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[54] **FUEL INJECTION APPARATUS IN AN INTERNAL COMBUSTION ENGINE**

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[52] **U.S. Cl. 123/139 AW,** 123/119 R, 123/140 MC

[51] **Int. Cl.** **F02m 69/00**

[58] **Field of Search** ..... /Machine Searched Steroids

[56] **References Cited**

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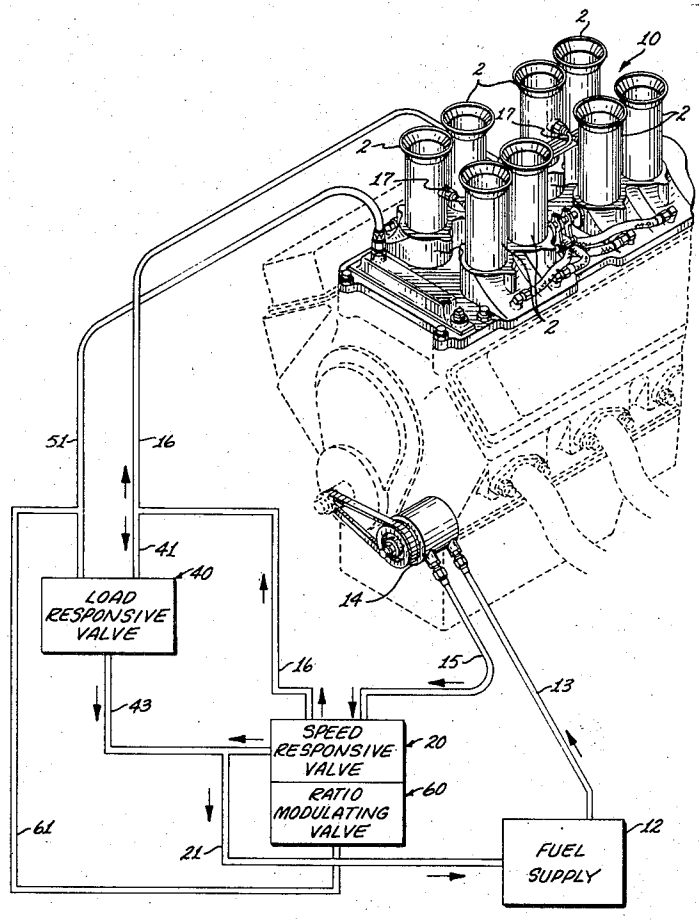
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[57] **ABSTRACT**

Apparatus for injecting fuel into an internal combustion engine in predetermined amounts responsive to operating conditions of the engine.

