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Showalter et al.

[11] **3,815,562**

[45] **June 11, 1974**

[54] **PRESSURE COMPENSATED AIR THROTTLE AND AIR-FUEL CONTROL SYSTEM**

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[52] **U.S. Cl.** ..... **123/119 R,** 123/139 AW, 123/100, 123/106

[51] **Int. Cl.** .. **F02m 39/00,** F02b 3/00, F02m 23/00

[58] **Field of Search** ..... 123/119 R, 139 AW

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Primary Examiner—Wendell E. Burns

Attorney, Agent, or Firm—Witherspoon and Lane

[57] **ABSTRACT**

An air throttle is disclosed which meters a constant airflow for each control position over the range of manifold vacuums encountered in engine operation. Throttle metering area is the product of two perpendicular openings, an x-opening proportional to desired airflow and a y-opening controlled as a function of manifold vacuum to compensate throttle area for variations in manifold vacuum so that airflow for a given x-opening is constant or a desired function over the range of manifold vacuums. If flow per unit area is a function of intake manifold vacuum g(IMV) the y-opening of the throttle is proportional to 1/g(IMV) to maintain constant airflow at a given control setting x. If fuel flow is controlled proportionately to x and an air-fuel ratio function h(IMV) is desired, the throttle will produce it with a y-opening controlled to vary in proportion with h(IMV)/g(IMV).

9 Claims, 11 Drawing Figures

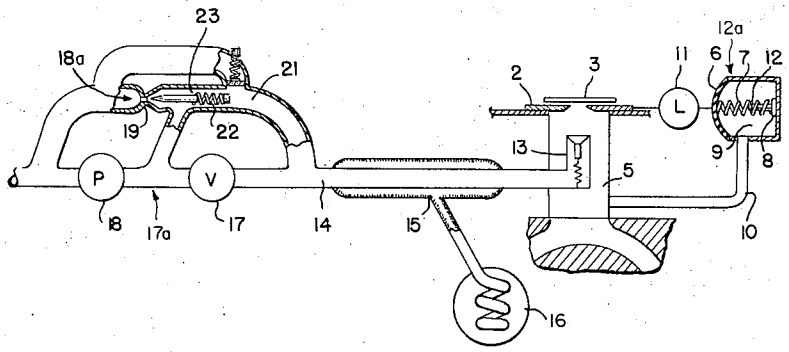


FIG. 1.

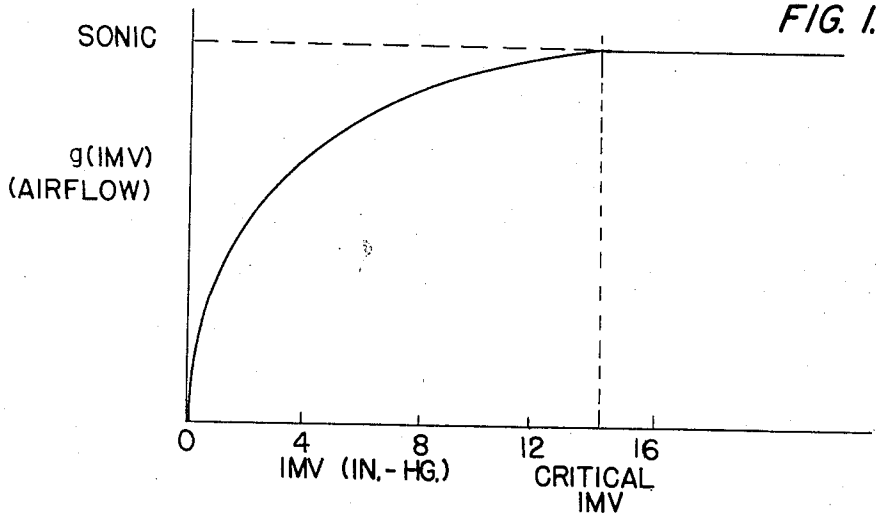


FIG. 1a.

