turn may secure diaphragm 168 therebetween, by any appropriate fastening means. The diaphragm plate 170 is secured to a rod 172 which is in turn connected to the orifice 22. Apertures 176 provide communication between chamber 179 on the interior of the orifice housing 20 and the orifice 22. The orifice 22 is located and is movable within interior bore 178 of the orifice housing 20.

A compression spring 174 extends about the rod 172 within one of the expansible chambers defined by the housing and the diaphragm, specifically between an end wall of the housing 162 and the diaphragm plate 170. The spring urges the rod 172 to move the orifice 22 to the left as shown in FIG. 1, which results in the movement of the orifice 22 away from the tapered metering rod 24. This results in an increase in the flow of fuel from chamber 179 through apertures 176 and through orifice 22 into chamber 180, and ultimately results in an increase in the fuel delivered to nozzle 72. As the vacuum within the intake manifold 70 increases, or as the load imposed on the engine decreases, the intake manifold vacuum through conduit 175 increases within the housing 162 and moves the diaphragm 168 and the diaphragm plate 170 and 171, and the rod 172 connected thereto against the bias of the spring 174 to move the orifice to the right, as shown in FIG. 1. Relative motion is thus provided between the orifice and the tapered rod therein and results in a decrease in fuel between chamber 179 and chamber 180 and thus ultimately results in a decrease in the amount of fuel delivered to nozzle 72. Atmospheric pressure in one ex-

pansible chamber and engine vacuum in the other expansible chamber, as defined between the housings and the diaphragm, are balanced against the bias of the spring to move the orifice within the orifice housing.

Associated with the movement of fuel through orifice 22 between chamber 179 and 180 is a corresponding flow of fuel in conduits 21 and 23 to the sensor units 30 and 50, respectively. That is, as the flow of fuel between the chambers 179 and 180 through the orifice 22 varies, so also does the fuel flow vary through conduit 21 to sensor unit 30, which in turn is reflected in the level of the float 32 within the sensor unit 30, and, correspondingly, through conduit 23 to sensor unit 50 and a corresponding movement of float 52 therein. (See FIG. 2) Movement of the respective floats 32 and 52 balances the output of the fuel pumps 12 and 26, as has been explained.

FIG. 3 discloses an alternate embodiment of the sensor unit disclosed in FIG. 2. Only one of the units is disclosed in FIG. 3 rather than the two units as shown in FIG. 2. The reasoning is, of course, that the units are substantially the same in construction, even though with respect to operation or to the signals emanating therefrom to the amplifiers and to the fuel pumps which they control, each sensor unit operates oppositely from the other one. In FIG. 3 a radio frequency sensor unit is shown. The unit includes a housing 101 which includes a float chamber 102 therein. A float 103, which is preferably made of a conductive metal, is shown resting on an interior lower shoulder 104 of the housing 101. A lower opening 105 connects the housing 101 with the interior of the orifice housing 20 by means of a conduit such as either 21 or 23 of FIG. 1. An upper opening 106 may be connected to a source of atmospheric air pressure, modulated if so desired, as shown in FIG. 1 through conduits 98 and 99, or to a source of venturi vacuum, as by conduit 78 of FIG. 1, according to its particular use. Fuel flows through the opening 105 and into the float chamber 102 and lifts the float from the shoulder 104. A radio frequency coil 108 is shown schematically wound about the housing 101. The coil 108 may be connected to any well known radio frequency type amplifier. The position of the float within the housing can be sensed by the amplifier connected to the coil 108. In this manner, a signal, corresponding to the output of the photo sensitive means 42 and 62 of FIG. 2, which varies according to the location or position of float 103 within the housing 101, can be used to control the speed of fuel pumps 12 and 26 of FIG. 1. As with the system described according to FIGS. 1 and 2, the pressure differential between the float chambers determines the actual fuel flow across the orifice and the sensor units, with the fuel pump control amplifiers, control or balance the output of the fuel pumps.

FIG. 4 discloses another embodiment of a sensor unit which may be used in the environment of FIG. 1. Again, as with respect to FIG. 3, only a single unit is disclosed in FIG. 4. It is, however, understood that a pair of such units may be used, such as disclosed in FIG. 2, in the environment of FIG. 1.