9 Claims, 5 Drawing Figures



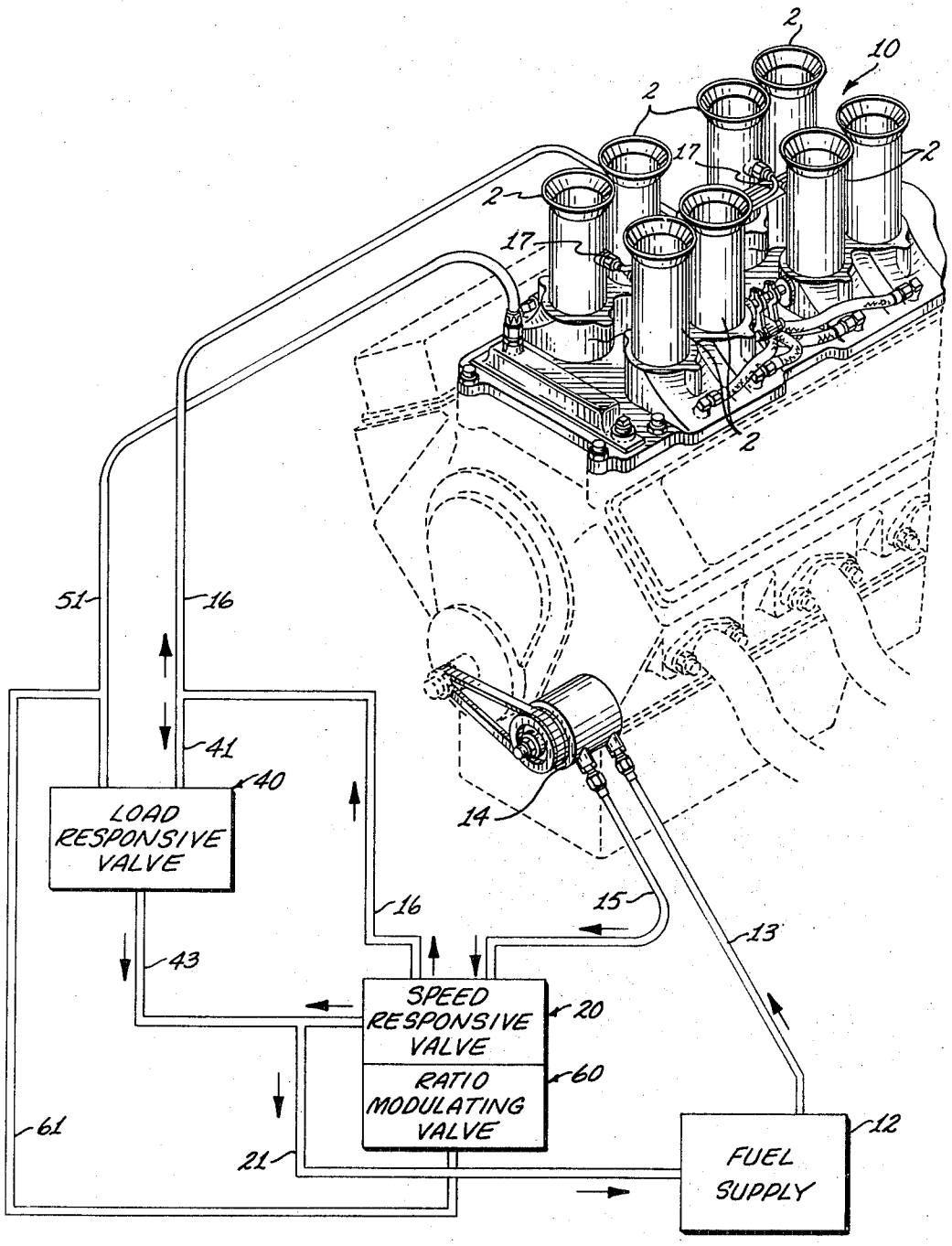


Fig-1

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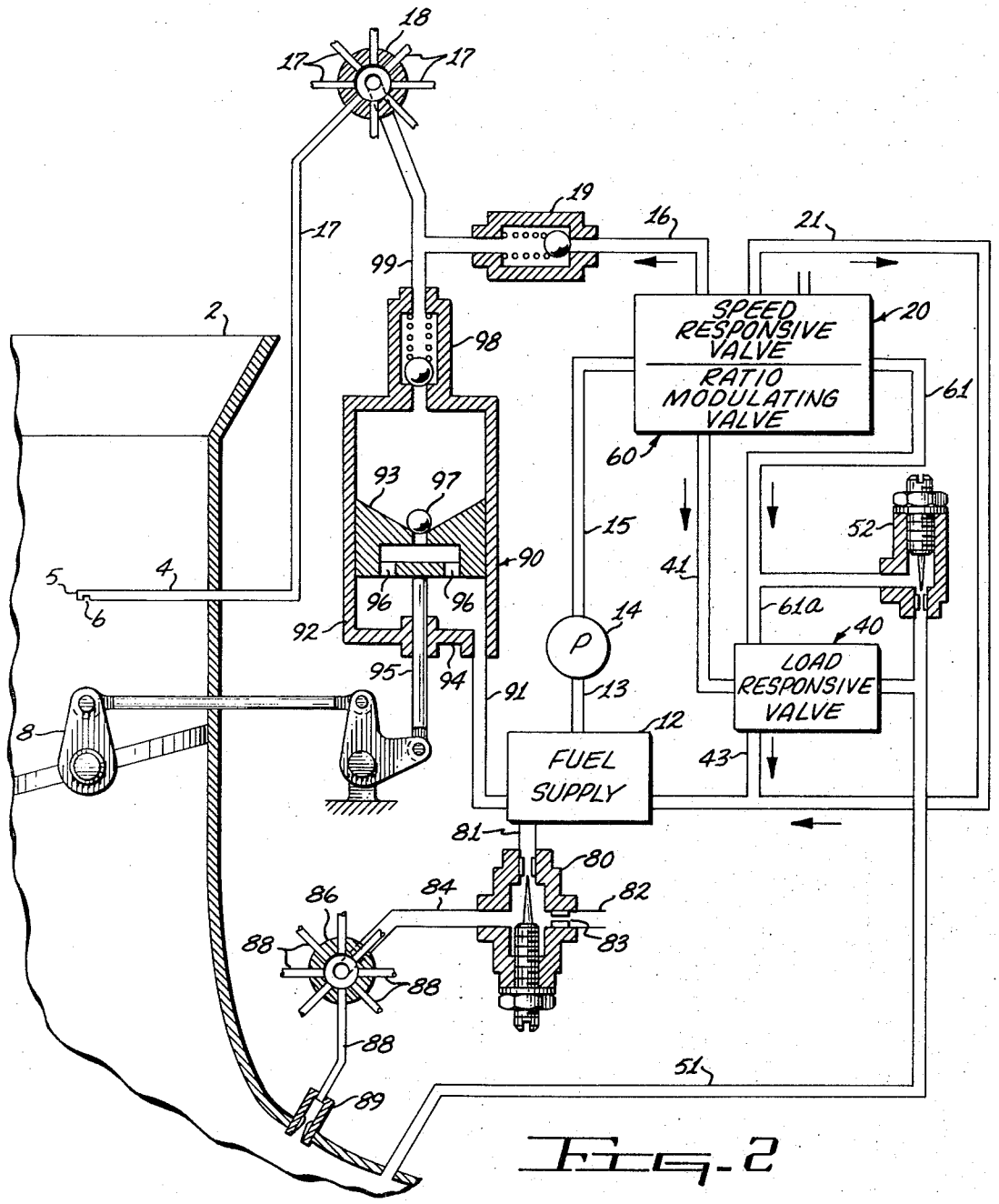


Fig-2

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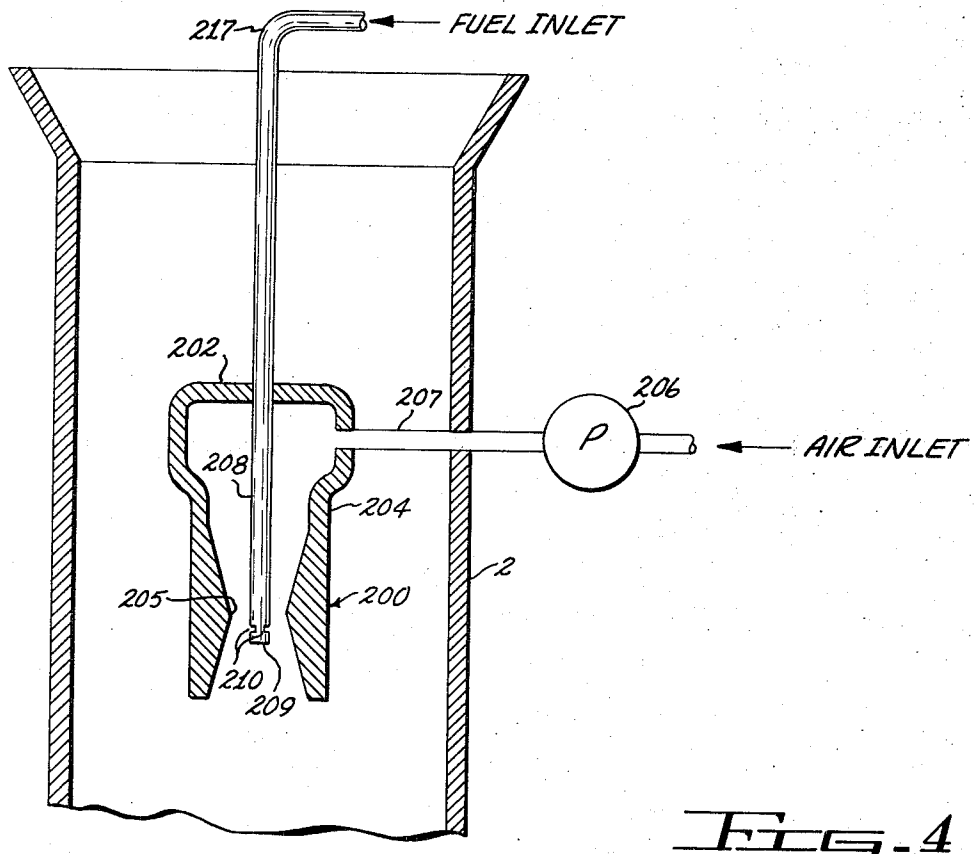