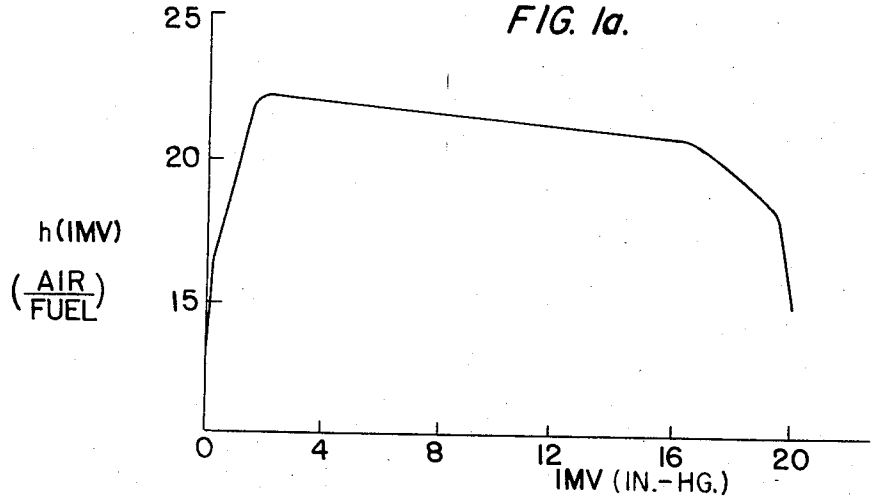


FIG. 2.

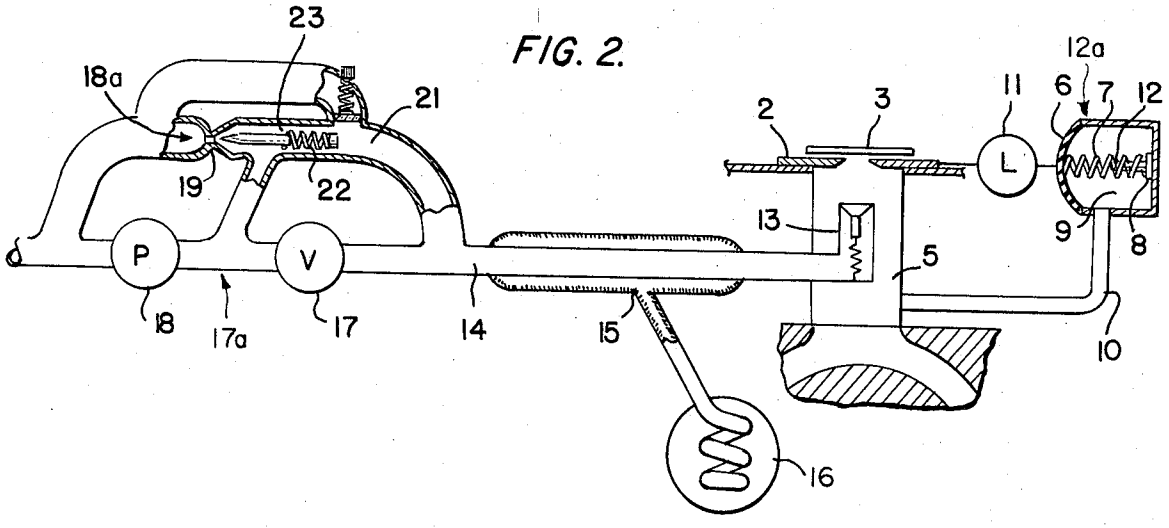


FIG. 3.

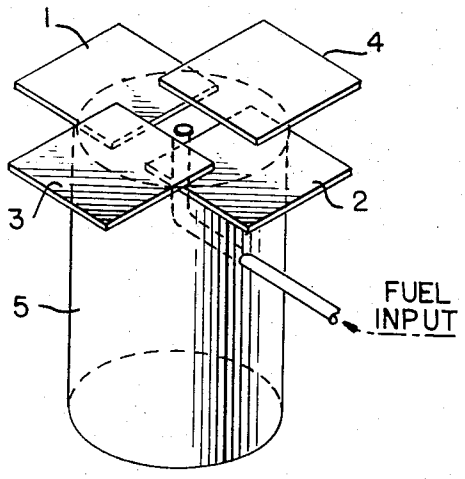


FIG. 3a.

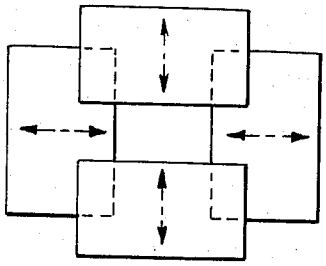


FIG. 3b.

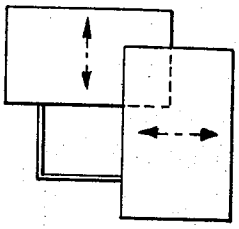


FIG. 3c.

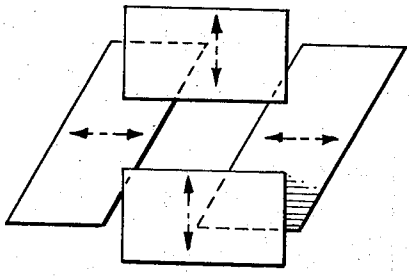


FIG. 3d.

