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(54) Fuel metering system for an internal combustion engine.

(57) A fuel metering system for an internal combustion engine uses a digital computer to calculate the desired fuel flow to maintain an air/fuel ratio required under the engine operating conditions existing at the time. This desired fuel flow is obtained from a basic fuel metering system and, under equilibrium engine operating conditions, is the actual fuel flow demand of the engine. Under transient engine operating conditions, the invention provides compensation of the basic fuel metering system calculations to take into account the effects of the transfer of fuel from the liquid state on the wall surfaces of the engine's intake passages to the gas or vapor state in the inducted air fuel mixture and also takes into account transfers of fuel from the inducted air/fuel mixture onto the intake passage surfaces as a liquid deposit.

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DESCRIPTION.

This invention relates to a fuel metering system for internal combustion engines.

In internal combustion engines, the rate at which fuel is metered to the engine varies during engine operation. Changes in engine load cause the engine's fuel metering apparatus to increase or to decrease the rate at which fuel is metered to the engine. As a result, the engine must change from a first state, where engine operation and fuel flow rate is quite stable, to a second state, where these conditions again become stable. The conditions in between the stable states are of a transient character in that the rate of fuel flow varies continuously and can produce undesirable air/fuel ratios. For example, with carburetion or other central location of the fuel metering apparatus, there is an intake manifold passage that the vaporized or atomized fuel must traverse in order to reach the engine's combustion chamber or chambers. At a given engine load, prior art fuel control systems under transient engine operation are unable to maintain precise air/fuel ratios until the conditions in the engine's intake passages have stabilized. Sudden accelerations cause an increase in the rate at which liquid fuel is deposited on the walls of the intake passages (wall wetting), and sudden declerations produce a lessened rate of deposition. The reason for this has to do with the changing vapor pressures. The higher the vapor pressure, the more the fuel tends to accumulate on the walls of the intake passages. Vapor pressure is a partial pressure, and the major contributor to pressure in the intake passage is air. The air pressure in the intake passages in general is below atmospheric, unless the usual throttle valve is fully open, during engine operation.

While the wall-wetting changes, the amount of fuel metered by the fuel metering apparatus on the engine is not the amount of fuel that actually reaches the engine's combustion chambers within the charge transport time (air/fuel delivery time) applicable to the particular engine speed and load conditions at the time. The engine speed and load under stable engine operating conditions are the factors primarily determinative of the transport time of the air/fuel mixture from the fuel metering apparatus to the engine's respective combustion chambers. This applies to both central point fuel metering and multipoint fuel metering systems. Central point fuel systems include both the conventional carburetion system and the recently developed central point fuel injection system that has two electromagnetic fuel injectors positioned in a throttle body (air valve) to inject fuel into the incoming airstream. The multipoint system is exemplified by electronic fuel injection systems that provide an electromagnetic fuel injector for each of the engine's combustion chambers, with each injector injecting fuel into the intake passage immediately upstream of the intake valve for the associated combustion chamber.

A number of electronic engine control systems have been proposed previously. For example:-

U.S. Patent No. 3,794,003 to Reddy teaches an electronic deceleration control system which is responsive to engine RPM and intake manifold absolute pressure. The system computes the first derivative of the manifold pressure to provide an immediate indication of the deceleration demand independent of throttle position or minimum manifold pressure. The system curtails or terminates fuel delivery to the engine when manifold pressure is above a predetermined value. Fuel delivery is restored after the manifold pressure has returned above a second predetermined value. Engine RPM also is a factor employed in this fuel control system.

U.S. Patent No. 3,969,614 to Moyer et al discloses an engine control system employing a digital computer that calculates on a real-time basis the proper setting for one controlled variable while taking into account the effect of a setting of another controlled variable to provide stable engine operation at all times. The computer is programmed to repetitively calculate values for the controlled variables from an algebraic function or functions describing a predetermined desired relationship between a first controlled output variable and a second controlled output variable.