The sensor unit comprises a housing or cylinder 111 which includes a lower end wall 112 and an upper end wall or cylinder head 114. An opening or aperture 113 is located in the lower end wall 112 and serves to com-

municate by means of an appropriate conduit, such as 21 or 23 of FIG. 1, with a chamber within the interior of orifice housing 20. The fuel from within the orifice housing 20 thus flows through a conduit and through aperture 113 to the interior of the cylinder or housing 111. An opening 115 in the cylinder head 114 communicates with either vacuum pressure via a vacuum line such as 78 of FIG. 1, or with a balance line such as conduit 99, which provides air at substantially atmospheric pressure, vacuum modulated, if desired, to the interior of the housing 111. Whether vacuum or atmospheric pressure is admitted to the interior of the housing 111 depends on the use of the unit with respect to the fuel pump which it is to control. An expansible chamber device, such as expandable bellows unit 116, is secured to the lower end wall 112 about the aperture 113 so as to restrict or confine the fuel flowing through aperture 113 to the interior of the bellows 116. The bellows includes a movable end wall 118, the position of which fluctuates according to the flow of fuel within the bellows through aperture 113 and according to the pressure on the interior of the housing 111 about the bellows 116. A rod 116 is secured to movable end wall 118 and the rod supports an opaque partition or shutter 122. If desired, the rod may be omitted and the shutter may be directly secured to the bellows end wall 118. Located opposite each other in the chamber or cylinder 111 is a light source 124 and light sensitive means, which may be a photo cell 126. Power to the light source 124 is by conductor 125 from fuel pump control amplifiers, such as disclosed in FIG. 1. One terminal of both the light source and the photo cell is illustratively grounded, as in FIGS. 1, 2, 5, and 6 with similar and other electrical components, and as is typical of ground return electrical systems in automotive use. The light source and the light sensitive means function in substantially the same manner as described with respect to FIG. 2. That is, as the flow of fuel within the bellows 116 varies, the bellows expands and contracts and accordingly moves the shutter 122 secured to the bellows end wall 118 by the rod 120. As the shutter is moved with respect to the light source and to the light sensitive means, the illumination from the light source varies on the light sensitive means, or photo cell, and the output therefrom is accordingly varied. As with FIG. 2, the output from the photo cell may be received by fuel pump control amplifiers through conductor 127 and in turn used to control the speed, and thus the output, of a fuel pump such as fuel pump 12 or fuel pump 26. As previously noted, the pressure differential between the interiors of a pair of units such as shown in FIG. 4 determines the actual fuel flow, and the pair of sensor units balance the output of the fuel pumps which they control.

Another embodiment of the fuel metering system is shown in FIG. 5. Fuel from fuel supply 210 flows through conduit 211 to variable speed fuel pump 212 and from the fuel pump through conduit 213. The speed of fuel pump 212 is controlled by sensor unit 270 through fuel pump control amplifiers 202. The fuel pump control amplifiers are connected to the fuel pump through conductor 207. From conduit 213, fuel flows through conduit 215 into a cylinder 216 and from cylinder 216 through conduit 229 through variable orifice 232 and through conduit 239 to fuel heater 240.

The fuel is substantially vaporized by fuel heater 240 and it then flows through conduit 241 to fuel nozzle 242 for delivery into intake manifold 254 above the venturi 256 and also above the throttle plate 244.

The purpose of cylinder 216 is to serve as an acceleration-deceleration pump to either remove fuel or to add fuel upon movement of the throttle either to the closed or to the open positions. Cylinder 216 includes a cylinder head 218 through which extends a piston rod 226. At the opposite end of cylinder 216 from the head 218 is a cylinder end wall 220. An aperture 222 extends through the end wall 220 and vents part of the cylinder to the atmosphere. Secured to one end of piston rod 226 is a piston 224. The aperture 222 in end wall 220 vents that portion of the cylinder below the piston 224 to atmospheric pressure while the head end of the cylinder above piston 224 is open for the flow of fuel therethrough. The piston rod 226 extends through cylinder head 218 and is directly connected to throttle 244 such that the opening of the throttle 244 moves the piston on its exhaust stroke so as to cause fuel to flow out of cylinder 216 through conduit 229. This amount of fuel exiting the cylinder by virtue of the movement of the piston 224 is greater than the normal flow of fuel through fuel conduit 229 which is due only to the fuel pump 212. A check valve could be placed in conduit 215 to prevent a back flow of fuel through conduit 215 as piston 224 pumps fuel out of the cylinder 216 and to insure that the fuel so pumped flows into conduit 229. The reverse situation also occurs as the throttle is closed. The closing of the throttle moves the piston rod 226, with piston 224 attached thereto away from the piston head 218 on the intake stroke and draws fuel from lines 215 and 229 into the interior of the cylinder 216. The withdrawal of the fuel from the line therefore decreases the amount of fuel going through lines 229, 239, and 241, and through nozzle 242 into the engine. The net result of this is to decrease the amount of unburned gases, and therefore the pollutants, from the atmosphere as the engine is decelerated. Such acceleration-deceleration pump could, of course, also be used with the embodiment of FIG. 1.