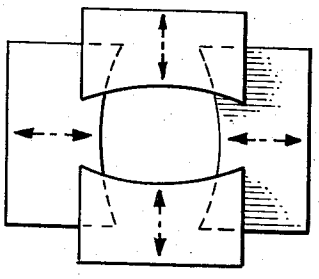


FIG. 4a.

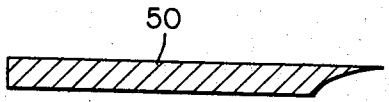


FIG. 4.

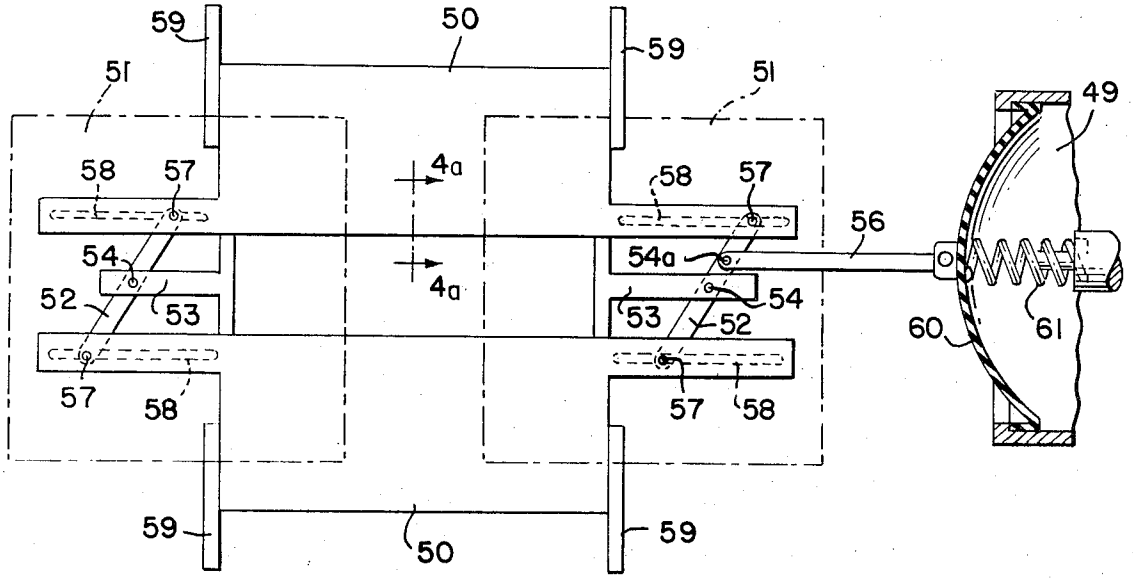
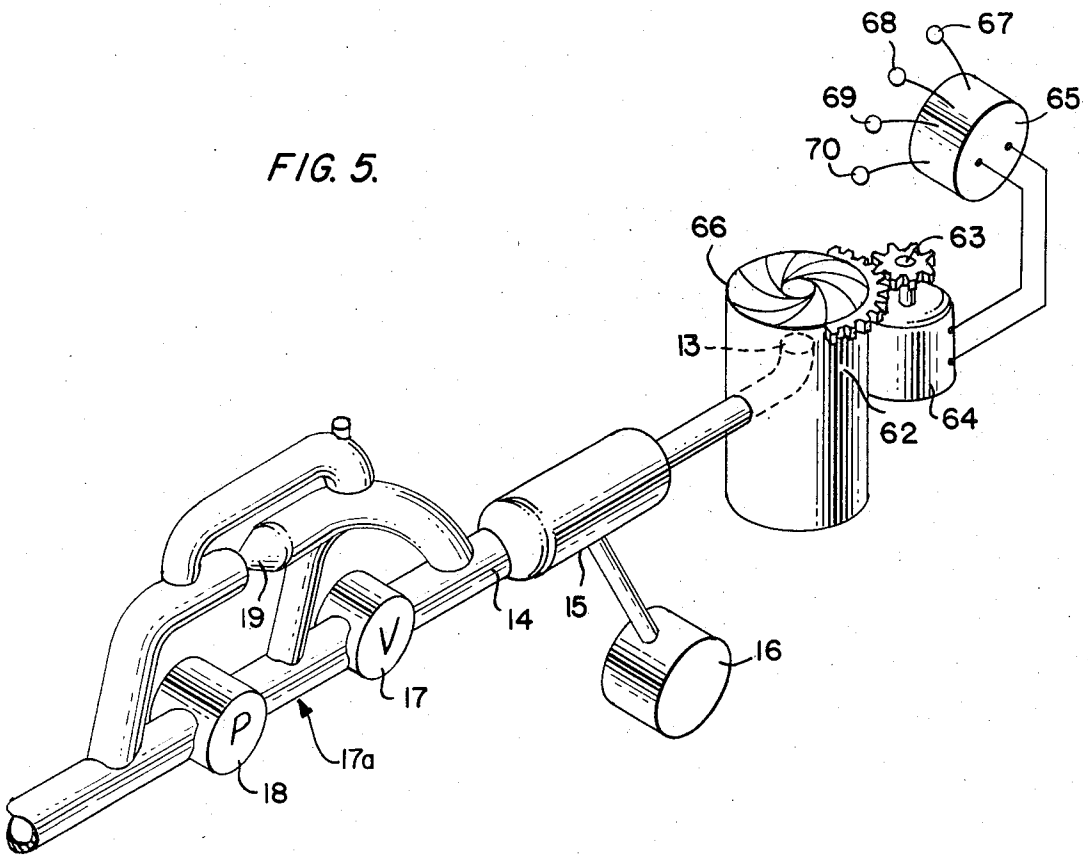