Fig. 4

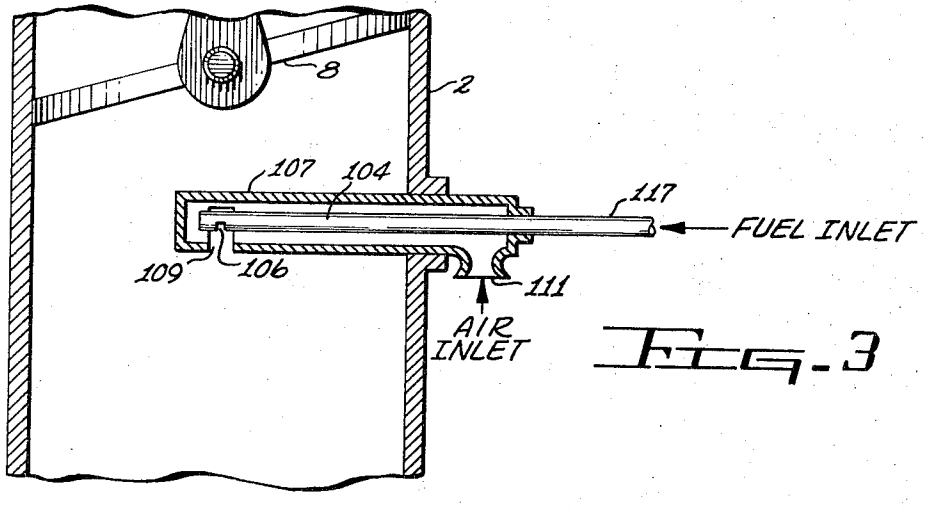


Fig. 3

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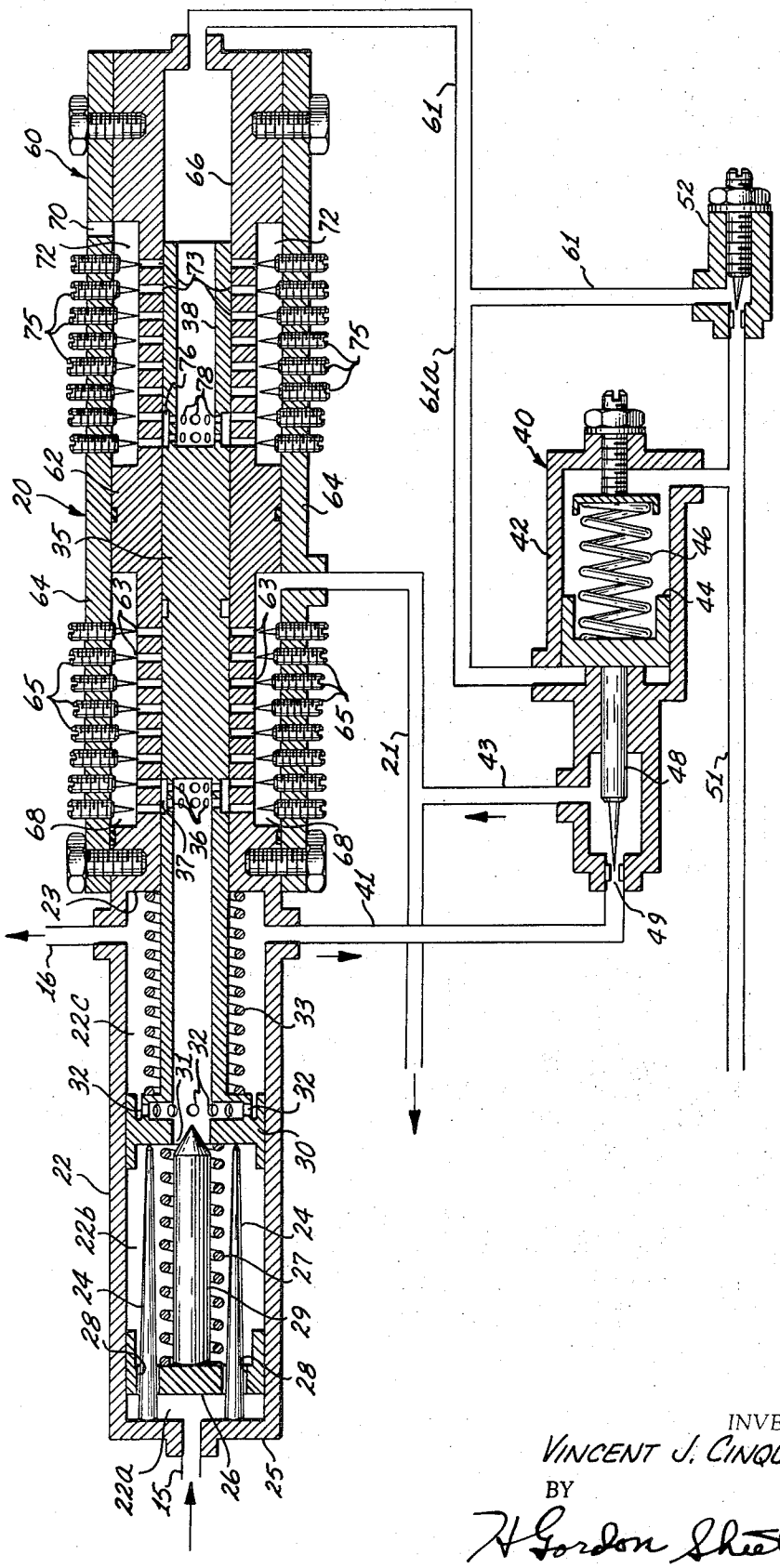


FIG-5

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FUEL INJECTION APPARATUS IN AN INTERNAL COMBUSTION ENGINE

This is a continuation of application Ser. No. 83,040, filed Oct. 22, 1970.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an internal combustion engine and more particularly for apparatus for providing predetermined quantities of fuel to an engine in response to the needs of the engine, as evidenced by speed, load, volumetric efficiency, and other operating conditions of the engine.