From fuel conduit or line 229 the fuel passes through variable orifice 232 prior to entering line 239. The variable orifice 232 includes a valve body 230 which includes a needle valve 234 therein. The needle valve includes a tapered portion which extends into the orifice 232. Movement of the tapered needle valve 234 within the orifice 232 governs the size of the orifice and thus controls the amount of fuel flowing therethrough. The tapered needle valve 234 is mechanically connected to piston rod 226 by a rod or link 236, which is connected to pivot 237 secured to the valve body 230. The link or rod 236 is connected at one end to the needle valve 234 and at its other end to piston rod 226, and its pivots between the two ends on pivot 237. Movement of the throttle 244 imparts movement to piston rod 226 which in turn moves the link 236 and the needle valve connected therewith. As the throttle 244 is opened, movement of the piston rod 226 withdraws the needle valve from orifice 232, allowing more fuel to flow therethrough. As the throttle 244 is closed, movement of rod 226, which is transmitted through link 236, moves needle valve 234 into the orifice and decreases the flow of fuel therethrough.

From fuel line 239 the fuel flows through fuel heater 240 where it is substantially vaporized, in a manner similar to that described above for fuel heater 28. That is, by use of a heater, such as a propane or butane heater, the temperature of the fuel is raised sufficiently to cause the fuel to be vaporized from its liquid state for ultimate transmittal into the intake manifold in such vaporized state. The more complete the vaporization of the fuel, the more complete is the combustion of the fuel air mixture. Thus the vaporizing of the fuel prior to delivery into the manifold insures more complete combustion which gives greater efficiency to the engine and also decreases the amount of pollutants exhausted to the atmosphere. The fuel flows from the fuel heater 240 to conduit 241 for delivery to fuel nozzle 242 into the intake manifold system where the fuel is mixed with air.

Air enters air intake chamber or manifold 250 from an appropriate source, either directly from the atmosphere, or, preferably, from an air filtering system (not shown), and flows through variable venturi 252 into an upper portion 254 of the intake manifold. Within the venturi 252 is a venturi piston 260 which moves into or away from the venturi in response to the movement of the throttle for more or less air flow. As the engine demands more air, according to the movement of the throttle, the venturi piston 260 is withdrawn from venturi 252 which allows more air to flow through. Within the upper portion 254 of the intake manifold the air comes into first contact with the fuel as the fuel exits nozzle 242. Just below, or downstream, from nozzle 242 the fuel and air passes through another venturi 256 which serves to increase the mixing or the combining of the air fuel mixture prior to delivery into lower portion 258 of the intake manifold below the throttle 244.

The variable venturi is also controlled by mechanical linkage with the opening and closing of the throttle. The venturi piston 260 moves into and out of venturi 252 by movement of rod 262 which is connected to the venturi piston 260. The rod or link 262 is pivotally connected intermediate its ends at pivot 263 which is in turn secured to a portion of the intake manifold 250. At the end of link 262 opposite that which is connected to the piston 260, the link is connected to piston rod 226. Accordingly, as the throttle 244 is opened, movement of piston rod 226 imparts movement to link or rod 262 which in turn pivots at pivot 263 to withdraw the piston from the venturi. As the throttle is closed, movement of piston rod 226 in the opposite direction reverses the movement of link 262 and moves venturi piston 260 into the venturi 252 and decreases the flow of air therethrough.

The flow of both fuel and air, through the mechanical linkage above described, thus controls the flow of air and the flow of fuel according to the setting of the throttle to provide the correct fuel air mixture under all throttle settings of the engine. In addition to the mechanical linkage described with respect to the throttle positions and to the flow of fuel and the flow of air, the flow of fuel, with respect to the fuel pump, is independently controlled by sensor unit 270. The sensor unit 270 includes a lower housing 272, including a lower end wall 273 through which an aperture extends which connects the housing 272 to fuel conduit 213,

and an upper housing 274, a diaphragm 276 is secured at its outer periphery between the lower housing 272 and the upper housing 274 and thus divides the housings into two expansible chambers. The upper housing includes an upper end wall 275. While the outer periphery of the diaphragm 276 is secured by the housings 272 and 274, the inner portion of the diaphragm is secured, by an appropriate fastening means, between two diaphragm plates, upper plate 277 and lower plate 278. Located within the lower housing 272 and above the aperture in the lower end wall 273 and thus communicating with fuel conduit 213, is another expansible chamber device, a flexible bellows 281. The bellows includes a movable end wall, remotely located from the aperture in lower end wall 273, which is secured to lower diaphragm plate 278. Thus movement of the bellows, either expanding or contracting, results in movement of the diaphragm 276 through diaphragm plates 278 and 277 connected therewith. The diaphragm separates the housings into two chambers, a lower chamber 279 within the lower housing 272, and an upper chamber 280 within upper housing 274.