U.S. Patent No. 3,964,443 to Hartford teaches a digital engine control system that may be used to control a fuel injection system in which engine intake manifold pressure, engine RPM and engine temperature are utilized as inputs to a computer.

U.S. Patent 4,086,884 to Moon et al teaches a fuel control system for a spark ignition internal combustion engine wherein the fuel is delivered with central point fuel injection. The fuel injection pulse width determines the quantity of fuel delivered to the engine and this is calculated by the speed-density approach for determining the mass air flow.

According to the present invention, there is provided

A fuel metering system for an internal combustion engine, the engine having a passage through which a mixture of air and fuel is inducted into the combustion chamber of chambers of the engine, the fuel metering system comprising:-

(a) a fuel system having electrically settable means for controlling the rate at which fuel is metered into the engine's intake passage; and

(b) means for modifying the rate at which fuel is metered into the engine's intake passage to take into account the rate at which fuel is transferred from the surfaces of the intake passage to the inducted air/fuel mixture or from the air/fuel mixture to the surfaces of the intake passage.

The preferred fuel metering system of the invention is particularly suitable for use with a spark ignition internal combustion engine. The principles of the improvement may, however, be extended to other engine designs, such as Diesel, external combustion and turbine. Each of these other engine types requires an air/fuel mixture and may need the transient control provided by the invention. A diesel engine involves the direct injection of fuel into the engine's combustion chamber or prechamber (indirect injection Diesel), but the quantity of fuel that remains on the walls of the combustion chamber or prechamber and the variation of such quantity may be of considerable importance in the adequate control of Diesel engine exhaust emissions and fuel economy. Continuous combustion engines, on the other hand, do not require the degree of fuel control required by internal combustion engines because combustion is continuous and an excess of air is always available. It is not inconceivable, however, that such engines may one day require compensation for transient deposits of fuel in the intake passage to the "external" combustion chamber of such an engine. Such compensation would be of particular importance where the response of the engine to changes in rate of fuel flow is significant.

The improved fuel control system of the invention is designed to take into account the variations that occur in the quantity of fuel that is deposited in the liquid state in the intake passage or passages of an engine. The air/fuel ratio of the mixture in the intake passages varies depending upon the initial metering of fuel in proportion to the incoming air and also as a function of the net transfer of fuel from the surfaces of the intake passages to the inducted air/fuel mixture or vice versa. The incoming air, after being mixed with fuel at some point or points in the intake passage, flows into the engine's combustion chambers. Liquid fuel on the walls of the combustion chambers may be included in the net transfer.

. The liquid fuel on the walls of the intake passage is transferred into and removed from the air/fuel mixture that flows through the intake passages into the combustion chambers. This transfer and removal occurs at a rate which varies both locally within the passage and also on an overall basis. The variations of rate are a function of engine speed, load on the engine, engine and intake air and fuel temperatures, and some other less significant parameters.

A preferred embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a schematic block diagram of a basic fuel control system and a transient compensation system that is used to modify as necessary the computer-calculated fuel quantity determined by the basic system; and

Figure 2 is a graph of the intake manifold absolute pressure of an internal combustion engine versus the quantity of liquid fuel residing on its intake manifold under equilibrium conditions of engine operation.

With reference now to the drawings, there is shown in Figure 1, a basic fuel metering system 10 and a transient compensation fuel metering system 12. The basic fuel metering system has an engine 16 that produces certain operational conditions that are sensed via an engine sensor system 14, as is indicated by the arrow 15. With the sensor system connected by electrical leads 32, which may be in the form of a data bus for transmitting digital information, the engine operating conditions may be used in a computer calculation of the rate at which it is desired that fuel be metered to the engine 16 at a particular instant in time. This rate is calculated by the basic fuel metering system 10. Fuel is supplied to the engine with the use of a fuel system 18 that delivers fuel to the engine, as indicated by arrow 17, in response to a suitable signal appearing on the electrical or mechanical path represented by the arrow 19.