2. Description of the Prior Art

A discussion of prior art fuel injection systems is found in my copending application, Ser. No. 817,082, filed Apr. 17, 1969. That application includes a description of a method and of apparatus for overcoming the deficiencies of prior art fuel injection systems.

Internal combustion engines require various quantities of fuel for proper operation under various speed and load conditions, volumetric efficiency, and combustion characteristics of the engine. Generally speaking, as the speed of an engine increases, the fuel requirement also increases, and as the load on the engine increases, the fuel requirement also increases. However, the fuel quantity increases, compensating for the various operating conditions, are generally not straight line functional increases. Most prior art fuel injection and carburetion systems have provided fuel quantities in generally straight line functional increases. For example, the output of an engine driven positive displacement fuel pump is substantially a straight line function of the speed of the pump. The pump therefore compensates only - and incorrectly - for speed requirements of the engine.

Prior art fuel metering systems have not provided engines with fuel in accordance with the actual requirements of the engines over a plurality of operating conditions, including variations in speed, load, and combustion characteristics of the engine. The usual, or more common, situation is to provide an engine with an excess amount of fuel in accordance with the output of the fuel pump. As the speed and load of the engine increases, the amount of excess fuel increases because the difference between the actual fuel demand of an engine and the quantity of fuel supplied by engine driven fuel pumps increases with speed.

Most prior art fuel metering systems have not compensated for the differences in the volumetric efficiency of an engine over its operating range. Briefly, the volumetric efficiency of an engine may be defined as the ratio of the volume of the charge, the fuel and air mixture, inducted into the engine at atmospheric pressure, to the piston displacement of the engine. The volumetric efficiency generally varies throughout the speed range of the engine, in a predeterminable manner.

Another problem with prior art fuel metering systems is the proper atomization of fuel prior to delivery into the cylinders. The delivery of fuel into the cylinders in a state of only partial atomization, or incomplete atomization, results in a loss of efficiency and power.

Vibration is another problem of prior art fuel injection systems, particularly in the environment of engines used for racing purposes. Vibration associated with sustained high speed operations, quick acceleration and deceleration, and rapid maneuvering contribute to mechanical problems of fuel injection systems, such as reliability and accurate metering.

SUMMARY OF THE INVENTION

This invention comprises apparatus for a fuel injection system for metering and injecting fuel in an internal combustion engine.

The following are among the objects of this invention:

To provide apparatus for metering fuel in an internal combustion engine;

To provide apparatus for injecting fuel in an internal combustion engine;

To provide apparatus for metering fuel in an internal combustion engine in accordance with the speed of the engine, the load of the engine, the volumetric efficiency, and the combustion characteristics of the engine;

To provide apparatus for atomizing fuel prior to delivery to cylinders of an internal combustion engine;

To provide apparatus for metering predetermined quantities of fuel in an internal combustion engine in accordance with speed, load, combustion characteristics, and volumetric efficiency conditions of the engine.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a semi-schematic drawing of a fuel injection system in an internal combustion engine;

FIG. 2 is a semi-schematic embodiment of a fuel injection system for an internal combustion engine;

FIG. 3 is a sectional view of an embodiment of fuel delivery apparatus;

FIG. 4 is a sectional view of another embodiment of fuel felivery apparatus; and

FIG. 5 is a semi-schematic view of hydraulically actuable fuel metering apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENT

An internal combustion engine **10**, of a configuration particularly adapted for a racing engine, is shown generally in FIG. **1**. Included are basic components of the engine as they relate to the apparatus of the present invention. No attempt is made to disclose any specific engine and no attempt is made to show all components of an engine, but rather the engine is shown to illustrate the relationship among the various components in a fuel injection system for an internal combustion engine. The engine **10** contains a plurality of cylinders, intake and exhaust valves for each cylinder, crankshaft, pistons, oil pump, and the various components, accessories, and parts normally associated with the block, cylinders, pistons, valves, etc. A fuel supply tank **12** holds fuel for later combustion in the cylinders of the engine. A fuel supply line **13** connects the fuel tank **12** with a fuel pump **14** which may typically be a positive displacement engine driven pump. Another fuel supply line **15** extends between the fuel pump **14** and speed responsive volumetric efficiency valve means **20**, and line **16** extends from valve means **20** to a fuel nozzle junction block from which a plurality of fuel distribution lines **17** convey fuel to a plurality of nozzles. In the configuration shown, each cylinder has a separate air

intake manifold **2** and each manifold has fuel injection nozzle upstream of the throttle (see FIG. **2**).

A fuel return or bleed line **21** runs from speed responsive volumetric efficiency valve means **20,** hereinafter sometimes referred to as volumetric efficiency valve means or as speed responsive valve means to fuel supply **12.** The fuel output, or the amount of fuel bled from line **15** to return line **21,** through valve means **20** varies in a predeterminably adjustable manner with the speed of the engine. The purpose of the speed responsive volumetric efficiency valve means **20** is to compensate for changes in the volumetric efficiency and combustion characteristics of the engine. The flow of fuel through the valve means **20** is predeterminably adjustable and therefore varies in accordance with preset conditions according to the speed of the engine. The valve means **20** will be described in detail infra. Fuel return line **21** serves to return the fuel bled through volumetric efficiency valve means **20** to fuel supply **12.** It will be readily apparent that fuel return line **21** may connect with fuel supply line **13** upstream from pump **14** rather than with fuel supply tank **12.**

Fuel bleed line **41** extends between fuel supply line **16** at the speed responsive valve means **20** and load responsive metering valve means **40,** the output of which, or the amount of fuel bled therethrough, varies in a predeterminably adjustable manner with the load of the engine, as derived from, or determined by, engine manifold vacuum. The purpose of load responsive valve means is to meter fuel according to the load of the engine. Valve means **40** will be described in detail infra. Fuel return line **43** extends from load responsive valve means **40** to return line **21.**

Ratio modulating valve means **60** is responsive to the speed of the engine and it is therefore mechanically associated with volumetric efficiency valve means **20,** and it is directly related to the load responsive valve means **40.** The ratio of the fuel output, or bleed, of the valve means **20** and **40** does not remain constant as speed and load vary. Rather, the ratio varies as speed, load, combustion characteristics, volumetric efficiency, and other engine characteristics and requirements vary. The ratio modulating valve compensates for the ratio variations between the speed responsive volumetric efficiency valve means **20** and the load responsive valve means **40** by modulating the engine vacuum on valve means **40.** Thus it provides for the metering of fuel to different volumetric efficiency curves of the engine, such as at no load conditions, near no load conditions, or road load conditions. Moreover, it provides for a wide range of choices for fuel ratios at different RPM ranges of the engine independently of full load fuel ratio settings. That is, rather than adjust for fuel/air ratio at no load, or idle conditions, which should normally be a rich air/fuel ratio, the ratio can be predeterminably adjusted for various load and speed conditions. The valve means **60** modulates the engine vacuum to the load responsive valve means **40** in a predeterminably adjustable manner throughout the speed range of the engine.