A vacuum conduit 283 extends between the throat of venturi 252 and lower housing 272. The vacuum existing at the throat of the venturi is thus sensed through line 283 within the lower housing 272 beneath the diaphragm 276 and exteriorally of the bellows unit 281. The fuel pressure through conduit 213 within bellows 281 causes the bellows to expand or contract, in accordance with the pressure of the fuel. The pressure or extent of the vacuum existing within the housing 272 through line 283 also exerts an influence on the expansion or contraction of the bellows 281. If the vacuum existing at the throat of the venturi is high, the pressure existing in chamber 279 within the housing 272 will be low and will thus tend to urge the contraction of the bellows unit by urging the diaphragm 276 and the plates 277 and 278, to which the diaphragm and the bellows are secured, toward end wall 273. If the vacuum existing at the venturi 252 is low, the pressure existing within the housing 272 will correspondingly increase, which in turn will tend to urge the expansion of the bellows unit 281 by movement of the diaphragm and plates away from end wall 273 and towards the upper end wall 275, thus increasing the size of chamber 279 and decreasing the size of chamber 280.

Vacuum pressure from the throat of venturi 252 through vacuum conduit 283 also is transmitted through a branch line or conduit 285 from conduit 283 through a mixture adjustment valve 286 and conduit 289 to upper chamber 280 above the diaphragm 276 and within the upper housing 274. Within mixture adjustment valve 286 is an adjustable needle valve 288. The needle valve 288 may be adjusted as desired to permit the vacuum pressure to be transmitted to chamber 280. The vacuum pressure through conduits 283, 285, needle valve 286 and conduit 289 serves to modulate the pressure within chamber 280, which is normally at atmospheric pressure through air conduit 293 from air valve 290.

The air valve 290 includes an aperture 291 through which air is introduced to orifice 292 which is in turn connected to air conduit 293. A movable needle valve 294, which includes a tapered portion, extends into orifice 292 and the movement of the needle valve in the

orifice controls the flow of air from aperture 291 to conduit 293. The needle valve 294 is moved by a bellows 296 which is fastened to a cover plate 297 of bellows housing 298. The interior of the bellows housing 298 is vented to atmospheric air pressure through a pair of apertures 299. With one end of the bellows unit 296 secured to the cover plate 297, the other end, which comprises a movable end wall, is free to move according to the expansion or contraction of the bellows unit 296. The needle valve 294 is secured to the movable end wall of the bellows 296 and extends into the air valve body 290 with the tapered needle valve portion extending into the orifice 292. The bellows 296 comprises a sealed bellows unit and expands and contracts according to the temperature and pressure of atmospheric air. Accordingly, the air pressure within chamber 280 is modulated according to the temperature and pressure of the atmospheric air and according to the vacuum existing at the throat of venturi 252 through mixture adjustment valve 286 to either richen or lean the fuel air mixture, as described in detail below.

Secured to the upper diaphragm plate 277 is a rod 302 which supports a shutter 304. On opposite sides of the upper chamber housing 274 are light source 306 and light sensitive means, such as photocell 308. The illumination or light from the light source 306 striking the photo cell 308 results in an output from photo cell 308 to fuel pump control amplifiers 202 through conductor 205. Light source 306 receives power through conductor 203 from fuel pump control amplifiers 202 when the engine ignition switch is on. The greater the illumination on photo cell 308, the greater its output. The shutter 304 serves to block the illumination or light from 306 to photo cell 308 in varying degrees, depending on its specific location. Movement of the shutter with respect to the light source 306 and photo cell 308 is determined by movement of the diaphragm 276 and the diaphragm plates 277 and 278 according to the movement of bellows unit 281 and the relative pressures within chambers 279 and 280. In turn, the pressure in chambers 279 and 280 are affected by pressure transmitted to the respective chambers through conduits 283 and 289. Movement of bellows 281, either with respect to its expansion or its contraction, is determined primarily by the pressure of the fuel in the bellows from fuel line 213. As the pressure of fuel in the bellows increases, the bellows expands and causes the upward movement of the diaphragm and the diaphragm plates and the shutter, which blocks the illumination between light source 306 and photo cell 308. This results in a decrease in the output from photo cell 308 and the fuel pump control amplifiers accordingly send a signal to fuel pump 212 through conductor 207 to decrease the speed and thus the output of fuel pump 212. As the output of the fuel pump decreases, the pressure of the flow through line 213 to the bellows 281 and also through conduit 215 and ultimately through the fuel conduits to nozzle 242 decreases. If desired, the rod 302 may be omitted and the shutter 304 may be secured directly to plate 277.

As the fuel pressure in bellows unit 281 decreases, the movement of the diaphragm plates and ultimately the shutter 304 is in response to the contraction of the bellows 281, which in turn moves the shutter from

between the light source and the photo cell. This movement is accompanied by an increased output from photo cell 308 to the fuel pump control amplifiers through conductor 205 and, in response thereto, a signal is transmitted through conductor 207 to the fuel pump to increase the speed thereof and thus the output. The increased output of the fuel pump in turn means an increase in fuel flow to the nozzle 242.

