

[54] **FLUIDIC FUEL INJECTION DEVICE
HAVING AIR MODULATION**

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represented by the Secretary of the
Army, Washington, D.C.**

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261/DIG. 69

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[58] **Field of Search**..... 261/DIG. 69, 50,
261/51, 69; 123/119 R, 32 EA, DIG. 10, 139
AW, 140 MC

[56]

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Primary Examiner—Wendell E. Burns

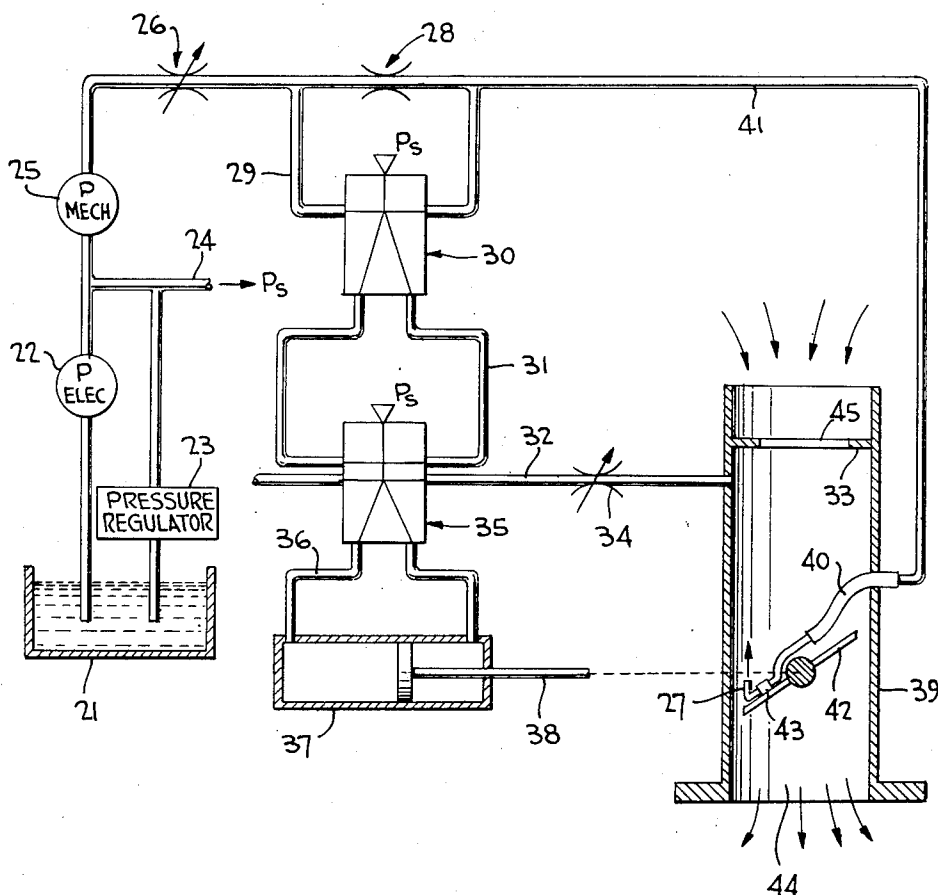
Attorney—Harry M. Saragovitz et al.

