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Turek

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[54] **FLUIDIC FUEL INJECTION SYSTEM UTILIZING SIMPLIFIED FLUIDIC COMPUTATION ELEMENT**

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[21] Appl. No.: **181,531**

[52] **U.S. Cl.** ..... **123/119 R,** 137/81.5

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

[58] **Field of Search** .. 123/DIG. 10, 119 R, 139 AC; 137/81.5; 73/194 R

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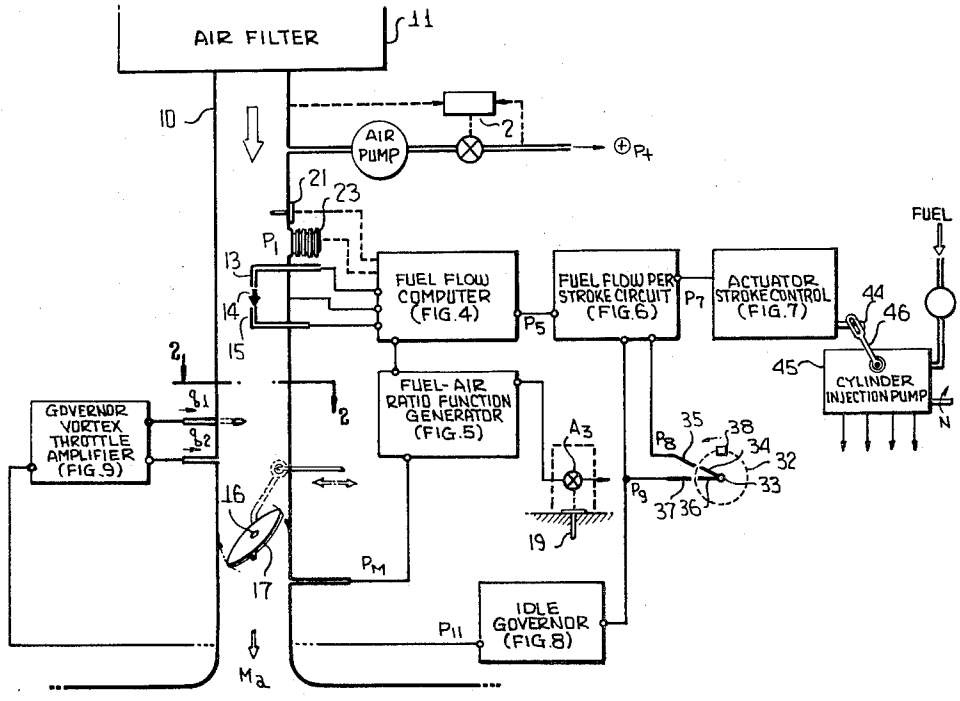
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[57] **ABSTRACT**

Fluidic computation is simplified in a system wherein one of plural input parameters is a fluid flow which is to be multiplied by the sum of the other parameters. The primary computation element is a parallel flow sensor in which a fluid sensing jet is issued from within and parallel to the fluid flow and is received as a linear function of the fluid flow. The effects of other input parameters are included by utilizing each to vary the supply pressure for the sensing jet to thereby sum the effects of these parameters and multiply the sum by the fluid flow. In a preferred embodiment, the computation element is utilized in a fluidic fuel injection control for an internal combustion engine wherein the fluid flow is air flow through the intake manifold and the other input parameters include fuel-to-air ratio, inlet air pressure, inlet temperature and engine temperature. The resulting output signal represents the required fuel flow which is then modified by fluidic circuitry to deliver the proper quantity of fuel per cylinder stroke.