In addition to the control of the fuel pump directly by the movement of the bellows, the pressure within chambers 279 and 280 is used to indirectly influence the expansion or contraction of the bellows which in turn is reflected in an increase or decrease in the output of the fuel pump. This is accomplished, for example, according to the flow of air through venturi 252 and/or by the expansion and contraction of bellows 296 according to ambient air temperature and pressure. As air flow through venturi 252 increases, the vacuum at the throat of the venturi also increases, decreasing the pressure in conduit 283 and in turn decreasing the pressure in chamber 279. The decreased pressure in chamber 279 tends to urge the diaphragm downwardly, as shown in FIG. 5, toward the end wall 273 of the lower housing 272 which in turn urges the contraction of the bellows 281. The contraction of the bellows 281 is accompanied by an increase in the output of photo cell 308 which in turn results in a signal to the fuel pump to increase its speed and output. Thus the decreasing pressure within chamber 279, urges or causes the chamber 279 to decrease in size due to the displacement in a downward direction of the diaphragm 276.

The opposite result is achieved as the air flow through the throat of the venturi 252 diminishes, thus lowering the vacuum at the throat of the venturi, or increasing the pressure at the throat of the venturi. The lowering of the vacuum, or the increasing of the pressure, at the throat of the venturi is sensed within the chamber 279 through the conduit 283. The chamber 279 is thus increased by an upward movement of the diaphragm 276 and of the diaphragm plates, the bellows, and the resultant movement of the shutter 304 between the light source 306 and the photo cell 308. This in turn results in the decreasing output of the fuel pump and a diminishing fuel flow to nozzle 242.

The pressure within the upper chamber 280 also is correlated with the speed of the fuel pump 212 through the movement of the diaphragm 276, rod 302 secured to upper diaphragm plate 277 and shutter 304. The bellows unit 296 expands and contracts according to atmospheric air temperature and pressure. When the air temperature is high, the bellows unit tends to expand and move needle valve 294 into orifice 292, which decreases the flow of atmospheric air from aperture 291 to conduit 293 and into chamber 280. As the flow of air through orifice 292 is diminished, the vacuum from the throat of venturi 252 through conduits 283 and 285 and mixture adjustment valve 286 and conduit 289 is increased to chamber 280. That is, the air through conduit 293 is modulated to a greater extent by the low pressure or vacuum through conduit 285 and mixture adjustment valve 286 and conduit 289. This in turn causes a lowering of the pressure within chamber 280 and results in the urging of the diaphragm 276 in an upward direction to decrease the size of

chamber 280 which in turn moves the shutter 304 between the light source 306 and the photo cell 308. Again, the output of the photo cell 308 is diminished which in turn results in a signal to the fuel pump to decrease its output. Thus the fuel air mixture is leaned to an extent depending on the temperature and pressure of the atmospheric air and the setting of the needle valve 288 in the mixture adjustment valve 286. When the temperature of the atmospheric air is low, and a richer mixture is desired, the bellows 296 is contracted, which moves the needle valve 294 out of the orifice 292 and causes an increase in the flow of air from aperture 291 through conduit 293 into chamber 280. The increased pressure in chamber 280, with respect to the low pressure in chamber 279 from the throat of venturi 252, urges the movement of the diaphragm 276 away from top cover plate 275, and towards lower end wall 273, increasing the relative size of chamber 280 and diminishing the relative size of chamber 279. This results in a movement of the shutter 304 from between the light source 306 and the photo cell 308 and in turn increases the output of photo cell 308 which in turn results in an increase in the output of fuel pump 212. The force of the fuel pressure within the bellows 281 is balanced by the pressure differential across the diaphragm 276. This pressure differential includes the atmospheric pressure, as modulated, in chamber 280 and the vacuum pressure at the throat of venturi 252 in chamber 279. The pressure differential across the diaphragm thus determines the pressure of the fuel, and thus the fuel flow, the nozzle 242.

Another embodiment of the sensor unit of FIG. 5 is shown in FIG. 6. The apparatus comprises a lower housing 312 which includes a lower end wall 314 and an aperture 316 in the lower housing 312 which communicates with the vacuum from the throat of venturi 252 as through conduit 283. A cylinder 318 extends or depends downwardly from the lower end wall 314 of the lower housing 312. The cylinder includes an interior bore 320 which communicates with a source of fuel flow, such as from conduit 213, through an opening or aperture 322. A piston 326 is disposed within the bore 230 and the movement of the piston depends on the fuel pressure within the cylinder 318 through aperture 322. A lower diaphragm plate 328 is connected to the upper portion of piston 326. An upper diaphragm plate 330 secures, by appropriate fastening means, the inner periphery of a diaphragm 332 to lower diaphragm plate 328, for movement therewith in accordance with the movement of piston 326.