Vacuum line **51** extends from the engine intake manifold to load responsive valve means **40.** A line **61** extends from ratio modulating valve means **60** to line **51.**

The amount of fuel delivered to the cylinders according to the teachings of the present invention varies according to the requirements of the engine at various speed and load conditions of the engine. As heretofore stated, the fuel demanded by an engine varies according to the requirements of the engine at various speed and load conditions of the engine. As heretofore stated, the fuel demanded by an engine varies according to the speed, volumetric efficiency, load, and other factors, but not in a straight line relationship. However, the output of positive displacement fuel pumps generally varies in a substantially straight line relationship with the speed of the engine. It is thus necessary to bleed off, and return to the fuel supply, a quantity of the fuel output of the fuel pump. The amount of fuel returned to the fuel supply from the volumetric efficiency valve and from the load valve is predeterminably adjusted according to the particular engine to provide the correct amount of fuel under a wide range of engine operating conditions. The ratio modulating valve varies, in a predeterminably adjustable manner, the ratio of fuel bled through the volumetric efficiency valve means and through the load valve means.

FIG. **2** shows a semi-schematic representation of a fuel injection system in the environment of the engine of FIG. **1.** Fuel from fuel supply **12** flows through speed responsive volumetric efficiency valve means **20** and through a check valve in fuel line **16** to an engine driven timing valve **18.** While the term "timing valve" is used, it is obvious that a continuous flow distribution system could also be used. Fuel is also bled through the speed responsive valve means and is returned to fuel supply **12** through line **21,** and through load responsive valve means **40** to fuel supply **12** through lines **41** and **43.** The amount of fuel thus bled through the valve means **20** and **40** is predeterminably adjustable, as will be described in detail, infra, in connection with FIG. **5.** The amount of the fuel flowing through line **16** to the timing valve **18,** which in turn distributes the fuel to fuel nozzles in each of the intake manifolds or barrels, is the proper amount according to the various operating conditions of the engine, such as speed, load, volumetric efficiency, and other operating parameters of an individual engine.

Fuel distribution lines **17** extend between the engine driven timing valve **18** and fuel nozzles in each intake barrel or manifold **2.** As shown, the line **17** terminates in a fuel nozzle **4** inside intake manifold **2** upstream from the throttle **8.**

The fuel injection nozzle **4** comprises a tube, such as an extension of fuel distribution line **17,** which is closed at its distal end **5.** Fuel exits nozzle **4,** and enters the air stream in manifold **2,** through a narrow slot **6.** The slot **6** comprises an arcuately extending opening such that the fuel exiting the nozzle enters the air stream generally parallel thereto, and in the same direction. The width of the slot is such as to cause the fuel exiting therethrough to break up into small particles to enhance the atomization of the fuel and to thoroughly mix the fuel and air prior to entry of the fuel/air mixture into a cylinder. The combustion of the fuel/air mixture within the cylinder is thus enhanced also. The length of the slot will vary according to the desired fuel flow, the desired angle of the fuel stream with respect to the air stream, the fuel pressure, the cohesive force of the fuel, the diameter of the nozzle, and other factors. If desired, such as when a high flow capacity is needed, a plurality of slots may be required. If a plurality of slots is used, they should be spaced apart sufficiently to prevent cohesive forces of the fuel particles from causing the

small fuel particles or atomized fuel from combining into fuel droplets. It should be noted that the width of each slot will vary according to the diameter of the nozzle, and that the greater the diameter, the narrower the slot. The discharge nozzle **4** extends perpendicular to the air flow within the manifold **2.**

Another fuel line **81** extends from fuel supply **12** to an idle mixture needle valve **80,** where fuel flowing therethrough is mixed with air through air intake manifold **82** and orifice **83.** The fuel/air mixture then flows through line **84** to idle distribution manifold **86** and through fuel/air distribution lines, such as line **88,** which extends to a nozzle **89** in barrel **2** below the throttle **8.** The purpose or function of this fuel distribution system is, of course, to supply a quantity of fuel and air in the proper ratio at idle speed. Needle valve **80** may be adjusted for the desired fuel/air ratio.

A vacuum line **51** extends from barrel **2** to load valve means **40.** This vacuum line will be discussed in greater detail, below.

Another fuel line **91** extends from fuel supply **12** to a priming and accelerator pump **90.** The pump comprises a cylinder **92** with a piston **93** therein mechanically linked to the throttle linkage. Fuel enters the cylinder **92** from fuel line **91** through cylinder head **94** and flows through ports **96** and through a check valve **97** in the piston.

As the throttle **8** is opened, mechanical linkage moves piston rod **95** and piston **93** in the up direction, as shown in FIG. **2,** closing the check valve, and forcing fuel through spring loaded check valve **98** into fuel line **99** and to fuel line **16** and to the engine driven timing valve **18** where the fuel is distributed to the fuel nozzles and thence to the cylinders of the engine. As the fuel flows from the cylinder **92,** the check valve **98** between cylinder **92** and fuel line **99** is opened and the pressure of the fuel flowing from pump **90** in line **99,** which is greater at this time than the pressure in line **16** from the engine driven fuel pump, causes the spring loaded check valve **19** upstream in line **16** to close. The closing of the valve **19** prevents a back flow of fuel and allows all of the fuel from the priming and accelerator pump to flow to the engine driven timing valve **18** and on to the cylinders.

The closing of the throttle **8** moves the piston rod **95** and piston **93** in the down direction, as shown in FIG. **2,** and fuel in the lower portion of the cylinder **92** below piston **93** flows through ports **96** in the piston, through check valve **97,** and to the upper portion of the cylinder above piston **93.** It will be obvious that a diaphragm type pump or any other suitable pump may be substituted for the pump **90** as illustrated.