8 Claims, 9 Drawing Figures



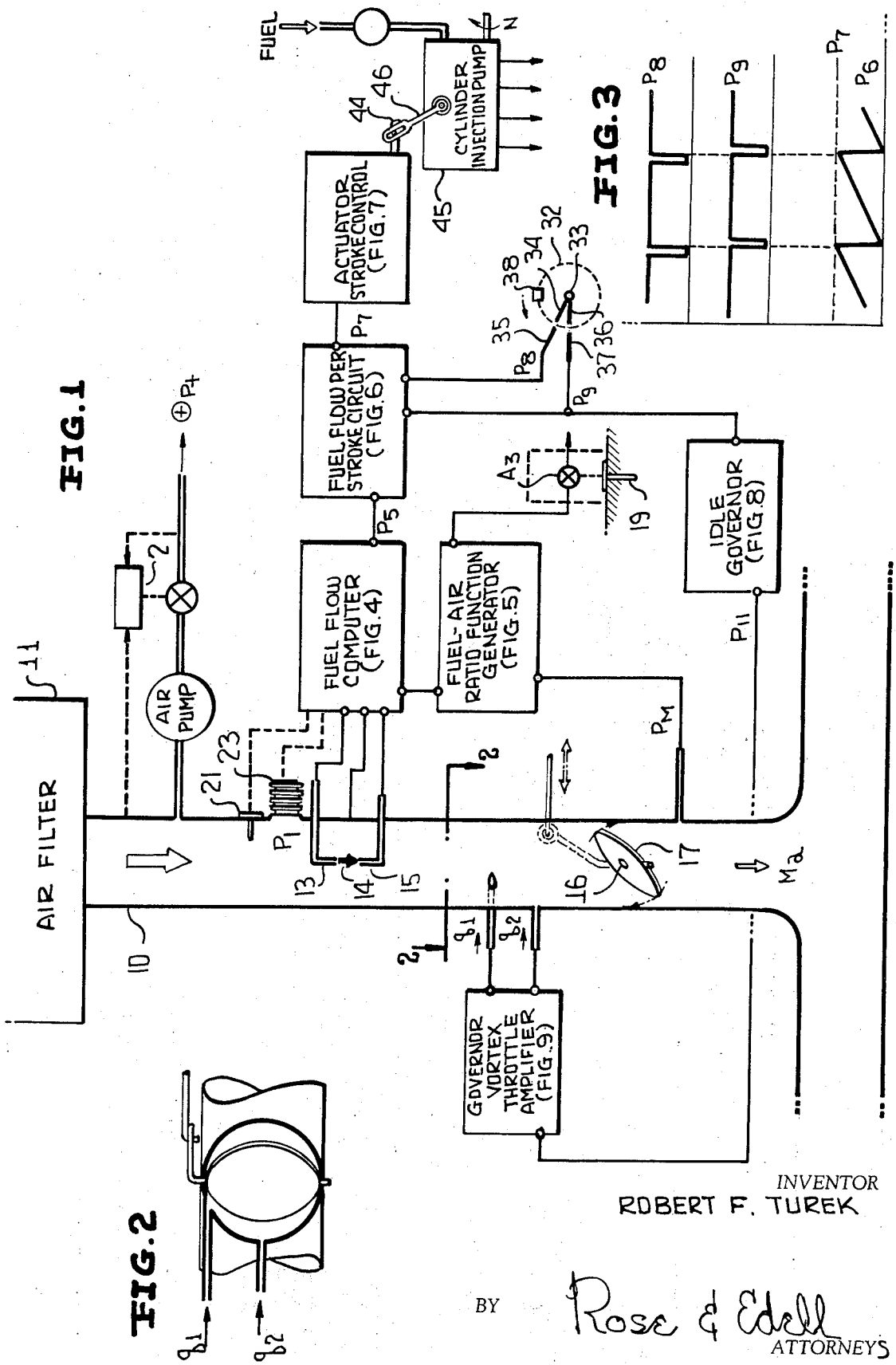


FIG. 1

FIG. 3

FIG. 2

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FIG.4

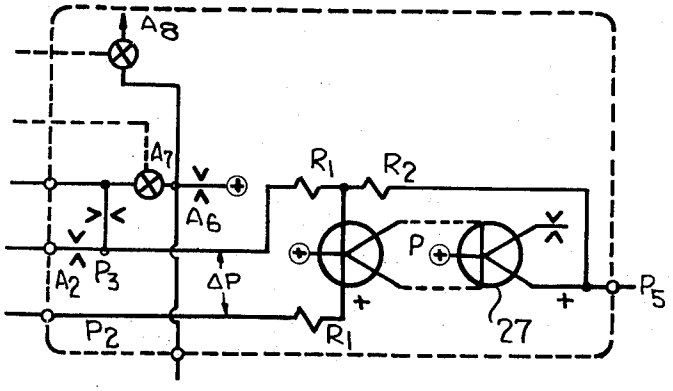


FIG.5

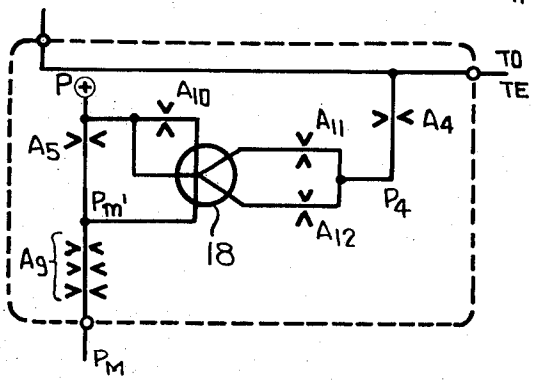


FIG.6

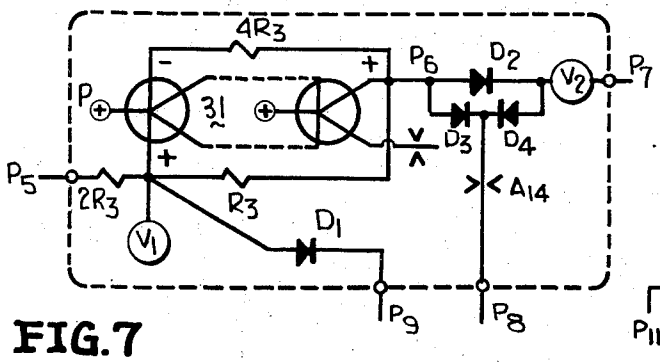


FIG.7

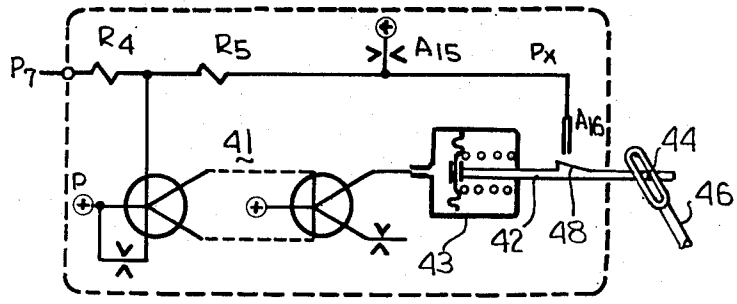


FIG.8

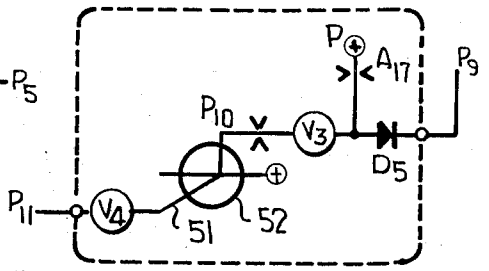
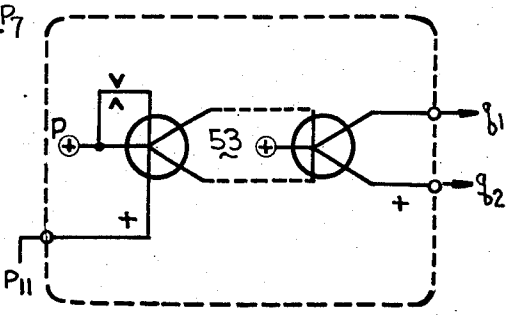


FIG.9



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FLUIDIC FUEL INJECTION SYSTEM UTILIZING SIMPLIFIED FLUIDIC COMPUTATION ELEMENT

BACKGROUND OF THE INVENTION

The present invention relates to fluidic computation elements, and more particularly to a fluidic computation element having particular utilization in a control apparatus for internal combustion engines.

Increased public concern about air pollution has resulted in governmental regulations being imposed in many countries for the purpose of limiting the allowable contaminating emissions from motor vehicles. The regulations become more stringent with each passing year and by 1975 substantially pollution-free vehicles will be required.

In order for the internal combustion engine to retain its usefulness in a pollution-free environment, it is necessary that an efficient approach to fuel injection be developed. Prior art fuel injection systems have been utilized in the past but require complex computation apparatus to compute the required fuel flow from various sensed engine parameters. The complexity, and resulting expense, of prior art fuel injection systems have rendered such systems impracticable for commercial use. Consequently, fuel injection systems have been used in the past only where special performance is desired, as in sport or racing cars, or as an option for luxury cars. If the internal combustion engine is to remain useful, a low cost fuel injection system for all production cars must be developed.

It is therefore one object of the present invention to provide a low cost and relatively simple fuel injection control apparatus.

Methods of computing engine fuel requirements may be divided into two general classes; direct, and indirect. The conventional methods are all indirect. The system of the present invention is direct because it measures the most important engine variable, air flow.