The basic fuel metering system 10 preferably includes a digital computer of the type employed in the fuel metering system described in U.S. Patent 3,969,614 to Moyer et al and preferably is capable of calculating a fuel injection pulse width to provide a desired air/fuel ratio. The pulse width may be determined by the use of a computer calculation that determines the quantity of fuel to be delivered to the engine per injection in response to the mass air flow into the engine's intake passages at the time of injection. A mass air flow meter or other device may be used to determine directly the mass air flow. Alternatively, a speed-density type of indirect determination of mass air flow into the engine may be made, as is done with the improved fuel metering system described in commonly-assigned U.S. Patent 4,086,884 to Moon et al. The system of the Moon et al patent now has been further improved in the manner described in our European Patent application Serial No. ...., (Case US-1092E).

The transient fuel metering compensation system 12 is intended to modify the basic rate of fuel metering calculated by the digital computer. The compensation takes into account the rate at which fuel is removed from or added to the liquid residing on the surfaces of the engine's intake passages. This transfer rate, if necessary, may include variations in the quantity of liquid fuel that remains within the combustion chamber of the engine as a deposit on its walls. When the fuel metering rate (a fuel injector pulse width multiplied by the number of injections per unit time and the fuel delivery rate during injection) is calculated by the basic fuel metering system 10, the rate of mass air flow into the engine must first be determined as indicated at 30 in Figure 1. At 33, a desired air/fuel ratio is determined based upon the engine operating conditions prevailing as of the time the rate of mass air flow is determined. Via the electrical or computer paths 34 and 35, the digital computer determines a desired rate of mass fuel flow into the engine by dividing the rate of mass air flow by the desired air/fuel ratio. The result, on electrical or computer path 37, then is used in the computation of a fuel flow demand, that is, a fuel flow rate that takes into account the transfer of fuel onto and from the quantity of liquid fuel residing on the surfaces of the engine's intake passages. This fuel flow demand appears on electrical or mechanical path 19 and controls the metering of fuel by the fuel system 18.

The fuel system 18 may be a conventional carburetor or a set of electromagnetic fuel injectors. In the preferred form of the invention, the fuel system is a throttle body mounted on the engine's intake manifold. The throttle body has two electromagnetic fuel injectors positioned to inject liquid fuel into the airstream entering the intake manifold through the throttle body. The injectors may be pointed downwardly at a location just above the throttle plate or plates mounted within the throttle body to control the rate of mass air flow into the engine.

The fuel flow demand is determined at point 20 in the system depicted in Figure 1. This signal is a combination of the desired fuel mass flow rate with a second rate term, identified ($TRISF_n$) (constant). The second term accounts for variation in the quantity of liquid fuel residing on the surfaces of the engine's intake passages. The constant in this term is a scaling factor. The factor $TRISF_n$ is the transfer rate of the fuel on the surfaces of the engine's intake passages. This factor, along with other quantities used in the description below, is defined as follows:

$$TRISF = \frac{d(AISF)}{dt}$$ = Transfer Rate of the Intake Surface Fuel

AISF = Actual Intake Surface Fuel

EISF = Equilibrium Intake Surface Fuel

ISTC = Intake Surface Time Constant

The transfer rate is expressed in units of mass per unit time. Actual and equilibrium intake surface fuel is expressed in mass units, and the intake surface time constant is in units of time. The intake surface time constant is a measure of the actual time required for fuel leaving the liquid state on the intake surfaces to become a gas or vapor in the intake mixture moving toward the engine's combustion chamber or chambers and vice versa.

The product of the transfer rate of the intake surface fuel and the time constant is equal to the difference between the equilibrium intake surface fuel and the actual intake surface fuel, or, stated mathematically:

$$(TRISF)\ (ISTC) = ISTC\ \frac{d(AISF)}{dt} = EISF - AISF$$

This is a differential equation. Under steady state conditions, d(AISF)/dt is equal to zero and the actual intake surface fuel AISF is the equilibrium intake surface fuel. However, under transient conditions of engine operation, where the equilibrium intake surface fuel EISF is changing between two different values corresponding to two different states of substantially stable engine operation, the differential equation above may be solved for the purpose of allowing the engine's fuel metering system to take into account the quantity of fuel entering and leaving the induction stream due to changing EISF states. The fuel flow demand is a fuel flow rate equal to the desired fuel flow rate less the net transfer rate from the intake surfaces to the inducted mixture.