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FIG. 5.


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PRESSURE COMPENSATED AIR THROTTLE AND AIR-FUEL CONTROL SYSTEM

BACKGROUND AND OBJECTS

In injection carburetors and injection systems for throttled internal combustion engines, it is necessary to control air-fuel ratio closely and this results in many problems in the design of these systems. In the past, it has generally been the practice to throttle the airflow with a conventional butterfly valve, and to either measure airflow through a venturi meter or calculate it in some way as a function of intake manifold vacuum, IMV, and engine RPM to actuate a control on fuel flow to secure the desired air-fuel ratio. The result has been some complexity in the fuel metering arrangement to overbalance the simplicity of the air throttle.

It is a purpose of the present invention to provide an air throttle which meters a constant airflow (or a desired air-flow function) for each throttle control position over the range of manifold vacuums encountered in engine operation so that the pressure compensated throttle will automatically produce the desired air-fuel ratio function when used in conjunction with a fuel flow system where fuel flow is linear with control position and invariant with intake manifold vacuum. It is a further purpose to provide a pressure compensated throttle which, used in conjunction with a linear fuel flow device, is readily adaptable to supplementary air-fuel ratio control as a desired function of RPM, air temperature, engine temperature, altitude, and other parameters if necessary.

It is yet another purpose of the present invention to produce a throttle valve which is readily adaptable to injection of fuel directly below the air throttle to take advantage of the very high velocity flow (which is generally sonic velocity flow during engine operation) for fuel atomization.

It is another purpose of the present invention to provide an air throttle which requires a negligible manifold pressure drop from atmospheric pressure for efficient high power operation.

These and other objects are attained by an air throttle where throttle area is proportional to the product of two perpendicular openings, an x-direction opening proportional to desired airflow and positively linked to desired fuel flow, and a y-direction opening controlled as a function of manifold vacuum to compensate throttle area to produce the desired airflow per unit x-opening as a function of intake manifold vacuum. The viscosity of air is so low that its flow through a knife-edged orifice is frictionless shear flow to an adequate approximation; therefore, flow per unit throttle area can be expressed as a function of intake manifold vacuum g(IMV).

Airflow through the metering throttle is a function of intake manifold vacuum, IMV, throttle flow cross sectional area, A, and a characteristic flow constant k:

$$f = k_1 g(\text{IMV})\ \text{A}$$

If throttle cross section A is the product of an x-opening and a Y-opening controlled as a function of vacuum IMV, airflow per unit x-opening is constant regardless of IMV if y is inversely proportional to g (IMV):

$f = k_1 g(\text{IMV})\ (k_2/g(\text{IMV}))\ x$ reduces to

$f = k_1\ k_2\ x$ for all IMV.

If the y-opening of the rectangular throttle is controlled by a diaphragm with one side at manifold pressure and the other side at atmospheric pressure and with a spring on the intake pressure side so wound that the diaphragm controls the throttle y-opening to be proportional to the reciprocal of g(IMV), airflow through the throttle will be proportional to the throttle x-opening and invariant with intake manifold vacuum.

If it is desired to maintain the engine's air-fuel ratio constant, it is sufficient to control the y-opening proportional to $1/g$(IMV), but it is generally desired to control air-fuel ratio as a function of intake manifold vacuum. If the air-fuel metering system is designed so that fuel flow and the x position of the throttle always vary proportionately, a variable air-fuel ratio function of manifold vacuum h(IMV) will be generated by the system if the y-opening of the throttle is controlled to be proportional to $h(\text{IMV})/g(\text{IMV})$.

Airflow per unit flow cross section can be adequately approximated as a function g(IMV) because airflow is a weak enough function of atmospheric temperature changes and expected variations in operating altitude for automobiles, and the function g(IMV) can be adequately compensated for these variations to provide air metering to any required degree of accuracy.