All conventional systems require complex, non-linear functions of two variable. Thus, conventional mechanical computers use 3-dimensional cams, analog computers (either electronic or fluidic) use very complex circuits of active, passive, linear and non-linear components, and in digital computers, large numbers of memory units are required. In contrast, the direct approach permits a simple design using a non-linear function of only one variable. This function, if properly selected, permits other measured engine parameters to simply modify the function with simple computing functions. As described in the detail herein, the one variable selected is fuel-to-air ratio, and the non-linear function is the relationship between engine load and fuel-to-air ratio.

Fluidics technology, by its very nature, lends itself to utility in fuel metering systems. This technology, as is now well known, involves the control of fluid streams by means of pressures or other fluid streams to effect amplification or switching without moving parts. Several fluidics control system approaches, which have been developed for other applications and which appear on the surface to be useful for fuel injection control, cannot in fact be utilized for fuel injection. The major limitation in this regard is the fact that the input-output characteristics of fluidic elements are not precisely repeatable in elements which are mass produced in large quantities. Therefore, highly accurate performance must be achieved with accurate passive components which can be manufactured with more consistent performance characteristics. Thus, a number of prior art approaches to fuel metering with the aid of fluidics appear promising on the surface but suffer from lack of repeatability in operational characteristics from unit to unit. Examples of such fluidic control arrangements for fuel systems may be found in the following U.S. Pat. Nos. 3,406,951; 3,477,699; 3,389,894; 3,574,346; and 3,548,795. The deficiencies of the systems disclosed in these patents are based on the fact that a fluidic element, with its non-repeatable operational characteristic, cannot be used for directly metering a precise quantity of fuel within a 1 to 2 percent accuracy requirement.

It is therefore and object of the present invention to provide a fluidic computational element suitable for utilization in a fuel injection control system.