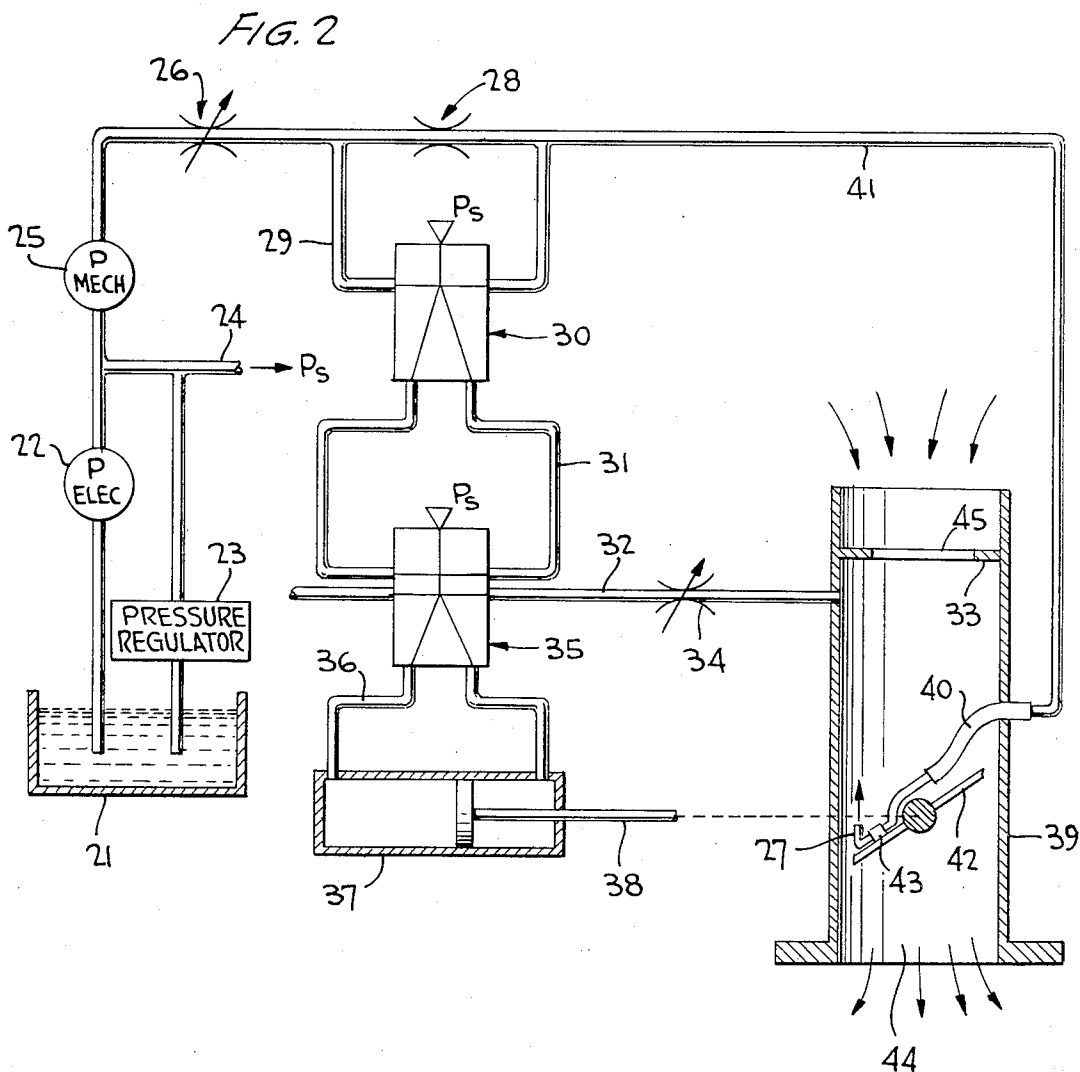
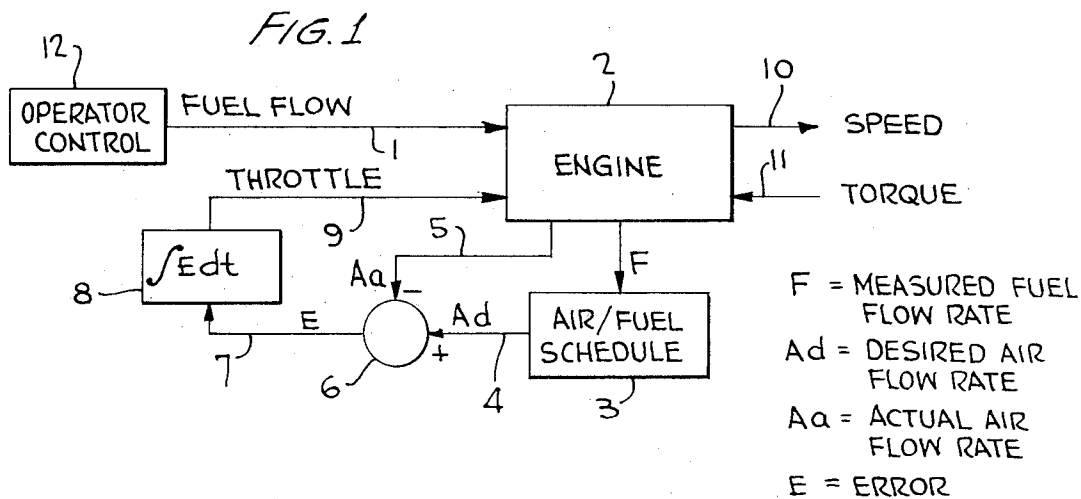
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ABSTRACT