Airflow through a properly designed ("knife edged") air throttle is to an excellent approximation a frictionless isentropic flow from a reservoir at atmospheric pressure to intake manifold pressure. For subsonic flows:

$$m = \rho_o a_o\ \text{A}\quad \sqrt{2/\gamma - 1}\ [(\text{P}/\text{P}_o)^{2/\gamma} - (\text{P}/\text{P}_o)^{\gamma+1/\gamma}]^{1/2}$$

where $a_o = \sqrt{\gamma \text{P}_o/\rho_o}$

m = mass flow

A = flow cross section of throttle

P_o = reservoir (atmospheric) pressure

P = throttle back pressure (absolute manifold pressure)

ρ_o = reservoir (atmospheric) density

$\gamma = c_p/c_v$ = the ratio of specific heat at constant pressure to specific heat at constant volume.

Maximum flow per unit cross sectional area A occurs at sonic velocity, where:

$$m = (2/\gamma + 1)^{1/\gamma - 1}\quad \sqrt{[2\gamma/(\gamma + 1)\ \text{P}_o\rho_o]}\ \text{A} \qquad (4.7.14)$$

for air, $\gamma = 1.4$ and (4.7.14) reduces to

$$m - 0.684\ \sqrt{(\text{P}_o\rho_o)}\ \text{A}$$

(page 51, 220 FLUID MECHANICS AND HEAT TRANSFER, J. M. Kay Cambridge University Press 1957) Therefore, for set values of γ, atmospheric pressure p_o, and atmospheric density ρ_o flow per unit throttle area, g(IMV) or $g(\text{P}_o - \text{P})$, is a unique function. Since γ is tolerably constant for air in the engine operating range, adequate air fuel metering with a rectangular iris throttle can be attained by varying the ratio of throttle x-opening to fuel flow as a function of temperature and barometric pressure if this degree of metering accuracy is required, and the spring or servo setting of k_2/g(IMV) can be a simple function of intake manifold vacuum, $\text{P}_o - \text{P}$.

The desired air-fuel ratio function, h, for a particular engine is in general a function of atmospheric pressure P_o, manifold pressure P, RPM, intake air temperature, engine temperature, and other parameters such as exhaust back pressure, fuel density, fuel hydrogen-carbon ratio, etc. However, in practice the airfuel ratio function is a function of only some of these parameters, of which intake manifold vacuum is always one

$h(\text{IMV}, \ldots)$.

An air-fuel ratio function of the following form will operate satisfactorily:

$$h(\text{IMV}, \ldots) = h_1(\text{IMV})\ h_2(T_e)\ h_3(P_o, T_o)\ h_4(\text{RPM})$$

where:

T_e = engine temperature

T_o = temperature upstream of throttle

RPM = engine speed

Those skilled in the art of air-fuel control systems will realize that other general forms are obviously necessary for some control systems (for instance where some of the correction functions are additive rather than multiplicative) but commonly desired air-fuel ratio functions are generally approximated adequately by a function of IMV times some other slowly moving correction functions.

A rectangular iris air throttle will generate the desired air-fuel ratio function if the ratio of x-opening to fuel flow

$$x/\text{fuel} = k_3\ h_2(T_e)\ h_3(P_o, T_o)\ h_4(\text{RPM}) \ldots$$

and the air throttle y-opening

$$y = k_4\ [h_1(\text{IMV})/g(\text{IMV})],$$

since throttle area A is proportional to the x-opening time the y-opening. This variation of y as a function of IMV can be attained by a control consisting of a diaphragm with one side at manifold pressure and the other side at atmospheric pressure actuating the y-opening where the spring on the diaphragm is so wound that the y-opening of the air throttle is proportional to $h_1(\text{IMV})/g(\text{IMV})$.

Under some conditions, a degree of accuracy so great that the effect of viscosity on airflow cannot be ignored may be required and is probably best to plot $g(\text{IMV})$ empirically rather than theoretically. The effect of viscosity will be to produce relatively less airflow when the throttle is nearly closed, causing a relative enrichening of fuel-air ratio at low engine power and a relative enleanment at high engine power. This may even be desirable, and some intermediate value $g(\text{IMV})$ function may be built into the throttle system. Alternatively, the open area of the air throttle may be covered by a screen so that the relative edge effect will become very small with relation to the viscous drag of the screen. This will make the $g(\text{IMV})$ function valid throughout the flow range (for a fine mesh screen), simply reducing the coefficient of discharge of the throttle orifice without changing the shape of the flow function from the isentropic form mentioned previously.