SUMMARY OF THE INVENTION

In accordance with the present invention, the air flow in the intake manifold is measured by means of parallel flow sensor in which a sensing jet is issued in the manifold towards a receiver in a direction parallel to manifold air flow. Viscous interaction between the manifold air flow and sensing jet produce variations in the jet pressure at the receiver as a liner function of manifold air flow variations. The supply pressure for the sensing jet is itself rendered variable in response to manifold inlet air pressure and temperature, engine temperature, and the computed fuel-to-air ratio which is derived by means of a fluidic function generator circuit as a non-linear function of the intake manifold pressure. The effect of varying the sensing jet supply pressure in response to these parameters is the summation of these parameters and multiplication of this sum by the manifold air flow. The resulting pressure signal at the jet receiver represents the required fuel flow. This signal is then fluidically divided by engine speed to produce a signal representative of fuel quantity required per engine stroke. The latter controls the fuel pump to feed the proper amount of fuel to the engine during each engine stroke, thereby optimizing engine efficiency and minimizing emission of air pollutants.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of specific embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a functional block diagram of a fuel injection system according to the present invention;

FIG. 2 is a sectional view of an intake manifold taken along lines 2—2 in FIG. 1;

FIG. 3 is a timing diagram illustrating the waveforms of signals at various points in the block diagram of FIG. 1;

FIG. 4 is a scheatic diagram schematic a fluidic fuel flow computer utilized in the system of FIG. 1;

FIG. 5 is a schematic diagram of a fluidic fuel-air ratio function generator utilized in the system of FIG. 1;

FIG. 6 is a schematic diagram of a fluidic fuel flow-per-stroke circuit utilized in the system of FIG. 1;

FIG. 7 is a schematic diagram of a fluidic actuator stroke control utilized in the system of FIG. 1;

FIG. 8 is a schematic diagram of a fluidic idle governor utilized in the system of FIG. 1; and

FIG. 9 is a schematic diagram of a fluidic governor vortex throttle amplifier utilized in the system of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1 of the accompanying drawings there is illustrated a fluidic fuel injection control system employing the principles of the present invention. The intake manifold 10 of an internal combustion engine receives air inflow from air filter 11. The air supply for the fluidic control circuits described below comprises an air pump 1 and regulator 2. The source for the air pump comes from the ambient portion of intake manifold 10, after the air has been filtered by air filter 11. Regulator 2 also utilizes the manifold inlet pressure as a reference instead of atmospheric pressure. This provides the air flow sensor, described below, with a supply pressure accurately referenced to the static pressure in the flow sensing region. Although no direct connection is illustrated in the drawings, the regulated output pressure P+ from air pump 1 serves as a supply for all fluidic elements in the system.

Air flow is sensed by means of a parallel flow sensor including supply nozzle 13 and receiver tube 15 disposed within the intake manifold 10. The parallel flow sensor is of the type disclosed in my co-pending U.S. Pat. application Ser. No. 36,627, filed May 12, 1970, and entitled "Fluidic Flow Sensing Techniques". The flow sensor operates by issuing a flow sensing jet 14 of pressurized fluid, in this case air, in a direction generally parallel to the flow being monitored, in this case the intake manifold air flow. For this purpose nozzle 13 is emersed in and axially aligned with the direction of manifold air flow. Likewise, receiver 15 is positioned to receive a portion of jet 14 which does not include the constant pressure central core of the jet. The portion of the jet thus received at receiver tube 15 is subjected to pressure changes resulting from flow variations in the manifold air flow, since manifold air flow is viscously coupled to sensing jet 14. Importantly, the parallel flow sensor employed herein provides a signal at receiver 15 which is a linear function of air flow variation in the manifold. Moreover, the quiescent pressure (i.e., at zero manifold air flow) is raised to a workable level by virtue of sensing jet 14 so that even relatively low manifold air flow can be sensed by the described parallel flow sensor without the need for ultra-sensitive low pressure detection devices.

Referring to FIG. 4, the supply pressure P+ for nozzle 13 is delivered through fixed flow restrictor A_6 connected in series with variable flow restrictor A_7. The output pressure from receiver tube 15 is designated P_2 and, as mentioned above, varies in proportion to manifold air flow. The supply pressure for nozzle 13 is also supplied to series connected fixed flow restrictions A_1 and A_2, the latter being referenced to manifold 10. Flow restrictors A_1 and A_2 are selected to render the pressure P_3 at the junction between these two restrictors equal to pressure P_2 when air flow through manifold 10 is zero. Thus the pressure difference ΔP between P_2 and P_3 is nulled for zero air flow in manifold 10 and varies proportionally with air flow in manifold 10.

As described below, modification of the supply pressure at nozzle 13 is the means utilized for introducing the effects of fuel-to-air ratio, engine temperature, manifold temperature and manifold air density at the air flow sensor. ΔP is in this way modified to provide the required fuel flow signal for controlling the amount of fuel injection. Importantly, the introduction of these effects, their summation, and the multiplication of the sum by the air flow signal, is achieved right at the flow sensor. In this regard, a signal representing air flow per se (unmodified) does not actually exist; nor does a separate fuel-to-air ratio signal exist except as an implicit component in the pressure supplied to nozzle 13.