Means for regulating the air-fuel mixture ratio in a fuel delivery system. The present invention departs from other known fuel delivery systems in that the air flow is scheduled as a function of the operator's selected fuel flow. In conventional systems the fuel flow is scheduled as a function of the operator's selected air flow. Fluidic technology is utilized in a preferred embodiment for the sensing, computation, and actuation of the required variables.

9 Claims, 5 Drawing Figures





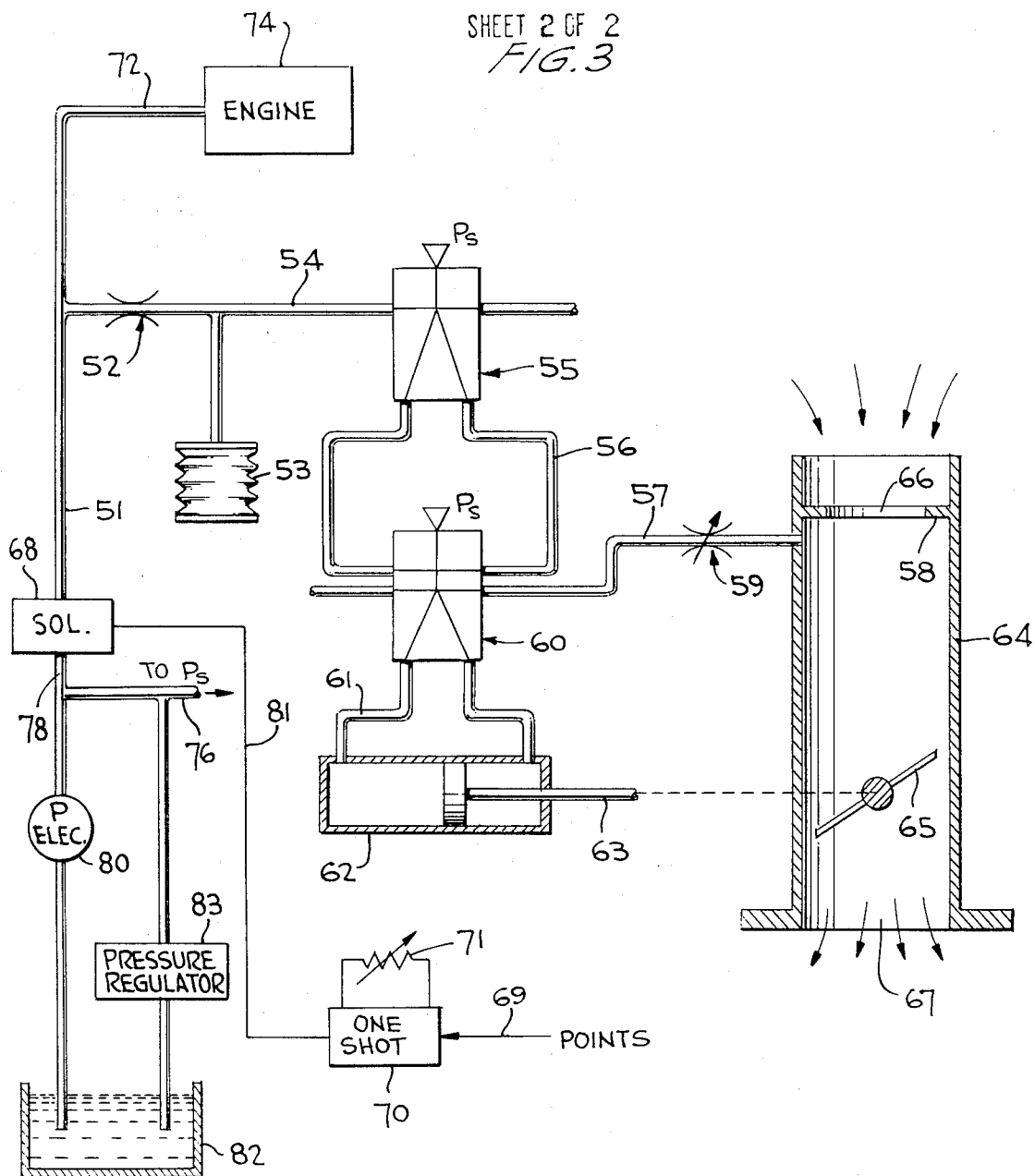


FIG. 4

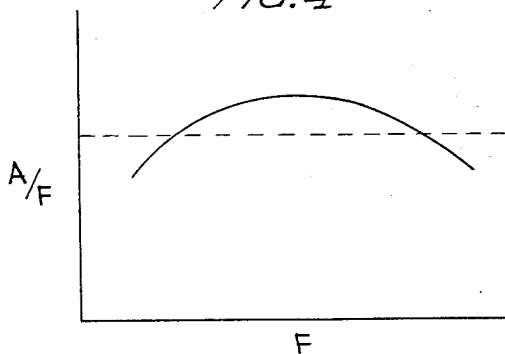
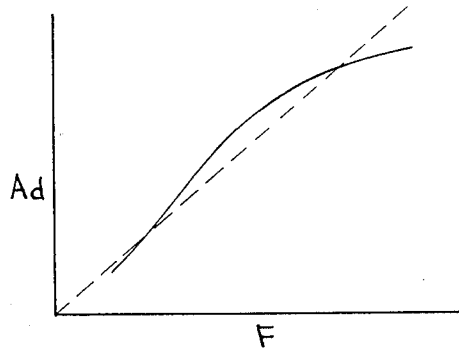


FIG. 5



FLUIDIC FUEL INJECTION DEVICE HAVING AIR MODULATION

RIGHTS OF GOVERNMENT

The invention described herein may be manufactured, used, and licensed by or for the United States Government for governmental purposes without the payment to me of any royalty thereon.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to fuel delivery systems, and more particularly, to systems for regulating the air-fuel mixture ratios for internal combustion engines.

2. Description of the Prior Art

There has long been interest in fuel control systems for spark ignition internal combustion engines. Systems to improve economy, boost power and performance, or to decrease cost have been investigated in large numbers. The present emphasis is toward reduced exhaust emissions. Very complicated and/or precise fuel management systems are being developed in the hope of finding and developing means for finer scheduling of air-fuel mixtures to reduce emissions. As a result, economy and power considerations for low emissions are suffering since in conventional systems, these are generally nonconcomitant requirements.