The desired fuel flow rate is calculated as previously described, but the TRISF compensation of the basic fuel metering system computation is accomplished separately by the digital computer preferably used to handle both the basic fuel metering and TRISF computations. In the transient compensation system, the $EISF_n$ is calculated or is found in computer tabular memory and is available as a number applicable to the particular engine operating conditions prevailing at the time the fuel metering computation is being made. The subscript "n" denotes the current EISF, AISF and TRISF values and the subscript "(n-1)" denotes the values thereof at a prior time, such as the immediately preceding computer computation cycle.

In the solution of the differential equation defining TRISF, several computer or electronic techniques could be employed. There are several mathematical methods of approximating the solution using a trial and error technique. The solution also may be obtained by employing tables that contain TRISF values for various engine operating conditions. The preferred form of the invention uses a combination of these techniques and approximates the solution to the equation based upon results obtained from a prior solution. The prior solution, as well as the solution in progress at a given time, is calculated from values obtained in the prior solution of the differential equation as well as with the use of a table of values for the equilibrium intake surface fuel (EISF).

The EISF may be expressed as a function of one or more engine operating parameters, such as engine speed and engine load. In Figure 2, EISF is related to intake manifold absolute pressure, a quantity that is closely related to the load on the engine. Other parameters indicative of intake air or mixture flow rate or indicative of engine torque also may be used. A family of curves is shown to indicate that EISF also is a function of engine speeds indicated by RPM numbers that appear at the right-hand side of each curve. The variables could be interchanged if a different family of curves were to be used. Points 93 and 97 on the 1000 RPM curve designate two different engine power output requirements at the same engine speed. In a vehicle application of an engine, this might correspond to a change from operation of the vehicle on level ground to operation on an upward incline with increased throttle opening to maintain engine speed. In such situation, the engine speed would remain substantially constant if the throttle valve (conventionally used on the engine to control airflow and power output) were to be opened to increase the engine's power output. Opening of the throttle causes the intake manifold absolute pressure (MAP) to increase and thus, engine operation shifts from point 97 to point 93. Pressures corresponding to these points are indicated by lines 99 and 95 respectively. The EISF values at these points are respectively indicated by lines 96 and 94.

Line 98 in Figure 2 designates an actual intake surface fuel (AISF) that necessarily occurs at some time betweeen equilibrium engine operation at points 97 and 93. The AISF value or values occurring between equilibrium points are used in determining the transfer rate of the intake surface fuel and determination therefrom of the fuel flow demand as indicated in block 20. In this way, transient compensation of the fuel metering rate calculated by the basic system 10 may be achieved to take into account the liquid fuel transferred from the engine's intake passages to its induction mixture and vice versa.

The intake surface fuel at equilibrium engine operation is not changing and can be ignored. During changes or transients occurring in engine operation, however, accurate fuel metering requires that allowance be made for the contribution of the inducted air/fuel mixture to the quantity of liquid fuel residing on the intake passage surfaces or the contribution of fuel to the air/fuel mixture from the intake surface deposits. The fuel leaving the intake surfaces becomes an aerosol or vapor or gas and mixes with the air and fuel moving along the intake passage. This intake surface fuel is added to the metered quantity of fuel as determined by the current fuel setting. On the other hand, gaseous fuel that is deposited on the intake passage surfaces undergoes a change in state and subtracts from the quantity of fuel that actually reaches the engine's combustion chamber.