Beyond a certain level of complexity of $h(\text{IMV}, \ldots)$ it becomes worthwhile to use a computer air-fuel ratio control analogous to the electronic computer control systems now used with certain fuel controls. Even in this case, it is advantageous to control fuel using a simple linear fuel flow control and control air-fuel ratio as a desired function of engine parameters by varying the air throttling area as a function of manifold vacuum and other parameters. In this manner, the control actuator need only move slowly (as opposed to solenoid injection valves), and the simplicity of fuel metering across a constant pressure drop can be used to advantage. This scheme is compatible with any desired accuracy and complexity of air-fuel ratio control.

IN THE DRAWING

FIG. 1 is a graph representing the function $g(\text{IMV})$.

FIG. 1*a* is a graph representing one possible function $h(\text{IMV})$.

FIG. 2 is a schematic of the throttle in combination with a simple linear fuel flow control; the combination forms an engine's air-fuel control.

FIG. 3 shows a rectangular throttle iris on a manifold.

FIGS. 3*a*, 3*b*, 3*c* and 3*d* show exemplary shapes for the variable area air throttle.

FIG. 4 shows a linkage for the variable area air throttle.

FIG. 4*a* is a sectional view taken along line 4*a*–4*a* of FIG. 4 showing the desirable edge shape of the plates.

FIG. 5 is a schematic of an iris computer controlled throttle in combination with a simple linear fuel flow control.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 plots $g(\text{IMV})$, airflow per throttle opening cross sectional area for a knife edged orifice air throttle, and is characteristic for air. Note that flow rates increase rapidly between O IMV and 2"Hg IMV, where flow is already about half of sonic velocity, and flow increases approximately as the square root of IMV until sonic velocity is reached at the critical IMV. Since $g(\text{IMV})$ is constant at sonic velocity above critical IMV, any change in the y opening proportional to $h(\text{IMV})/g\text{IMV})$ above critical IMV is due to variation in $h(\text{IMV})$ in this high vacuum range. Note that engines under normal operating conditions spend the great majority of time with airflow rates which are nearly sonic or sonic. The energy contained in this high velocity airstream can be used to produce excellent atomization, as will be discussed later.

FIG. 1*a* represents one of the many possible $h(\text{IMV})$ functions which can be programmed into the air throttle air-fuel ratio control system. The $h(\text{IMV})$ function operates lean within the normal loaded range of IMV for fuel economy and NO and CO control, richening for very low manifold vacuums so that maximum engine power is obtainable, and also richening at the relatively high vacuums where flame propagation requires a richer mixture than is required in the middle IMV range. Other $h(\text{IMV})$ functions can, of course, be substituted for the one shown in FIG. 1*a* depending on the detailed design requirements of the engine the system is to be matched with.

FIG. 2 shows a schematic of the throttle invention in combination with a fuel control system designed so that fuel flow is proportional to the x-opening of the x–y rectangular iris air throttle. Opening and closing iris plates 1, 2, 3 and 4 are mounted on passage 5 which is the intake passage of an automobile engine (not shown). The chamber in passage 5 is at intake manifold pressure. Plates 3 and 4 open and close together and

the distance between them is the x-opening of the air throttle. Plates **1** and **2** open and close together and the distance between them forms the y-opening of the air throttle. The opening and closing of y-plates **1, 2** is controlled by a linkage **11** to a spring loaded diaphragm assembly **12***a* which controls the y-opening of plates **1, 2** to be proportional to $h(IMV)/g(IMV)$. Diaphragm **6** opens and closes y-plates **1, 2** through linkage **11** and moves to balance the differential pressure across diaphragm **6** with the spring tension of calibrated spring **7,** which spring is mounted in compression between diaphragm **6** and mount **8.** Stop **12** constrains the maximum travel of diaphragm **6** towards mount **8.** Linkage **11** serves to open and close y-plates **1, 2** in response to the interaction of **11** and spring loaded diaphragm assembly **12***a* so that the y-opening between plates **1, 2** is proportional to $h(IMV)/g(IMV)$ as required.

Fuel is introduced into the high velocity airstream below the throttle by means of a pintle nozzle **13** of the type disclosed by Robert Showalter in copending U.S. Pat. application Ser. No. 126,179 filed Mar. 19, 1971 where fuel is maintained as a pressurized liquid prior to ejection through pintle nozzle **13** and is heated to a temperature where its vapor pressure is substantially in excess of the pressure in chamber **5** so that the fuel ejected from nozzle **13** immediately flashes to vapor and micronic stable aerosol droplets. Fuel is heated to the required temperature prior to passing to nozzle **13** in line **14,** which is heated inside heat pipe fuel heater **15,** which maintains the fuel in line **14** within a narrow desired temperature range. Heat pipe fuel heater **15** is heated by an evaporator section in the exhaust passage **16** of an automobile engine. Other assemblies for introducing fuel into the engine could be substituted for the one shown, including continuous or pulsed fuel injection systems and simpler nozzle assemblies, for use in conjunction to the pressure compensated air throttle.