One of the parameters employed to modify the sensor supply pressure is the fuel-to-air ratio which is derived from the manifold pressure, P_m. This static pressure in the manifold, sensed downstream of manifold throttle valve 17, is a measure of engine load and is applied directly to the fuel-air ratio function generator of FIG. 5. Thus function generator is an active fluidic circuit which produces an output pressure signal P_4 as a non-linear function of P_m. The P_4 pressure signal is the raw fuel-to-air ratio signal and is utilized to vary the supply pressure to the flow sensor as a function of fuel-to-air ratio. The manifold pressure signal P_m is applied through a series of orifice-type flow restrictors A_9 and in turn to orifice restrictor A_5 which is referenced to supply pressure P+. The signal P_m' at the junction between restrictor A_5 and restrictors A_9 varies in proportion to signal P_m and is always above atmospheric pressure in order to serve as a control signal for a fluidic amplifier 18. The reason for a multiple orifice network comprising restrictors A_5 and A_9 is to prevent sonic flow in the path between P_m' and P_m; sonic flow, if it were to exist in this path, would permit P_m' to remain constant as P_m varies. Fluidic element 18 is a proportional fluidic amplifier utilized in producing the required non-linear function of input signal P_m'. A constant bias pressure, acting in opposition to P_m' at element 18, is generated by supply pressure P+ in conjunction with restrictor A_{10}. The output passages of element 18 include respective fixed flow restrictors A_{11} and A_{12}, the output sizes of which are chosen to provide the desired output versus input characteristic. Specifically, P_4 should be low for mid-range values of manifold pressure P_m and high for both low and high values of manifold P_m. More specifically, the desired shape of the P_4 versus P_m characteristic is obtained by properly adjusting and selecting restrictors A_{11} and A_{12}. Techniques for employing orifice type restrictors in conjunction with fluidic elements for the purpose of curve shaping are described in U.S. Pat. No. 3,250,469 to Colston and U.S. Pat. No. 3,398,759 to Rose. Signal P_4 is applied through pressure isolating restrictor A_4 to the junction between restrictors A_6 and A_7 where it forms a component of the supply pressure applied to nozzle 13.

Also effecting the supply pressure applied to nozzle 13 is the engine temperature which is sensed by a bimetal sensor 19 illustrated in FIG. 1. Movement of bimetal sensor 19 in response to temperature changes in the engine adjusts the opening of adjustable bleed valve A_3. The latter is connected between ambient and the junction between restrictors A_6 and A_7. More specifically, increasing engine temperature produces an increase in the bleed area provided by valve A_3, thereby lowering the supply pressure for the flow sensor. The

primary purpose of sensing the engine temperature is to permit an enriched fuel-to-air ratio during engine warm up.

A similar arrangement is utilized to introduce the effect of manifold air temperature and is best illustrated in FIGS. 1 and 4. Specifically, a bi-metal sensor 21 (FIG. 1) senses the air pressure at the manifold inlet and controls the bleed orifice in valve A_8 (FIG. 4) accordingly. Valve A_8 is connected between ambient and the junction between restrictors A_6 and A_7. The purpose of introducing the effect of manifold air inlet temperature is to compensate the air flow sensor for changes in inlet air density produced by variations in air temperatures. Air density, of course, affects the fuel-air mixture and therefore must be considered when computing the fuel flow required for optimum fuel-to-air ratio.

Restrictor A_7 is of itself variable as a function of the position of aneroid or bellows sensor 23 (FIG. 1). The latter is positioned to expand or contract in response to the manifold inlet air pressure P_1. Signal P_1 is employed to compensate the air flow sensor for changes in inlet density due to altitude changes or pressure losses in air cleaner 11.

The various signals described above are utilized to vary the supply pressure for nozzle 13 either by changing the value of a passive loading orifice in the supply circuit or by varying a pressure in the supply circuit with an active element. Each in its own way adds to or subtracts from the supply pressure for the air flow sensor to produce an effect on the sensor output signal ΔP. Since ΔP varies as a function of the sensor supply pressure, the summed effect of the four supply pressure-varying parameters is multiplied by the manifold air flow sensed at receiver 15.

Signal ΔP is applied between opposed control ports of proportional fluidic amplifier 25. As indicated by the dashed lines between amplifier 25 and amplifier 27 in FIG. 4, a plurality of cascaded proportional fluidic amplifiers may be employed for the purpose of amplifying ΔP. The last stage in the group of cascaded amplifiers is amplifier 27 which provides a single ended pressure signal P_5. The pressure signal P_5 is an amplified version of ΔP and represents the product of fuel-to-air ratio multiplied by measured air flow as compensated by other engine parameters. P_5 is thus at a pressure level representative of the required fuel flow. The actual gain function for the amplifier arrangement in FIG. 4 is determined by the ratio of feedback restrictor R_2 to input restrictor R_1 in a manner well known for operational amplifiers.

The fuel flow signal P_5 is applied to the fuel flow per stroke circuit of FIG. 6 which functions to divide P_5 by engine speed to obtain a fuel flow per stroke signal P_7. The circuit includes an operational amplifier 31 comprising a plurality of cascaded proportional amplifiers having as an input signal P_5. The input terminal to the operational amplifier is also connected to a fluidic capacitor (storage volume) V_1. The non-inverting + output terminal of operational amplifier 31 provides a signal P_6 which is applied through a fluid diode gate arrangement to an output capacitor V_2. The diode gate comprises a series diode D_2 poled to conduct flow from the output terminal of the amplifier to capacitor V_2. Also included are a pair of series connected diodes D_3 and D_4 poled in opposite directions, the series arrangement in parallel with D_2. Diodes D_2, D_3 and D_4 are preferably rubberized check valves which completely cut off the flow in one direction and permit relatively unimpeded flow in the other direction.