Absent the movement of the piston **93** to pressurize the fuel from cylinder **92** to line **99,** the normal fuel pressure in line **16** is sufficient to close check valve **98** and thus prevent a reverse flow of fuel through the cylinder and line **91** to the fuel supply **12.**

Fuel from accelerator and priming pump **90** could be introduced into idle nozzles, such as nozzle **89,** or into a third set of nozzles (not shown), as desired for convenience.

FIG. **3** discloses another embodiment of the fuel injection nozzle of FIG. **2.** In this embodiment the nozzle is located in the intake manifold below the throttle and is thus subject to the vacuum existing there. To prevent the vacuum or low pressure from affecting the flow of fuel from the nozzle, a vented housing is placed around the nozzle. A portion of intake manifold **2** is shown, and throttle **8** is shown without the linkage included in FIG. **2** for purposes of clarity. Within manifold **2** and below or downstream from throttle **8** is located nozzle **104,** similar in construction to nozzle **4** of FIG. **2,** which comprises the termination of a fuel distribution line **117.** Nozzle **104** includes an arcuately extending narrow slot **106,** comparable to slot **6** of nozzle **4** in FIG. **2,** out of which flows a fine spray of fuel particles to be atomized and mixed with air flowing down manifold **2** past throttle **8** and into a cylinder (not shown). Surrounding the nozzle is a housing **107.** A slot **109** in the housing permits the fine spray of fuel from slot **106** to exit nozzle **104** in an unrestricted manner. The slot **109** is thus wider and longer than the slot **106.**

An aperture or inlet **111** in housing **107** is located external of the manifold **2** and allows air at atmospheric pressure or above to enter the housing. The slot **109** is sufficiently large to provide an unrestricted flow of air at atmospheric pressure therethrough. The air pressure within housing **107,** which surrounds nozzle **104,** thus prevents low pressure within manifold **2** from adversely affecting the flow of fuel from slot **106** of nozzle **104.** As discussed in conjunction with the fuel injection nozzle **4** of FIG. **2,** nozzle **104** may include a plurality of slots through which fuel may be discharged. Accordingly, the slot **109** would be enlarged so as not to restrict the flow of fuel therethrough.

FIG. **4** discloses another embodiment of a fuel injection nozzle. This nozzle may be inserted in the intake manifold upstream from, or above, the throttle. Nozzle **200** is shown within intake manifold **2** above the throttle. An air plenum chamber **202** is surmounted on a venturi tube **204.** An air pump **206** is located outside the intake manifold. The air pump includes an air intake tube through which air at atmospheric pressure enters the pump. Air is compressed within the pump, which may be of any appropriate, well known, design, and flows through conduit **207** to plenum chamber **202.** The plenum chamber communicates directly with the venturi tube **204.** Fuel distribution line **217,** which distributes fuel to the intake manifold, enters into the interior of plenum chamber **202** and passes through the chamber and into the venturi tube **204.** Fuel distribution line **217** becomes a fuel discharge nozzle **208.** The nozzle **208** is terminated by an end wall **209.** At or below the throat **205** of venturi tube **204** are narrow fuel discharge slots **210** through which fuel enters the pressurized air stream emanating from plenum chamber **202** through venturi tube **204.** The fine spray of fuel from slots **210** is discharged into the air stream perpendicularly thereto. The mixing of the fine spray and the pressurized air stream enhances the atomization of the fuel prior to the entry of the fuel and air mixture into the cylinders (not shown). Fuel and air from the nozzle **200** enter the air stream within intake manifold **2** where further mixing of the fuel and air mixture occurs. Discharge slots **210** extend arcuately in such a manner that fuel is sprayed radially with respect to the nozzle, and perpendicularly with respect to the flow of air, at or below the throat **205** of the venturi tube **204.** If the nozzle is located below the throttle, the slots **210** should be above the throat.

FIG. **5** shows a semi-schematic representation of a hydraulically actuable fuel injection system in the environment of the engine of FIGS. **1** and **2.** Fuel from fuel supply **12** (see FIGS. **1** and **2**) flows through the engine

driven positive displacement pump and through line **15** into a chamber **22a** of compound fuel metering cylinder **22.** The cylinder includes a plurality of tapered rods **24** fastened to cylinder head **25.** The taper of the rods is such that the diameter decreases away from the head **25.** A first piston, sensing or metering piston **26,** is located in the compound fuel metering cylinder with the head of the piston **26** adjacent the cylinder head **25.** The tapered rods extend through a plurality of apertures or variable fuel metering orifices **28** in the head of metering piston **26.** Piston rod **29** extends from the head of the metering or sensing piston and comprises a needle valve for an orifice **31** in the second piston, servo piston **30,** in the compound fuel metering cylinder **22.** A compression spring **27,** which extends about the piston rod **29** between metering piston **26** and servo piston **30,** urges the metering piston toward the cylinder head **25** and away from servo piston **30** so as to maximize the size of the orifice **31.** This occurs as the needle valve portion of the piston rod **29** moves away from, or out of, the orifice **31** from a decrease in the pressure of the fuel from the fuel pump through line **15** against the head of metering piston **26** which allows the bias of the spring **27** to move piston **26** and the piston rod needle valve secured thereto.

With an increase in the speed of the engine, there is a consequent increase in the fuel flow from the fuel pump through fuel line **15** and chamber **22*a*** against sensing or metering piston **26,** urging the piston against the bias of the spring **27.** Fuel flows from chamber **22*a*** through the variable orifices **28** in the piston head to chamber **22*b*** in the interior of compound cylinder **22** between metering piston **26** and servo piston **30.** By using variable orifices **28** between chamber **22*a*** and chamber **22*b*** in the interior of the compound cylinder, the fuel pressure across the orifices inside the cylinder is relatively constant.

Fuel pressure acts on the face of servo piston **30** and moves it against the bias of compression spring **33.** The significance of the motion of the servo piston will be described in detail below.