When fuel is added to the air/fuel mixture, it must be subtracted from the desired quantity that is obtained from the step indicated in block 36 of Figure 1. Thus, fuel that is removed from the walls of the intake passages and added to the inducted mixture is given an opposite mathematical sign as compared to the desired fuel flow so that, when combined in an additive process, the result is a value that represents the actual fuel flow demand, that is, the quantity of fuel that must be metered to provide the desired air/fuel ratio, taking into account the transient fuel addition provided by the fuel removed from the intake passage surfaces and inducted into the engine's combustion chambers. Of course, fuel removed from the air/fuel mixture moving toward the combustion chambers is given the same mathematical sign as the desired fuel flow so that, when combined in additive fashion therewith, the fuel flow demand will include an extra allowance for that fuel which is removed from the inducted mixture and deposited on the intake passage surfaces.

When the fuel flow demand is the same as the desired fuel flow determined as indicated by block 36, the fuel supply system is not providing any transient compensation. The air/fuel ratio of the air/fuel mixture inducted into the engine under transient conditions is a combination of the metered fuel and the quantity of fuel obtained from or added to that deposited previously on the intake passage surfaces. This latter quantity is obtained as a result of changes in the pressure within the intake manifold under the various conditions of engine operation. If the pressure increases as a result of increased throttle opening or reduced load on the engine, then the partial pressure of oxygen and noncombustible gases in the intake mixture increases correspondingly and the partial pressure of the fuel vapor decreases. Fuel removed from the mixture of gases deposits as a liquid on the surfaces of the intake passages. Conversely, if the fuel partial pressure increases as a result of other partial pressures that are reduced, the amount of liquid fuel deposited on the intake passage surfaces decreases and the fuel removed from that residing on the surfaces is inducted into the engine's combustion chambers. In addition to pressures, there are other factors that influence the quantity of liquid fuel on the surfaces of the engine's intake passages.

When the air supplied to the engine is cold, the amount of liquid fuel deposited on the intake passage surfaces is greater than it is as the engine warms up. This is because the partial pressure of the engine's intake air is greater at lower temperatures than it is at higher temperatures, and also because the fuel condenses more easily at the lower temperatures. Also, at lower intake air or fuel temperatures, the fuel metering device or system 18 employed may not be as effective in thoroughly mixing the air and fuel inducted into the engine. For these reasons, it conventionally has been necessary to employ fuel enrichment devices and techniques (the general equivalent of the choke function conventionally employed on spark ignition engines) in order to compensate for operation at lower temperatures. Unfortunately, the fuel enrichment that occurs results in increased hydrocarbon engine exhaust emissions and this has necessitated the use of elaborate choke control devices and systems to reduce the hydrocarbon emissions as much and as rapidly as possible. Such reduction of the hydrocarbon emissions has impeded or reduced the performance of the associated engines during the warm-up period.

The temperature of the intake system or its constituents is of significance with respect to the quantity of liquid fuel that can be deposited on the intake surfaces of the engine. The engine's intake passages may contain air, air and fuel in mixture, or air, fuel and exhaust gas in mixture. The temperature of any of these, or of the engine and its intake conduit, may be used in the determination of the rate at which fuel is transferred to and from the intake mixture from and to the intake passage surfaces. The physical properties of the fuel itself also are of importance and vary both geographically and seasonally.

When it is desired to compensate the rate at which fuel is metered to the combustion chamber or chambers of an engine for variations in the quantity or rate of transfer of liquid fuel residing on the intake passages surfaces in the engine, this may be accomplished in the manner depicted in the transient fuel metering system 12 of Figure 1.

In the Figure 1 transient fuel metering compensation system 12, the value of the current transfer rate of intake surface fuel $TRISF_n$ appears on path 46 leading to block 20 in the basic fuel metering system 10. The $TRISF_n$ value is a number that is repeatedly calculated and updated based upon changes in various engine operating parameters. As indicated in block 44, the current transfer rate of the engine's intake surface fuel is a function f_4 of variables that may be related to one another as follows:

$$TRISF_n = \frac{EISF_n - AISF_n}{ISTC_n} \qquad (1)$$

The $TRISF_n$ value cannot be calculated in the block 44 computer step until the $EISF_n$, $AISF_n$ and $ISTC_n$ values are known on a real-time basis, that is, while the engine is operating and being controlled by the basic and transient compensation fuel metering systems 10 and 12. $EISF_n$ can be determined from the engine operating parameters illustrated in Figure 2, but in reality is a function f_1 of engine intake manifold absolute pressure, engine speed, engine intake air or mixture temperature, engine intake system temperature (here partially represented by the engine coolant temperature TC_n), time and air/fuel ratio (A/F_n). Fuel physical properties also may be considered. The A/F_n is, of course, the ratio of air to fuel within the gaseous mixture adjacent the surfaces of the intake passage and varies with position within the intake passage. The $EISF_n$ also may be obtained from a computer memory which has stored within it constants that define the slope and EISF axis intercepts of a family of curves that can represent one or more of the curves illustrated in Figure 1. If this is the case, engine speed RPM_n may be used to select the proper set of constants and a single value of the intake manifold absolute pressure (MAP) may be used to obtain a value for the current equilibrium intake surface fuel $EISF_n$. Of course, the variables may be interchanged if desired. In any event, the current $EISF_n$ is determined from values of one or more engine operating parameters.

The $TRISF_n$ value of equation (1) cannot be determined until the $AISF_n$ and $ISTC_n$ values have been obtained; the former is subtracted from the $EISF_n$ value obtained as described in the preceding paragraph and the difference between the $EISF_n$ and $AISF_n$ values is divided by $ISTC_n$, the current intake surface time constant.

$AISF_n$ is approximately equal to the previous actual intake surface fuel $AISF_{(n-1)}$ modified to account for changes that may have occurred during the time elapsed since $AISF_{(n-1)}$ was determined. If $AISF_n$ is regarded as a function f_3 of the elapsed time Δt just mentioned, of $AISF_{(n-1)}$ and of $TRISF_{(n-1)}$, the following equation results;

$$AISF_n = AISF_{(n-1)} + [TRISF_{(n-1)}] \; [\; \Delta t]. \qquad (2)$$

From equation (2) above, it is clear that $AISF_n$ can be determined, at least to a good approximation, from previous values of TRISF and AISF used to effect compensation of the basic fuel metering system 10 for variations in the quantity of liquid fuel on the engine's intake passage surfaces.

The $ISTC_n$ is a time constant that represents the current or instantaneous rate at which fuel is being transferred from the liquid state on the intake surfaces to the vapor or gaseous state in the inducted mixture or vice versa. In view of this, the $ISTC_n$ may be described as a function of one or more engine operating parameters that influence this rate of transfer. Thus, as is indicated in block 42 of Figure 1, $ISTC_n$ is a function f_2 of intake manifold absolute pressure, engine speed, engine air or intake mixture temperature, engine intake system temperature, time, A/F_n, and the physical properties of the fuel. The intake surface time constant is not a constant in the sense that it does not change, but rather is variable under some engine operating conditions.

The ISTC is a measure of the time required for a fraction of the fuel that will be transferred, in response to a difference between the equilibrium intake surface fuel $EISF_n$ and the actual intake surface fuel $AISF_n$ existing during the transient engine operation, to be transferred. Variation in the ISTC results primarily from variations in the engine intake system temperature and the temperature TI_n of the intake air or gaseous mixture; there may be other engine operating parameters, such as the intake manifold absolute pressure, engine speed, or time in the engine cycle, that affect the ISTC. The ISTC variation is analogous to the variation of an RC time constant in an electrical circuit as a result of temperature or other variations that cause the resistance and capacitance values to change. At normal engine operating temperatures, the ISTC may be regarded as a constant, but for more accurate fuel metering capability, it is desirable to use a plurality of values for the ISTC. The values may be selected for a particular temperature range in which the engine is operating or some other parameter of engine operation may be selected for the determination of which value for ISTC will be used.