A control signal P_8 is applied to the junction between diodes D_3 and D_4 through orifice restrictor A_{14}. Another control signal P_9 is operatively connected to the input terminal of operational amplifier 31 by means of diode D_1, the latter being poled to conduct flow from the input terminal of the amplifier toward the source of P_9. The P_8 and P_9 signals are timing pulses generated by a synchronizer such as the type schematically illustrated in FIG. 1. More particularly, the synchronizer includes a drum 32 which is caused to rotate at one-half the engine rotational speed. Interiorly of the drum is a manifold tubing 33 containing pressurized air which is directed radially outward toward the drum periphery by means of angularly spaced jet nozzles 34, 36, etc. Receiver tubes 35, 37, etc. are disposed about the drum periphery in alignment with respective jet nozzles 34, 36, etc., to receive pressurized fluid therefrom through an appropriately provided slot in the peripheral wall of drum 32. A small portion of this slot is blocked by a fluid impervious member 38 which rotates with the drum and momentarily interrupts flow of pressurized air from each jet nozzle to its aligned receiver tube in sequence. Thus, as member 38 passes between jet nozzle 34 and receiver tube 35, the pressure P_8 in receiver tube 35 is momentarily reduced to substantially zero. Likewise when member 38 passes between jet nozzle 36 and receiver tube 37, the pressure P_9 in receiver tube 37 is momentarily reduced to zero. P_8 and P_9 may therefore be considered timing pulses, each being repeated once each cycle of drum 32. Drum 32 can be linked to the engine cam shaft or distributor shaft as necessary to produce the required synchronized rotational speed at one half that of the engine.

The operation of the circuit of FIG. 6 may now be understood with reference to the wave forms illustrated in FIG. 3. The output signal P_6 from amplifier 31 has a sawtooth wave form which is initiated each cycle to discharge capacitor V_1. Upon termination of P_9, V_1 begins charging under the control of input signal P_5 through resistor $2R_3$. The combination of resistor $2R_3$ and capacitor V_1 form an integrating circuit which in effect renders the slope of the charging portion of signal P_6 proportional to the input signal pressure P_5. This may be represented mathematically by equation (1) as follows:

$$dP_6/dt = K_1P_5 ; \quad (1)$$

wherein K_1 is a constant of proportionality dependent upon the values of $2R_3$ and V_1 and the gain of amplifier 31.

Since the frequency of timing pulse P_9 is proportional to engine speed, the period of duration of the charging cycle of V_1 is inversely proportional to engine speed. This period, Δt may be represented mathematically by equation (2) as follows:

$$\Delta t = K_2/N; \quad (2)$$

wherein K_2 is a constant of proportionality and N is the frequency of rotation of drum 32.

P_6, which is merely an amplified version of the pressure in capacitor, V_1, has a value at the end of each charge cycle which is proportional to the input signal

P_5 divided by engine speed. More specifically, since P_6 increases linearly with time at a rate $K_1 \cdot P_5$ per unit time, the value of P_6 at the end of Δt units of time may be represented by equation (3) as follows:

$$dP_6/dp\ \Delta t \neq K_1K_2\ P_5/N \quad (3)$$

The value of P_6 at the end of each cycle is sampled and held by the diode gating circuit and capacitor V_2. More particularly the end of each charging cycle is designated by the occurrence of negative going pressure pulse P_8. The pressure at the junction of diodes D_3 and D_4 is normally high, preventing diodes D_3 and D_4 from conducting. Once each cycle, timing pulse P_8 lowers the pressure at the junction of diodes D_3 and D_4 to permit the latter two diodes to conduct, if proper pressure conditions exist. Thus, if the peak value of P_6 is increasing, diode D_2 conducts flow into capacitor V_2. Signal P_7, which is the pressure of capacitor V_2, thus represents the peak value of P_6. If this peak value is decreasing, flow from capacitor V_2 is discharged through diode D_4 each time timing pulse P_8 occurs. After P_7 has decreased to the new lower value of P_6, diode D_3 is rendered conductive to flow. This terminates discharge through diode D_4, thereby causing the new value of P_7 to equal P_6.

The circuit of FIG. 6 effectively divides required fuel signal, P_5 by the engine speed to provide signal P_7 representing the required fuel per stroke. Signal P_7 is in turn applied to the actuator stroke control circuit of FIG. 7 which includes a high gain amplifier 41 comprising a plurality of cascaded proportional fluidic amplifiers. The output stage of amplifier 41 drives a shaft 42 by means of a bellows arrangement 43, shaft 42 being linked mechanically at 44 to drive a further shaft 46 which varies the volumetric displacement of fuel injection pump 45. A cam surface 48 on shaft 42 is angled to vary its proximity to an orifice restrictor A_{16} as a linear function of the position of shaft 42. Pressurized air, delivered from the P+ supply through restrictor A_{15}, is issued from orifice A_{16}. The pressure P_x upstream of orifice 16 varies as a function of the proximity of cam surface 48 to the downstream end of orifice A_{16}. Signal P_x is fed back through a flow divider comprising restrictors R_5 and R_4 as a negative feedback signal to the input stage of amplifier 41.