Note that any nozzle or fuel introduction means in the position of nozzle **13** is in a sonic or nearly sonic airstream. This sonic airstream will break up fuel into droplets of the order of 10 microns even when fuel is cold for simpler fuel introduction nozzles. The substantial atomization energy in the high velocity airstream downstream from the throttle is available whether it is used or not: the added energy cost of this atomization is zero.

Since the fuel outlet to the engine, nozzle **13,** is at the varying pressure of chamber **5,** fuel flow for a given control setting would vary with manifold pressure in chamber **5** unless the control were pressure compensated. However, constant pressure drop fuel metering assembly **17***a* assures that fuel flow is invariant with outlet pressure variations. Fuel pressurized at pump **18** is divided between fuel bypass circuit **18***a* and engine fuel control valve **17** by the interaction of needle valve assembly **19** with diaphragm **23** and spring **22** which assures that the pressure drop across diaphragm **23,** and hence the pressure drop across valve **17,** is a constant pressure drop dependent on the force of spring **22** on diaphragm **23.** The use of bypass control systems to control the fluid pressure across a metering valve, as in assembly **17***a*, is well known to the fluid control art.

Fuel flow through valve **17** is therefor a unique function proportional to valve orifice cross section of this valve. Assuming that valve **17** is to designed that its flow is linear with its control position, the control of valve **17** is to be linked to open and close proportionately with the x-opening of x-plates **3, 4** (linkage not shown). With this proportional linkage combined with the y-opening proportional to $h(IMV),/g(IMV)$, the system of FIG. **2** gives the desired air-fuel metering characteristics.

Various techniques can be used to change the constant of proportionality between fuel flow and throttle x-opening as a function of parameters such as barometric pressure, engine temperature, intake air temperature, etc., as previously described. Both the x control linkage and the linkage to valve **17** can be combined in a common radius arm, and the radius of one or both of the actuator points can be made to change as a desired function of correction parameters. Alternatively, the spring force of spring **23** can be varied, for instance by a servo controlled screw thread, to vary the pressure drop Δp across valve **17.** Fuel flow will vary as the square root of Δp. Various other proportioning linkages between the fuel control and throttle x-opening control are obvious to those skilled in the arts of mechanics and linkages.

FIG. **3** shows the position of rectangular iris throttle plates such as those of FIG. **2** on the manifold **5** where the distance between plates **1** and **2** forms the y-opening and the distance between plates **3** and **4** forms the x-opening of the iris throttle. Where the fuel outlet is positioned directly below the air throttle in the high velocity airstream to secure fuel atomization it is important that the fuel outlet remain in the center of the airflow opening as the throttle opens and closes to promote fuel distribution. If the fuel input did not utilize the airstream for atomization, a throttle geometry with a moving throttle area center could be used.

FIGS. **3***a*, **3***b*, **3***c* and **3***d* show some examples of plate sliding patterns to produce the desired pressure compensated area of the invention.

FIG. **3***a* shows a mounting where four plates slide apart and together to form rectangle iris opening with sides proportional to x and y. The distance between one pair of parallel plates forms the x-opening; the distance between the other pair of parallel plates forms the y-opening.

FIG. **3***b* shows a throttle with an opening which is also a rectangle with sides x–y and with opening area x times y, but here one perpendicular pair of sides is stationary and the other perpendicular sides move to adjust the x and y opening as required.

FIG. **3***c* shows a throttle assembly analogous to that of FIG. **3***a*, but here the opening is a parallelogram. The throttle opening of **3***c* will be proportional to x times y, as desired, so long as the sliding plates maintain adjacent angles constant and slide open and closed in proportion to x and y.

FIG. **3***d* shows a throttle analogous to FIG. **3***a*, but where the sliding plates are curved on the throttling edges rather than straight. The curves as shown are probably more exaggerated than would be useful in practice. Curving the plates rather than using straight lines can be useful for two purposes: **1**) small deviations from linearity on the edges of the plate which forms the throttle opening when the throttle is relatively closed can be used to correct for the small effect of air viscosity to produce more accurate air control, or **2**) curved plates can be used to bias $h(IMV)/g(IMV)$ for certain ranges of engine operation if this is desired.

Other iris air throttles which can vary their area in proportion to manifold vacuum as well as desired fuel flow can be designed: it is probably impossible to list all the geometrically possible configurations which could accomplish this. However, it is operationally useful for the airflow compensating function of a pressure compensated air throttle to be as described in this specification for automobile fuel-air control design.