The outer periphery of diaphragm 332 is clamped between lower housing 312 and upper housing 336. A lower expandable chamber 334 is defined by the diaphragm 332 and the lower housing 312. The diaphragm 332 and the upper housing 336 define an upper expandable chamber 335. The upper chamber 335 includes an aperture 338 which vents the upper chamber 335 to atmospheric air pressure, as modulated by vacuum, as through conduits 289 and 293 of FIG. 5. A rod 340 is secured to upper diaphragm plate 330 for movement therewith, and the rod 340 supports a shutter 342. As the diaphragm 332 moves, in accordance with the movement of piston 326 and diaphragm plates 328 and 330, the shutter 342 is also moved. As with similar structure in FIGS. 4 and 5, the

rod 340 may be omitted and the shutter 342 may be secured directly to plate 330. On opposite sides of upper housing 336 are light source 344 and light sensitive means, which may be a photo cell 346. The output of light responsive means 346 is as described with reference to FIG. 5, and the movement of the shutter 342 between the light source and the photo cell decreases the output of the photo cell to the fuel pump control amplifiers, such as amplifiers 202 of FIG. 5, and accordingly decreases the output of the fuel pump to which it is connected. The withdrawing of the shutter, or the lowering thereof, from between the light source and the photo cell results in an increased output from the photo cell which in turn causes the fuel pump control amplifiers to signal the fuel pump to increase its speed and therefore its output.

The movement of the piston 326 within bore 320 is directly related to the pressure of the fuel within the bore 320, as modulated by the venturi vacuum through aperture 316 within chamber 334 and as further modulated by the atmospheric air, modulated by the venturi vacuum, through aperture 338 within upper chamber 335. A decrease in the pressure within chamber 334 urges the diaphragm downwardly, as shown in FIG. 6, to decrease the side of chamber 334 to compensate for the lowered pressure therein, which in turn serves to lower the shutter from between the light source and the photo cell. Again, the increased light from the light source to the photo cell results in an increased output from photo cell 346 through conductor 347 to the fuel pump control amplifiers.

Air at atmospheric pressure entering upper chamber 335 through aperture 338 urges movement of the diaphragm 332 also in a downwardly direction, as shown in FIG. 6, and in turn results in the same phenomenon as has been described. If the atmospheric air is modulated by engine vacuum, the pressure within chamber 355 is in turn modulated and results in a corresponding change in the position of the diaphragm and of the shutter with respect to the light source and the photo cell. In turn, this results in a change in the signal to the fuel pump. When the ignition system of the engine is turned on, light source 344 receives power through conductor 345 from the fuel pump control amplifiers, such as amplifiers 202 of FIG. 5. It will be noted that, as shown in FIG. 6, both the photo cell and the light source are grounded and only one conductor is shown extending from the light source and the photo cell to connect with the fuel pump control amplifiers.

FIG. 7 is a view taken on line 7—7 of FIG. 6 and illustrates the shutter with respect to the light source. The rod 340 is shown supporting the shutter 342 thereon. The light source 344 is shown partially obscured by the shutter 342. Thus, due to the displacement of the shutter 342 between the light source 344 and the photo cell 346 (see FIG. 6), the total illumination from light source 344 to photo cell 346 would be diminished and the output of the photo cell would be less than its maximum as when the full illumination from the light source were impinging upon it. As the shutter moves in accordance with movement of the diaphragm and the diaphragm plates, the illumination from the light source to the photo cell is proportionately or accordingly varied, resulting in the varied output from photo cell 346 to the fuel pump control amplifiers

through conductor 347, which in turn results in the variable output of the fuel pump.

It is thus apparent that a fuel injection system has been described which will provide the correct amount of fuel and air to an engine in the correct proportions under conditions of varying speed and load. Moreover, the system will provide for the efficient use of the fuel with respect to a decrease in pollutants discharged or exhausted to the atmosphere by the correct metering of the fuel, by the provision of vaporized fuel which results in more complete combustion than does fuel which is only partially vaporized, and by the withdrawal of fuel from the fuel line upon deceleration. The use of various types of expansible chamber devices provides efficient and reliable components.

Because of the variable venturi, a broader range of air volumes, and therefore a broader range of operating limits, is possible. Air measurements to the engine are possible to provide a small amount of air at idle, and a large amount of air at higher speeds. Accordingly, with fuel-air ratio settings, the proper amount of fuel can be metered at all ranges.

While the principles of the invention have been made clear in illustrative embodiments, there will be immediately obvious to those skilled in the art many modifications of structure, arrangement, proportions, the elements, materials, and components used in the practice of the invention, and otherwise, which are particularly adapted for specific environments and operating requirements, without departing from those principles. For example, various types of expansible chamber devices may be substituted for those shown. The bellows unit and housing of FIG. 5, identified by reference numerals 296 and 298 could be substituted for the bellows units of FIG. 1, identified by reference numerals 16 and 94, and vice versa, and other types could also be used. Other modifications could be made in the sensor units with respect to the float systems, the sensors themselves, and/or the expansible chamber devices, such as the diaphragm systems and the bellows units. The appended claims are therefore intended to cover and embrace any such modifications, within the limits only of the true spirit and scope of the invention. This specification and the appended claims have been prepared in accordance with the applicable patent laws and the rules promulgated under the authority thereof.