The feedback signal P_x is a function of the area ratio of A_{16}/A_{15}. The shape of the area versus stroke function is contoured to provide correct relationship between signal P_7 and the actual effective pump displacement and, of course, depends upon the pump characteristics. The areas of restrictors A_{16} and A_{15} may be chosen to provide this relationship.

The system as thus far described is operative to inject the proper amount of fuel per stroke into the cylinders of an internal combustion engine as the engine load varies. The fuel flow computer circuit of FIG. 4 computes the desired fuel flow rate for measurements for various conditions of the engine and the environment. The fuel flow per stroke circuit of FIG. 6 computes the required fuel charge per stroke by dividing the computer fuel flow rate, as represented by signal P_5, by the engine speed, N. The actuator stroke control circuit of FIG. 7 controls the effective volumetric displacement of the cylinder injection pump by controlling the mechanical input position of the pump as a function of the fuel per stroke signal P_7. The control system arrangement illustrated and described above is not dependent upon repeatability of operational characteristics of fluidic elements; rather the fluidic elements themselves are employed as adaptable components of control arrangements. Precise determination of circuit characteristics is provided by passive components such as the various restrictors and capacitors described.

An idle governor arrangement, effective under engine idle conditions to provide accurate control of idle RPM, includes the idle governor circuit of FIG. 8 and the governor vortex throttle amplifier of FIG. 9. The idle governor circuit comprises a charging volume or capacitor V_3 which receives pressurized air from the system air supply through restrictor A_{17}. The junction between A_{17} and V_3 is connected to a diode D_5 poled to conduct flow away from the junction. The downstream end of diode D_5 is connected to receive the negative-going P_9 timing pulse. The output of capacitor V_3 is connected through a flow restrictor to the control port of a fluidic OR/NOR gate 51. Gate 51 provides a positive pressure output signal at its output terminal 52 when the input signal to its control port exceeds a predetermined positive pressure threshold. Output leg 52 of gate 51 feeds capacitor V_4 which in turn provides an output signal designated P_{11}. The latter increases in amplitude as the actual engine speed falls below a predetermined idle setting. P_{11} remains constant at a value of zero when the engine speed remains above idle.

The circuit of FIG. 8 operates as follows: between timing pulses P_9, capacitor V_3 charges through restrictor A_{17}. The pressure P_{10} at the control port of gate 51 increases slowly as V_3 charges. At the occurrence of each negative going pressire pulse P_9, capacitor V_3 discharges completely through the high speed discharge circuit comprising diode D_5. As the engine speed decreases, the interval between pulses P_9 increases, thereby permitting the pressure P_{10} to build up to a higher value between capacitor discharge times. The charging time constant of capacitor V_3 is selected to permit P_{10} to reach the threshold of gate 51 when the engine speed falls to idle. Gate 51 thus switches to provide an output pressure pulse in passage 52, the pulse terminating when the next timing pulse P_9 discharges capacitor V_3. If the speed decreases further, the width of the pulse delivered to capacitor V_4 in each cycle increases. This increasing pulse width increases the average value of the pressure in capacitor V_4, which average pressure is designated P_{11}. V_4 thus tends to smooth, by filtering, signal P_{11}, and P_{11} increases as the engine speed falls below idle.

Signal P_{11} comprises an input signal for the governor vortex throttle amplifier of FIG. 9. This amplifier is simply a plurality of cascaded proportional fluidic amplifiers designated 53 and provides a differential output flow signal q_1-q_2 as a function of the amplitude of P_{11}. The signals q_1 and q_2 are delivered to manifold 10 (FIG. 1) in a manner so as to cooperate with butterfly valve 17 to provide a simple vortex air flow throttle. More particularly, butterfly valve 17 includes a small hole 19 which is sized to provide the maximum idle air flow required by the engine; this maximum air flow occurs during warm up of the engine on a cold day. A typical size of such a hole would be 0.184 inches, but would vary depending upon the nature of the engine. Signal q_1 is introduced tangentially into cylindrical manifold 10 at a location upstream of butteryfly valve 17. Signal q_2 is introduced radially into manifold 10, also at a loca-

tion upstream of valve 17. When P_{11} is zero, indicating that the engine speed is above idle, q_1, the tangential control for the vortex valve is at maximum pressure. The tangential inflow to the manifold provided by q_1 causes a high degree of vorticity in the air flow attempting to pass valve 17. This vorticity effects a throttling action and limits the manifold air flow to a relatively low value. By way of example only, the throttling action at maximum value of q_1 would reduce the air flow in manifold 10 to one-third its maximum value.