FIG. **4** illustrates a linkage for a rectangular iris air throttle. This linkage operates two of the plates **50** (which are below the other two plates **51** shown in dotted lines); the linkage that operates the other pair of plates **51** would be similar and is not shown. The motion of the plates **50** is kept linear by the guides **59** when the pins **57** move in the slots **58.** The pins **57** are actuated by the cross arms **52** pivoting on pivots **54.** The pivots **54** are mounted on supports **53** which, with guides **59,** produce one-dimensional motion. The control arm **56** moves in response to diaphragm **60** and actuates the cross arm **52** to which it is connected by pivot **54***a*. The spring **61** is wound so that the distance between the plates **50** is proportional to the function $h(IMV)/g(IMV)$ when the intake manifold vacuum in chamber **49** acts on diaphragm **60.** This diaphragm assembly is operationally similar to diaphragm assembly **12***a* shown in FIG. **2.** A desirable knife edge shape for the plates **50** is illustrated in FIG. *4a*.

In FIG. **5** there is shown a linear fuel supply system comprising elements **13, 14, 15, 16, 17, 18, 19** as in FIG. **2** combined with a computer **65** controlling circular iris air throttle **66** to form an engine's air-fuel supply system. The computer **65** senses engine conditions through sensors **67, 68, 69, 70.** These sensors sense a number of control parameters in a manner well known to the art. The computer **65** responds to sensed conditions and accordingly controls the iris air throttle **66** by means of the servomotor **64** and the gear linkage **63.** The interaction of the computer **65** and the linear fuel supply system (**13, 14, 15, 16, 17, 18, 19**) produces the proper air-fuel ratio control for the engine connected to intake manifold **62.**

What is claimed is:

1. In an air-fuel control system for an internal combustion engine, the combination comprising:

a. fuel flow control means for supplying fuel to the engine;

b. an air intake manifold operated at less than atmospheric pressure;

c. a source of air at atmospheric pressure;

d. an air throttle connected between said source of air and the intake manifold for controlling airflow to said manifold, said air throttle having a variable flow cross section area; and

e. means for controlling the variable flow cross section area wherein said means is responsive to the fuel flow times a function of the pressure drop between the pressure at said air pressure source and the pressure in the intake manifold.

2. In an air-fuel control system for an internal combustion engine, the combination comprising:

a. fuel flow control means for supplying fuel to the engine;

b. an air intake manifold operated at less than atmospheric pressure;

c. a source of air at atmospheric pressure;

d. an air throttle connected between said source of air and the intake manifold for controlling airflow to said manifold, said air throttle having a variable flow cross section area; and

e. means for controlling the variable airflow cross section area wherein said means varies the cross section proportional to the fuel flow times a function of the pressure drop between the pressure of said source and the pressure in said intake manifold.

3. The invention as set forth in claim **2** and wherein the variable flow cross section area comprises a variable opening formed by adjustable inwardly extending closure members.

4. The invention as set forth in claim **2** and wherein the variable flow cross section comprises a rectangular opening formed by adustable inwardly extending closure members.

5. The invention as set forth in claim **4** and wherein the adjustable inwardly extending closure members move in response to the fuel flow and to a function of the pressure difference between atmospheric pressure and that in the intake manifold.

6. The invention as set forth in claim **3** and wherein the variable opening is a parallelogram having a width and height, wherein said (closure) members control the width of the opening in proportion to fuel flow and the height of the opening as a function of the pressure difference between atmospheric pressure and that in the intake manifold.

7. The invention as set forth in claim **3** and wherein the means for controlling the adjustable inwardly extending closure members comprises a spring diaphragm control linkage responsive to the pressure drop between the pressure of said source and the pressure in said intake manifold.

8. A method for controlling the air-fuel ratio in an internal combustion engine, said method comprising the steps of:

a. controlling the flow of fuel to the engine,

b. operating the intake manifold at a pressure less than atmospheric,

c. feeding air to the manifold from a source of atmospheric pressure air, and

d. controlling the airflow cross sectional area between the source of atmospheric pressure air and the intake manifold to vary said area in proportion to fuel flow times a function of the pressure difference between said manifold pressure and atmospheric pressure.

9. A method for controlling the air-fuel ratio in an internal combustion engine, said method comprising the steps of:

a. operating the intake manifold at a pressure less than atmospheric,

b. controlling the flow of fuel to the engine independently of the pressure of said intake manifold,

c. feeding air to the intake manifold from a source of atmospheric pressure air, and

d. controlling the airflow cross sectional area between said intake manifold and said source of atmospheric pressure air as a function of fuel flow and the pressure difference between said manifold pressure and atmospheric pressure.

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