With the advent of fluidic technology, engineers saw the possibilities of utilizing fluidic amplifiers in the sensing of engine operating conditions and the metering of air-fuel mixture requirements. See, for example, the following U. S. Pats. Nos.: 3,477,699; 3,388,898; 3,386,709; 3,406,951; 3,587,543; 3,386,710; 3,389,894; 3,463,176; 3,556,063. I acknowledge the advantages of the foregoing devices in the reduction of the number of moving parts and increased reliability and better fuel management; however, they all have the inherent disadvantage attendant existing carburetion systems in which the fuel flow is scheduled as a function of the operator's selected air flow.

Accordingly, it is a primary object of the present invention to provide a fuel management system for an internal combustion engine in which fuel flow is controlled directly by the operator whereby optimum air flow is scheduled and controlled as the function of the selected fuel flow.

Another object of the present invention is to provide a fuel management device having the simplicity of a carburetor combined with the operational capabilities of complex fuel injection systems.

A further object is to provide a fuel management system which delivers low emissions normally associated with precise scheduling of very lean economical mixtures but still having the capabilities of providing the rich mixtures required for maximum performance with no additional circuitry.

Another object is to provide a fuel management system that is applicable to either continuous or pulsed fuel injection systems.

A still additional object of the present invention is to provide a fuel management system in which the required control variables to be sensed are all available within the device thus requiring no additional circuitry.

Additional object of the present invention is to provide a fuel injection device that utilizes air modulation and has the characteristics of simplicity of design, no

moving parts, inexpensive to manufacture, and high reliability.