As the engine speed is lowered, the tangential flow q_1 is lowered accordingly and the radial flow q_2 is increased. The vortex throttling action is therefore reduced and air flow through the manifold is increased. It will be evident that, for throttling reduction, it is not necessary to introduce the non-tangential flow q_2, into the vortex region to increase air flow; rather, merely minimizing the tangential flow is sufficient to reduce the throttling action in the manifold. The radial or non-tangential flow is introduced however to keep a constant control flow ($q_1 + q_2 =$ a constant) into the manifold. This flow is not sensed by the air flow sensor because of its downstream location but, because the total is constant, a fixed bias can be utilized in the air flow sensor.

The disclosed fuel injection control system has a number of advantages. One advantage is its simplicity which results from the utilization of a fluidic air flow sensor which, in turn, permits direct measurement of the primary engine input parameter: air flow. The computation of the required fuel flow using the measured air flow directly is far simpler than computations in the prior art.

The disclosed control system also has the advantage of flexibility in that it is easily adapted to many engines.

Another advantage of the disclosed system is the fact that it permits precision fuel metering. The inclusion of a conventional metering pump and injectors takes maximum advantage of existing and proven engine know-how. This, coupled with an inherently correct computing approach, provides precise control of fuel-to-air ratio at each cylinder.

The basic computation element, namely the fluidic flow sensor having a parameter controlled supply pressure, has utilization in areas other than fuel injection, as long as plural parameters, including flud flow, are involved in the computation.

While I have described and illustrated specific embodiments of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

I claim:

1. A fluidic computation element for use in a system wherein an output signal is required as a function of the product of a fluid flow multiplied by at least one additional parameter, said computation element comprising:

a source of pressurized fluid;

a nozzle connected to receive pressurized fluid from said source and positioned in said fluid flow to issue a sensing jet of said pressurized fluid parallel to and within said fluid flow;

a receiver positioned within said fluid flow to receive a portion of said sensing jet having a pressure which varies with said fluid flow, said receiver providing said output signal; and

control means for varying the pressure of the pressurized fluid connected to said nozzle as a function of said additional parameter;

wherein said fluid flow is the air flow in an intake manifold of an internal combustion engine, and wherein said additional parameter is a parameter of said engine.

2. The element according to claim 1 wherein said control means comprises means for supplying a pressure signal in summing relationship with the pressurized fluid from said source, said pressure signal being variable as a function of said engine parameter.

3. The element according to claim 1 wherein said control means includes means for bleeding pressurized fluid connected to said nozzle as a function of said engine parameter.

4. The element according to claim 1 wherein said control means comprises:

means for providing a control pressure which varies in proportion to said engine parameter;

a fluidic circuit for providing a pressure signal which varies as a predetermined non-linear function of said control pressure, and

means for summing said pressure signal with the pressurized fluid from said source connected to said nozzle.

5. The element according to claim 1 wherein said output signal is required as a function of the product of said fluid flow multiplied by the sum of said one engine parameter and at least a second engine parameter, said element further comprising:

means for generating a pressure signal as a function of said one engine parameter;

means for summing said pressure signal with the pressure of said pressurized fluid connected to said nozzle; and

means for bleeding pressurized fluid connected to said nozzle at a rate which is a function of said second engine parameter.

6. A fuel injection control system for an internal combustion engine having an air intake manifold, said control system comprising:

first means for directly measuring air flow in said intake manifold;

second means for sensing engine load;

third means responsive to the sensed engine load for providing a first signal having an amplitude representing optimum fuel-to-air ratio required by the engine for the sensed load; and

fourth means responsive to said first signal and the measured air flow for providing a further signal representing the required fuel flow, said further signal having an amplitude which varies as function of the product of the measured air flow and the required fuel-to-air ratio for the sensed engine load;

wherein said first means comprises a fluidic parallel flow sensor including:

a nozzle arranged to receive pressurized air and issue a sensing jet within and parallel to the air flow in said intake manifold; and

a receiver arranged to receive a portion of said sensing jet in which the pressure varies in proportion to the manifold air flow;

wherein:

said second means includes means for providing a load pressure which varies in proportion to the sensed load;

said third means comprises a fluidic function generator for providing said first signal at a pressure which is a predetermined non-linear function of said load pressure; and

said fourth means includes means for adding the pressure of said further signal to the pressure received by said nozzle.

7. A fuel injection control system for an internal combustion engine of the type having an air intake manifold and a fuel injection pump with a controllable volumetric displacement for its fuel stroke, said system comprising:

a parallel flow sensor for directly measuring air flow in said intake manifold, said parallel flow sensor comprising:

a source of pressurized fluid;

a nozzle connected to receive pressurized fluid from said source and positioned to issue a sensing jet of said pressurized fluid within and parallel to the air flow in said intake manifold; and

a receiver positioned within the air flow in said intake manifold to receive a portion of said sensing jet having a pressure which varies with the velocity of said air flow;

means for sensing engine load;

means responsive to the sensed engine load for varying the pressure of fluid in said source of pressurized fluid and thereby varying the pressure of said sensing jet; and

fluidic amplifier means responsive to the pressure of the portion of said sensing jet received by said receiver for controlling the volumetric displacement of said fuel injection pump.

8. The fuel injection control system according to claim 7 further comprising:

means for providing a fluid signal having a parameter which varies as a function of the speed of said engine; and

means responsive to said parameter of said fluid signal for varying the gain of said fluidic amplifier means as a function of the speed of said engine.

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