Fuel flows through orifice **31** in the head of servo piston **30** and into the chamber **22c** of the compound cylinder **22** through ports **32** which communicate with the orifice **31** and bore **34** of piston rod **35.** The fuel flows from chamber **22c** to engine driven timing valve **18** (see FIGS. **1** and **2**) through fuel line **16** and fuel also bleeds through fuel return line **41** to the load valve **40** and on to the fuel supply through return lines **43** and **21.**

Fuel also flows from orifice **31** through hollow portion or bore **34** of piston rod **35** to the metering portion of the speed responsive volumetric efficiency valve means **20.** The bore **34** of the piston rod **35** comprises a conduit for fuel between chamber **22*b*** of the compound cylinder and the metering portion of the volumetric efficiency valve means **20.** The bore **34** of the piston rod **35** terminates in ports **36** which communicate with an annular recess or chamber **37** circumferentially extending about the piston rod.

The compound cylinder **22** is contiguous to the metering portions of both the valve means **20** and the ratio modulating valve means **60.** The metering portions include a valve body or block **62** and a pair of plates **64** suitably secured thereto by well known fastening means. Face **23** of block **62** comprises the head or end wall of the cylinder for chamber **22c.** The compression spring **33** extends between the face **23** of block **62** and the servo piston **30** to urge the piston against or towards the tapered rods **24.**

A bore **66** extends through the valve body and receives the piston rod **35.** The metering portion of the volumetric efficiency valve means **20** serves to bleed fuel from compound fuel metering cylinder **22** through chamber **22*b***, orifice **31,** bore **34,** ports **36,** annular recess **37,** and through a plurality of apertures or passages **63** in block **66** to chamber **68** and to fuel return line **21** to the fuel supply.

The amount of fuel bled through apertures **63** depends upon both the position of servo piston **30** and piston rod **35** attached thereto, and the setting of a plurality of adjustable screws **65.** The screws are adjusted so as to provide the proper amount of fuel flow from bore **34,** ports **36** and annular recess **37** through apertures **23** to chamber **68.** From chamber **68** the bleed fuel flows through return line **21.** Annular recess **37** on piston rod **35** communicates with a plurality of apertures **63** throughout the length of travel of piston rod **35.** The amount of fuel thus bled through the speed responsive volumetric efficiency valve means is thus predeterminably adjustable throughout the speed range of the engine.

Piston rod **35** includes two hollow portions, one of which is bore **34,** and the other of which is another bore **38** in the ratio modulating valve portion of block **62.** A solid shank portion of the rod **35** extends between the hollow portions. Appropriate sealing means may be used to prevent leakage of fuel or air between the respective bores **34** and **38.**

The ratio modulating valve means **60** serves to modulate, also in a predeterminably adjustable manner according to the speed of the engine, the engine vacuum at the load valve **40.** The load valve in turn bleeds additional fuel from the compound cylinder **22** in accordance with engine load conditions as manifested by engine vacuum modulated by the ratio modulating valve **60.** Air at atmospheric pressure enters the ratio modulating valve portion of the block **62** through aperture **70.** Aperture **70** communicates with an annular chamber **72.** Extending between chamber **72** and bore **66** of block **62** are a plurality of apertures **73.** A plurality of adjustable screws **75** extend into the apertures **73** and vary the size of the apertures and thus the air flow therethrough. Annular recess **76** on piston rod **35** communicates with ports **78,** which extend from bore **38** to the annular recess **76.** Throughout the length of travel of piston rod **35,** the recess **76** communicates with a plurality of apertures **73.**

The incoming air from chamber **72** flows through apertures **73** and annular recess **76** and ports **78** into bore **38** of piston **35.** The bore **38** is open to bore **66** and the air flows therethrough to line **61** which extends from bore **66** of block **62** to load valve **40.** The amount of air flow to the load valve varies in a predeterminably adjustable manner, according to the settings of the adjustable screws **75** and the position of servo piston **30** and its piston rod **35.** The positioning of the piston **30** and rod **35** varies, as previously discussed, according to the speed of the engine as manifested by the pressure of the fuel. Thus it may be seen that the servo piston **30** is hydraulically actuable and it controls the positioning of its piston rod **35,** which comprises the movable valve stem of both the volumetric efficiency valve means and the ratio modulating valve means.

Vacuum line **51** extends between an intake manifold (see FIGS. **1** and **2**) and the load valve **40.** Line **51** also connects with air line **61** from the ratio modulating valve **60** through an adjustable needle valve **52.** Engine manifold vacuum through line **51,** as modulated by air pressure from the ratio modulating valve through line **61,** causes movement of piston **44** in cylindrical valve housing **42.** Movement of the piston **44** is opposed by compression spring **46,** the bias of which may be adjusted, in a well known manner, as shown. Air pressure against the forward head or face end of piston **44** through line **61***a* from the ratio modulating valve aids in the movement of the piston against the bias of the spring **46.** Thus air pressure on one side of the piston combines with modulated engine vacuum on the opposite side of the piston to effect movement of it against the biasing action of the adjustable spring.

Secured to the face of piston **44** is a tapered needle **48** which, with orifice **49,** comprises a needle valve to control the flow of fuel from line **41** to lines **43** and **21** and thence back to the fuel supply. Under high load conditions, when engine vacuum through line **51,** as modulated by the air in line **61** through adjustable needle valve **52,** is low, e.g. 0–1 inches (gage) of engine manifold vacuum, piston **44** is moved by the bias of spring **46,** and the movement of the tapered needle **48** into orifice **49** decreases the size of the orifice and thus decreases the flow of fuel therethrough from chamber **22***c* of compound cylinder **22** through line **41** to return lines **43** and **21.** This in turn results in an increase in the amount of fuel to the fuel nozzle through line **16.**

When load conditions are lighter, and the engine vacuum is high, e.g. 18 inches (gage) of manifold pressure, the vacuum, as modulated, causes movement of piston **44** against the bias of spring **46** which in turn causes movement of the tapered needle **48** out of, or away from, orifice **49** thus increasing the size of the orifice. The enlarged orifice allows more fuel to be bled through line **41** to return lines **43** and **21** and back to the fuel supply.