SUMMARY OF THE INVENTION

Briefly, in accordance with the invention, apparatus for regulating the air-fuel mixture ratios in fuel delivery systems for an internal combustion engine is provided which comprises means for selecting a fuel flow rate under the direct control of the operator and means for controlling the desired air flow rate as a function of the fuel flow rate. Disclosed are two embodiments of the fuel delivery system: one which utilizes continuous fuel injection and the other which utilizes a pulsed fuel injection system. The embodiments are presented in the fluidic context, although it is understood that the system as described below can be implemented utilizing a variety of arts, such as mechanically, electronically, hydraulically, or fluidically.

BRIEF DESCRIPTION OF DRAWING

The specific nature of the invention as well as other objects, aspects, uses, and advantages thereof will clearly appear from the following description and from the accompanying drawings, in which:

FIG. 1 illustrates in block diagram form the fuel management system which is the heart of the present invention;

FIG. 2 illustrates a schematic representation of a preferred embodiment of the present invention;

FIG. 3 presents another preferred embodiment of the present invention; and

FIGS. 4 and 5 are graphs which are helpful in understanding the principles of operation of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A spark ignition internal combustion engine requires the delivery of air and fuel in proper proportions in order to support efficient combustion. The optimum air-fuel mixture ratio varies somewhat with operation; however, the two must be accurately coordinated for optimum engine operation.

The basic fuel management concept of the present invention is illustrated in FIG. 1. In FIG. 1, the fuel flow 1 is the independent input under the direct control of the operator via the control means 12 to the engine 2. The controlled variable of the system of the present invention is the optimum air flow rate scheduled as a function of the operator's selected fuel flow rate. For each value of fuel flow rate there is a corresponding optimum value for the air flow rate. This is illustrated by means of the graph in FIG. 4 wherein it is seen that for a given fuel flow, F , there is a single value for the optimum air-fuel ratio A/F regardless of engine speed. The dashed line of FIG. 4 represents the stoichiometric ratio. This optimum or desired air flow rate, A_d , is the output from a function generator 3 which schedules the desired air flow A_d as a function of the fuel flow F as shown by the curve of FIG. 5. Also measured from engine 2 along the conduit 5 is the actual air flow rate A_a . The desired air flow rate from conduit 4 and the actual existing air flow rate along conduit 5 are compared in a summing junction 6. The two should coincide; if they do not, an error signal is generated along conduit 7 that indicates the difference between the desired and the actual air flow rates. This error signal E is used to actu-

ate the throttle of the engine along conduit 9 until the error in the actual air flow is reduced to zero. An integrator 8 maintains the actuation signal required for zero error. With the proper scheduling of air flow and fuel flow, the engine 2 can produce an optimum speed 10 depending on the loading torque 11.

The above described system illustrated in FIG. 1 can be implemented utilizing a variety of arts including mechanical, electronic, fluid power, or fluidic. Components to implement each of the functions in the block diagram of FIG. 1 are well known to designers knowledgeable in the disciplines mentioned above. The following description of a preferred embodiment is directed towards a fluidic implementation since it appears to be the least complicated of the foregoing.

The fluidic embodiments can be realized in either continuous or pulsed fuel injection systems. In both cases the fuel consumption rate is controlled by the operator and the air consumption rate is controlled by the fluidic control circuitry. Fluidic control circuitry can be identical for the two types of systems. Another common feature of the two systems is fuel limiting sensitive to engine speed. The maximum fuel flow which an engine can consume without flooding is directly proportional to its speed. This maximum fuel flow occurs at full throttle. A device such as a mechanical fuel pump driven by engine speed may be necessary to produce a maximum fuel flow capability as a function of engine speed. The operator can select any fractional part of the maximum fuel rate obtainable at a given speed by means of a fuel consumption modulator. By limiting fuel flow in this manner, the operator can select any fuel flow rate he desires; the speed sensitive limiting will merely prevent him from selecting a fuel flow large enough to flood the engine. The location of fuel injection, the modulation and the measurement of fuel consumption differs for the two systems.