What is claimed is:

1. In an internal combustion engine, fuel injection apparatus comprising, in combination:

- a fuel supply;
- intake manifold means for providing a flow of air;
- means for sensing the flow of air in the intake manifold means;
- fuel conduit means extending from the fuel supply to the intake manifold means;
- fuel pump means for providing a variable flow of fuel from the fuel supply to the intake manifold means;
- orifice means for varying the flow of fuel to the intake manifold means;
- sensing means for sensing the flow of fuel; and
- control means coupled to said sensing means for sensing the flow of fuel and to the means for sensing the flow of air and to the fuel pump means to vary the flow of fuel from the fuel pump means.

2. The apparatus of claim 1 in which the intake manifold means includes an air intake chamber for providing a source for the flow of air.

3. The apparatus of claim 2 in which the intake manifold means further includes venturi means adjacent the air intake chamber.

4. The apparatus of claim 3 in which the venturi means includes a venturi throat.

5. The apparatus of claim 4 in which the venturi means includes means for sensing pressure within the intake manifold at the venturi throat.

6. The apparatus of claim 5 in which the venturi means further includes a venturi piston at the venturi throat.

7. The apparatus of claim 6 in which the venturi piston is movable in said venturi throat.

8. The apparatus of claim 7 in which the venturi means further includes means responsive to changes in pressure at the intake manifold for moving the venturi piston in said venturi throat.

9. The apparatus of claim 8 in which the means for moving the venturi piston comprises a cylinder; a piston movable in said cylinder; and a piston rod fastened to and extending between said piston and the venturi piston.

10. The apparatus of claim 9 which includes the first means for sensing pressure at the intake manifold coupled to the cylinder.

11. The apparatus of claim 7 in which the intake manifold means further includes throttle means, including a throttle plate located and movable within said intake manifold means to further control the flow of air in said intake manifold means.

12. The apparatus of claim 11 in which the throttle means includes mechanical linkage connected to the throttle plate for moving the throttle plate.

13. The apparatus of claim 12 in which mechanical linkage connected to said throttle means is interconnected to the venturi piston for simultaneous movement of the throttle plate and the venturi piston.

14. The apparatus of claim 13 which includes means for removing fuel from said fuel flow to the intake manifold means in response to movement of the mechanical linkage of the throttle means.

15. The apparatus of claim 14 in which the means for removing fuel comprises:

a cylinder connected to the fuel conduit means;

a piston in said cylinder; and

mechanical linkage connected to said piston and to said mechanical linkage of the throttle means for moving said piston in response to movement of said throttle means.

16. The apparatus of claim 13 in which orifice means includes an orifice and a needle valve movable in said orifice to control the flow of fuel therethrough.

17. The apparatus of claim 16 in which the orifice means further includes mechanical linkage interconnected between the needle valve and the mechanical linkage of the throttle means for providing simultaneous movement of the needle valve and the throttle plate.

18. The apparatus of claim 5 in which the orifice means includes housing means coupled to the fuel conduit means extending between said fuel supply and said manifold means, and an orifice movable within said housing means.

19. The apparatus of claim 18 in which the orifice means further includes means for moving said orifice.

20. The apparatus of claim 18 in which the means for moving said orifice includes:

a housing;

a diaphragm in said housing;

a rod fastened to and extending between said diaphragm and said orifice;

biasing means for biasing said diaphragm, and the rod and orifice fastened thereto, in a first direction.

21. The apparatus of claim 20 in which means for moving said orifice further includes means for biasing said diaphragm, and the rod and orifice fastened thereto, in a second direction.

22. The apparatus of claim 21 in which means for biasing the diaphragm in a second direction is responsive to pressure in the intake manifold.

23. The apparatus of claim 7 in which the orifice means includes a rod movable within the orifice.

24. The apparatus of claim 23 in which the rod movable within the orifice includes a tapered portion.

25. The apparatus of claim 24 in which the orifice means further includes means for moving the rod within the orifice.

26. The apparatus of claim 25 in which the means for moving the rod includes means coupled to the rod for movement responsive to the movement of the venturi piston.

27. The apparatus of claim 26 in which the means coupled to the rod responsive to movement of venturi piston comprises:

a lever coupled to the rod;

spring means biasing the rod in a first direction;

a plate secured to the piston rod; and

a plurality of adjustable members on said plate sequentially bearing against the lever in response to movement of the piston rod.

28. The apparatus of claim 27 in which the means for moving the rod further includes means fastened to the lever for moving the lever in a first direction and in a second direction.