The ratio modulating valve adjustably varies the air pressure and thus the engine vacuum at the load valve. The speed responsive volumetric efficiency valve and the load valve cooperate to bleed the proper amount of fuel away from the output of the fuel pump such that the correct amount of fuel, as predetermined, is delivered to the engine under the operating conditions, with respect to both speed and load, of the engine. The ratio modulating valve cooperates with the load valve in modulating the engine vacuum and thus the fuel bled through the load valve. At any given engine speed, the output of the fuel pump is constant, but the amount of fuel required between full load and no load may vary by a ratio of about 3 to 1. Therefore, if the output of the fuel pump is about 90 gallons per hour, and the demand of the engine is for only 30 gallons per hour, about 60 gallons must be bled off. The speed responsive volumetric efficiency valve bleeds some fuel according to the speed of the engine in accordance with predetermined settings or amounts. For example, at an output from the fuel pump of about 90 gallons per hour, the volumetric efficiency valve bleeds about 30 gallons per hour. The load valve must bleed off the remaining 30 gallons per hour. Since the ratio of the fuel bled by both valves is not constant over the speed range of the engine, the ratio modulating valve varies the ratio by varying in a predetermined manner the output of the load valve.

The above described fuel injection system, including the hydraulically actuable speed responsive volumetric efficiency valve means and the ratio modulating valve means and the various embodiments of fuel injection nozzles, provides the proper amount of fuel for the engine according to the demand of the engine under various, or a plurality of, speed and load conditions, and provides for the proper atomization of fuel prior to delivery into the cylinders.

While the principles of the invention have now been made clear in an illustrative embodiment, no attempt has been made to disclose, discuss, or illustrate all possible alternatives and modifications. Rather, the specification has been prepared in accordance with the applicable patent laws and the rules promulgated under the authority thereof. There will be immediately obvious to those skilled in the art many modifications in structure, arrangement, proportions, elements, and components, used in the practice of the invention, and otherwise, which are particularly adapted for specific environments and operating requirements without departing from the principles of the invention. The appended claims are therefore intended to cover and embrace any such modification, within the limits only of the true spirit and scope of the invention.

What is claimed is:

1. In an internal combustion engine having at least one cylinder, fuel injection apparatus comprising, in combination:

an air intake manifold communicating with said cylinder;

fuel supply means;

fuel pump means for providing a flow of fuel according to the speed of the engine;

speed responsive valve means responsive to the speed of the engine for varying the flow of fuel from the fuel pump means, said speed responsive valve means including a compound cylinder, a fuel metering piston movable in said cylinder, a variable orifice in said piston for metering fuel from said fuel pump means through said speed responsive valve means, a servo piston movable in the compound cylinder, a first chamber in said compound cylinder between said fuel metering piston and said servo piston, movement of said servo piston responsive to the flow of fuel in said first chamber, a second chamber in said compound cylinder, orifice means in said servo piston for controlling the flow of fuel from said first chamber, a piston rod secured to said servo piston, conduit means in said piston rod communicating with the orifice means, means for providing a flow of fuel from said orifice to said second chamber, a block, a chamber in said block, a bore in said block for the receiving the piston rod attached to said servo piston, apertures in said block for communicating between said bore and said chamber in the block, a recess on said piston rod providing a flow of fuel from the conduit in the rod to the apertures in the block, means for predeterminably varying the flow of fuel through the apertures in the block, and fuel return line for returning fuel from the chamber in the block to the fuel supply means;

load responsive valve means for further varying the flow of fuel from the fuel pump means responsive to air intake manifold pressure;

first conduit means for providing a flow of fuel from the chamber in the block to the load responsive valve means;

ratio modulating valve means for varying the air intake manifold pressure at the load responsive valve means in a predeterminably adjustable manner in response to speed of the engine;

second conduit means for providing a flow of fuel from the second chamber of the compound cylinder to the air intake manifold;

nozzle means in said air intake manifold for discharging fuel from the second conduit means in said air intake manifold;

a throttle in said air intake manifold; and

accelerator pump means for providing a flow of fuel to said air intake manifold responsive to movement of the throttle.

2. The apparatus of claim **1** in which the nozzle means comprises a discharge nozzle in said air intake manifold extending from the second conduit means perpendicularly to the flow of air in said air intake manifold, said nozzle including a closed distal end within the air intake manifold;

at least a single narrow slot on said discharge nozzle extending arcuately therealong for discharging small particles of fuel through said narrow slot generally parallel to, and in the same direction as, the flow of air in said air intake manifold.

3. The apparatus of claim **2** in which the nozzle means includes a housing, said housing extending around said discharge nozzle;

a slot on said housing adjacent the slot on said discharge nozzle to allow the discharge of fuel particles from the narrow slot on the discharge nozzle therethrough; and

means on said housing to provide air at atmospheric pressure in said housing.

4. The apparatus of claim **1** in which the nozzle means includes an air plenum chamber;

a venturi tube extending from said air plenum chamber, said venturi tube including a throat;

air pump means for providing a flow of pressurized air into said plenum chamber and said venturi tube;

a fuel discharge nozzle in said venturi tube;

slot means for discharging fuel particles into the flow of pressurized air in said venturi tube.

5. The apparatus of claim **4** in which the slot means discharge fuel particles perpendicularly to the flow of pressurized air.

6. The apparatus of claim **5** in which the slot means discharge fuel particles at the throat of the venturi tube.

7. The apparatus of claim **1** in which the accelerator pump means comprises:

a cylinder, said cylinder including a cylinder head;

a piston in said cylinder, said piston including a port therein for providing a flow of fuel therethrough;

a piston rod attached to said piston and extending through said cylinder head;

fuel line means extending from said fuel supply means to said cylinder;

fuel line means extending from said cylinder to said air intake manifold;

throttle means extending from said throttle to said piston rod for moving said piston rod in response to movement of said throttle.

8. The apparatus of claim **1** in which the fuel supply means includes an idle distribution manifold for providing fuel and air at idle speeds, and an idle mixture needle valve for providing a fuel and air mixture to said idle distribution manifold.

9. In an internal combustion engine, apparatus for metering fuel according to speed and load conditions of the engine, comprising, in combination:

an intake manifold;

nozzle means in said intake manifold;

fuel pump means for providing a flow of fuel according to the speed of the engine;

cylinder means for receiving the flow of fuel;

a piston for sensing the flow of fuel and movable in said cylinder means in accordance with the said flow of fuel;

a variable orifice in said piston through which the fuel flows and varying according to movement of said piston;

means for biasing the piston against the flow of fuel;

means for providing a first flow of fuel from said cylinder means;

means for providing a second flow of fuel from said cylinder means to the nozzle means in the intake manifold; and

load valve means responsive to load conditions of the engine for varying the second flow of fuel from said cylinder means.

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