The fluidic circuit for the continuous fuel injection systems is shown in FIG. 2. In operation, fuel from a reservoir storage tank 21 is pressurized by an electric fuel pump 22 which provides a power source for the fluidic circuitry and the fuel injection nozzle 27. A pressure regulator 23 maintains a constant fuel pressure along conduit 24 from fuel pump 22 for the fluidic control circuitry. A mechanical fuel pump 25 driven by the engine limits the maximum fuel consumption which can be delivered. A variable fluid resistor 26, which is controlled by the operator via e.g. a foot pedal, is used to modulate the fuel consumption rate. The operator's selected fuel flow rate is then directed along conduit 41 to a mixing device 39 which finely atomizes the fuel and mixes it with the intake air through opening 45. The fuel can be injected in a variety of places and manners. The fuel injection nozzle 27 provides a high velocity point for fuel injection both for idling and for high engine speeds. Conduit 41 ends in a flexible portion 40 to provide freedom of movement for nozzle 27 which is rigidly attached to throttle 42 at point 43. Injection at the orifice 33 or from the wall adjacent to throttle 42 are other alternatives to the one shown.

The fuel flow directed toward the engine is passed through a measuring fluid resistor 28. The pressure drop across resistor 28 is indicative of the fuel flow rate. This measured fuel flow signal is the input 29 to a proportional fluid amplifier 30. This fluid amplifier serves as a function generator and is specially designed to have input-output characteristics corresponding to

the optimum air-fuel mixture schedule. The graphical representation of the input-output characteristics is shown in FIG. 5 wherein the fuel flow F is plotted as the input to fluid amplifier 30 and the output is designed to follow the solid curve shown. The design of a suitable amplifier is well within the purview of one ordinarily skilled in the fluidic art. The output of amplifier 30 is a pressure signal along conduit 31 indicating the desired air flow rate A_d as a function of the measured fuel flow rate F .

The actual air flow rate to the engine A_a is indicated along conduit 32 by the pressure drop across a measuring orifice 33 located in the main air intake stream 45 of mixing device 39. A variable fluid resistor 34 is employed to allow adjustment in the overall air-fuel ratio. The desired air flow rate along conduit 31 and the actual air flow rate along conduit 32 are compared in a proportional fluidic summing amplifier 35. Fluidic summing amplifier 35 is specially designed to permit the operation of a gasoline power jet deflected by a pneumatic vacuum control jet without entrainment of gasoline in the control line. Summing amplifier 35 is designed such that if the desired and indicated air flows coincide, no error signal E will be produced. If these air flow signals are not the same value, an error signal will be generated along output 36 to actuate a fluid power actuator 37 that adjusts the throttle position by means of connection 38 and thereby adjusts the air flow in mixing device 39 until the error is reduced to zero. The actuator 37 provides the function of integration to maintain the throttle position required for zero error.

The fluidic control circuit for the pulsed fuel injection system is shown in FIG. 3. In this system a pulsed signal is generated by either mechanical, electronic or fluid means. An electrical circuit is shown in FIG. 3 wherein the signal from the points in the engine is passed via wire 69 to a one shot multivibrator 70. The one shot produces a pulse of specified duration each time it is triggered by the signal from the points. The operator's control of the pulse width is represented by the variable resistance 71. The pulse output of one shot 70 is fed to solenoid 68 which produces fuel pulses in accordance with the one shot 70. The frequency of fuel pulses so produced is directly proportional to the engine speed. This frequency and the pulse width or amplitude, or both, determines the fuel consumption. In the system of the present invention, it is convenient to consider only the pulse width as being variable. The amplitude may be maintained at a constant pressure, and the pulse frequency as determined by the engine speed in conjunction with the pulse width or duration will provide the desired fuel limiting.

In the operation the circuit of FIG. 3, the pulsed fuel signal along conduit 51 is smoothed to a continuous (DC) value by a fluidic resistive-capacitive filter. A fluid resistor 52 and a fluid capacitor 53 comprise the fluidic filter which is set to filter the maximum AC frequency to a usable DC signal. The filtered signal along line 54 is directly related to the engine fuel consumption. Once the fuel consumption signal is obtained, the operation of the air control circuit is identical to that of the continuous fuel injection system described in FIG. 2 above. That is to say, the measured fuel consumption signal is the input 54 to a specially fabricated proportional fluidic amplifier 55 which has input-output characteristics in the shape of the desired air-fuel schedule. The output of amplifier 55 is a pressure

signal along line 56 indicative of the desired air flow rate. The actual air flow rate along line 57 is indicated by the pressure drop across an orifice 58 located in the main air stream 66. A variable fluid resistor 59 is used to adjust the overall air-fuel ratio desired. The desired 56 and actual 57 air flow signals are compared in a fluidic summing junction 60 which has been specially designed to operate with a gasoline power jet and a pneumatic vacuum control signal without entrainment of gasoline in the control port. The output of summing junction 60 is an error signal through conduit 61 indicating the difference between the desired and actual air flow. The error signal is used to move a fluid power actuator 62 which in turn actuates the position of shaft 63 and throttle 65 which controls air consumption through port 67. The actuation continues until the error is reduced to zero.