29. The apparatus of claim 28 in which the means fastened to the lever for moving the in a first direction and in a second direction comprises:

an expansible chamber device including a movable wall;

linkage fastened to the movable wall of the expansible chamber and movable therewith; and

fastening means pivotally securing the lever to the linkage.

30. The apparatus of claim 5 in which the sensing means for sensing the flow of fuel includes:

chamber means;

means for providing a flow of fuel to said chamber means from said fuel pump means; and

means for sensing the flow of fuel to said chamber means.

31. The apparatus of claim 5 in which the sensing means for sensing the flow of fuel includes:

a housing;

a first expansible chamber in said housing;

means for providing a flow of fuel from said fuel pump means to the first expansible chamber;

a second expansible chamber in said housing;

means associated with the second expansible chamber for sensing the flow of fuel in said first expansible chamber.

32. The apparatus of claim 30 in which means for sensing the flow of fuel to the chamber means comprises:

a float in said chamber means; and
radio frequency detector means for detecting the location of said float in said chamber means.

33. The apparatus of claim 30 in which the means for sensing the flow of fuel further comprises a float in said chamber means and photo cell means for detecting the location of the float in said chamber means.

34. The apparatus of claim 30 in which the means for sensing the flow of fuel to the chamber means further comprises means responsive to the flow of fuel for varying the size of the chamber means and means for detecting the variation in the size of the chamber means.

35. The apparatus of claim 33 in which the chamber means includes wall means defining a chamber, said chamber including an upper portion and a lower portion, and means for admitting fuel to the lower portion of the chamber.

36. The apparatus of claim 35 in which the means for detecting the location of the float comprises:

a light source for providing light;
light responsive means for producing an output in response to light from the light source; and
skirt means on the float intermediate the light source and the light responsive means for interrupting light from the light source to the light responsive means in response to vertical movement of the float.

37. The apparatus of claim 30 in which the chamber means includes:

a first and second chamber;
a first float in the first chamber;
a second float in the second chamber; and
means for admitting fuel to said first and second chambers to move said first and second floats.

38. The apparatus of claim 37 in which the orifice means are intermediate the first and second chambers.

39. The apparatus of claim 38 in which the means for sensing pressure within the intake manifold at the venturi throat is connected to the second chamber, and the sensing means for sensing the flow of fuel includes means for admitting air at substantially atmospheric pressure to the first chamber.

40. The apparatus of claim 39 in which the sensing means for sensing the flow of fuel comprises a first sensing means for sensing the flow of fuel in said first chamber and a second sensing means for sensing the flow of fuel in said second chamber.

41. The apparatus of claim 40 in which the control means comprises a first control means coupled to the first sensing means and a second control means coupled to the second sensing means.

42. The apparatus of claim 41 in which the fuel pump means includes a first fuel pump coupled to said first control means and a second fuel pump coupled to said second control means.

43. The apparatus of claim 42 in which the sensing means comprises light responsive photo cell means responsive to the locations of the floats in the first and second chambers for sensing the flow of fuel.

44. The apparatus of claim 30 in which the chamber means comprises:

a housing; and
expansible chamber means in said housing for receiving a flow of fuel, and said expansible chamber means varying in size according to the flow of fuel thereto.

45. The apparatus of claim 44 in which the means for sensing the flow of fuel to the chamber means comprises means for detecting variations in the size of the chamber means.

46. The apparatus of claim 44 in which the means for detecting variations in the size of the chamber means comprises:

a diaphragm within said housing adjacent said expansible chamber means and movable therewith;
a shutter plate on said diaphragm and movable therewith;

light responsive means adjacent the shutter plate for producing an output in response to movement of the shutter plate.

47. The apparatus of claim 46 in which the expansible chamber means comprises a bellows.

48. The apparatus of claim 46 in which the expansible chamber means comprises a cylinder and a piston in said cylinder.

49. The apparatus of claim 30 in which the chamber means comprises a pair of housings; expansible chamber means in each of said housings, and each of said expansible chamber means varying in size according to the flow of fuel thereto.

50. The apparatus of claim 49 in which the expansible chamber means comprises bellows in each of said housings.

51. The apparatus of claim 50 in which means for sensing pressure within the intake manifold at the venturi is connected to one of said pair of housings.

52. The apparatus of claim 50 in which the chamber means includes means for providing air at substantially atmospheric pressure to the other of said pair of housings.

53. The apparatus of claim 52 in which the means for providing air at substantially atmospheric pressure includes means for modulating the provided air with pressure sensed within the intake manifold at the venturi throat.

54. The apparatus of claim 53 in which the means for modulating the provided air includes:

an orifice connected to the air at substantially atmospheric pressure and to the means for sensing pressure within the intake manifold at the venturi throat;

a needle valve movable in the orifice; and
an expandable bellows connected to the needle valve for moving said needle valve in said orifice in response to expansion of the bellows.

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