It is seen by the foregoing that I have provided a fuel injection device that utilizes a completely novel and unique air modulation technique. This philosophy of mixture scheduling permits the scheduling of lean economical or optimum emission mixture ratios for normal operation below full throttle. As fuel and loading are increased, the full throttle limit is reached in which the throttle 65 is fully opened and no more air can be naturally aspirated. With this system, the operator can then increase fuel flow if he so desires. This action will signal the control system to increase air flow; however, at full throttle no more air can be aspirated at a given speed. The net effect is that a rich mixture is delivered to the engine. Although this operation is not at optimum economy or emissions, more power can be obtained with the richer mixture. Thus, the lean mixtures for economy or emissions and the rich mixtures for power are both inherently delivered by this device without any changes in setting or progressive stages such as in a four barrel carburetor. Other fuel systems without progressive staging must be set either lean for economy or rich for power but not both.

The device of the present invention inherently provides acceleration enrichment. Since throttle actuation lags a sudden changes in fuel flow, the delivered mixture ratio is temporarily enriched for acceleration and leaned for deceleration. The actuation dynamics can be sized provide the proper lag. This eliminates the additional accelerator pump circuitry required in most carburetors. Most conventional systems do not have provisions for deceleration leaning, also inherently provided by the device of the present invention.

FIG. 5 makes it clear that the optimum air-fuel function has the shape of the input-output characteristics of a typical fluidic device. This allows simple and accurate mixture scheduling. Additionally, cold enrichment as a function of engine water temperature can be provided by a temperature sensing resistance in the cooling systems with no moving parts, whereas in conventional carburetors a moving part choke is necessary which is sensitive to exhaust temperatures. Compensation for environmental changes can easily be added. As an added feature, the required control variables to be

sensed are all available within the device of the present invention. All signals exist as fluidic signals so that the interfaces between fluid signals and mechanical or electrical signals required in most systems is avoided. The existing fuel pressure can be used in the fluidic circuit for computation and actuation, eliminating the need for a separate power source. The device of the present invention provides simplicity in design, minimal moving parts, high reliability and is inexpensive to produce.

I wish it to be understood that I do not desire to be limited to the exact details of the construction shown and described, for obvious modifications will occur to a person skilled in the art.

I claim:

1. Apparatus for regulating the air fuel mixture ratios in a fuel delivery system or an internal combustion engine, comprising:

- a. Means for selecting a fuel flow rate to said engine, said selecting means under the direct control of the operator of said engine;
- b. means for scheduling the desired air flow rate as a function of said fuel flow rate;
- c. means for comparing said desired air flow rate with the actual air flow rate and for issuing the first signal indicative of the difference therebetween; and
- d. means for adjusting said actual air flow rate in response to said signal to correspond to said desired air flow rate.

2. The invention according to claim 1 wherein said scheduling means and said comparing means have no moving parts.

3. The invention according to claim 2 wherein said scheduling means comprise a fluidic amplifier whose input-output characteristics correspond to the desired air-fuel mixture ratio.

4. The invention according to claim 3 further comprising means for mixing said fuel flow with said desired air flow.

5. The invention according to claim 4 wherein said mixing means comprises

- a. means for measuring the actual air flow rate to said engine and for delivering a second signal indicative thereof to said comparing means and
- b. a throttle for controlling the air flow rate to said engine.

6. The invention according to claim 5 wherein said comparing means comprises a fluidic summing amplifier.

7. The invention according to claim 6 wherein said adjusting means comprises a fluid power actuator that is connected to said throttle.

8. The invention according to claim 7 wherein said selecting means comprises a variable fluid restrictor that provide a continuous flow of fuel to said engine.

9. The invention according to claim 7 wherein said selecting means comprises means for generating a pulsed fuel signal to said engine.

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