If the ISTC value is selected from a table or if it is calculated from an equation programmed into the digital computer, then the ISTC becomes a variable that takes into account variations in the physical properties of the engine's intake manifold and its contents. This is analogous, mathematically, to the variations in an RC time constant of an electrical circuit which variations would be due to changes in the resistance R and capacitance C values that determine the time constant. The ISTC changes that result from variation of engine intake system physical properties are primarily due to engine operating and intake air temperature variations. These variations are quite minor after engine warm-up.

After the ISTC has been selected, the digital computer is allowed to calculate the current transfer rate of the intake surface fuel $TRISF_n$ from equations (1) and (2) above. The $TRISF_n$ is applied via path 46 to the determination of the fuel flow demand in the basic system 10, as shown in block 20.

After the $TRISF_n$ value is determined, the value is provided via path 47 to a memory update of the previous value. Otherwise stated, the latest or most current value $TRISF_n$ replaces the previous value $TRISF_{(n-1)}$, as indicated by block 50 in Figure 1, and the updated value is applied to a memory 52 over path 51. The memory uses the updated value as the value for $TRISF_{(n-1)}$ in equation (2) above for the calculation of what is to become the next $TRISF_n$, which again causes the memory 52 to be updated.

Similarly, the value for $AISF_n$, determined with the use of equation (2) above, is calculated repeatedly. A clock 60 or pulse generator, conventionally required by a digital computer engine control system to update the fuel-metering control setting, is used in the computer determination of the time elapsed since the last update of the $AISF_n$ calculation. The current $AISF_n$ value is via line 63 to the calculation of the $TRISF_n$ value and also is made available, as indicated in block 65, for the update via path 66 of a memory 67 containing the $AISF_{(n-1)}$ value used in the calculation of a new $AISF_n$ from equation (2). This process preferably is repeated at the same rate at which the $TRISF_n$ calculations are made.

CLAIMS

1. A fuel metering system for an internal combustion engine, the engine having a passage through which a mixture of air and fuel is inducted into the combustion chamber or chambers of the engine, the fuel metering system comprising:

(a) a fuel system having electrically settable means for controlling the rate at which fuel is metered into the engine's intake passage; and

(b) means for modifying the rate at which fuel is metered into the engine's intake passage to take into account the rate at which fuel is transferred from the surfaces of the intake passage to the inducted air/fuel mixture or from the air/fuel mixture to the surfaces of the intake passage.

2. A fuel metering system according to Claim 1 wherein the means for modifying the rate at which fuel is metered is a digital computer programmed to calculate repetitively a value representing a current transfer rate of the intake surface fuel and wherein the calculated value is used to modify the rate at which fuel otherwise would be metered into the engine's intake passage.

3. A fuel metering system according to Claim 2 wherein the fuel system is a part of a basic fuel metering system that determines a desired fuel flow rate based upon the mass of air flow into the engine and a desired air-to-fuel ratio.

4. A fuel metering system according to Claim 3 wherein the basic fuel metering system provides an electrical signal that determines the setting of the fuel system and wherein the means for modifying the rate at which fuel is metered into the engine's intake passage is an electrical signal that modifies the desired fuel flow rate to take into account the rate at which fuel enters or leaves the inducted mixture as it passes through the intake passage.

5. A fuel metering system according to Claims 3 or 4. wherein the transfer rate of the intake surface fuel is repetitively calculated and combined with the desired fuel flow rate to obtain the electrical signal that determines the fuel flow demand from the engine's fuel metering system.

6. A fuel metering system according to Claims 3 or 4 wherein the basic fuel metering system determines the settings of the electrically settable fuel system without modification of the desired fuel flow rate except during selected conditions of engine operation.

7. A fuel metering system according to Claims 3 or 4 wherein engine operating parameters are used to determine the quantity of liquid fuel that would be present on the surfaces of the engine's intake passage under equilibrium conditions of engine operation and wherein the actual intake surface fuel in the liquid state on such surfaces determines the modification of the desired fuel flow rate.

8. A fuel metering system according to Claim 7 wherein the actual intake surface fuel is approximated from a previous transfer rate of the intake surface fuel.

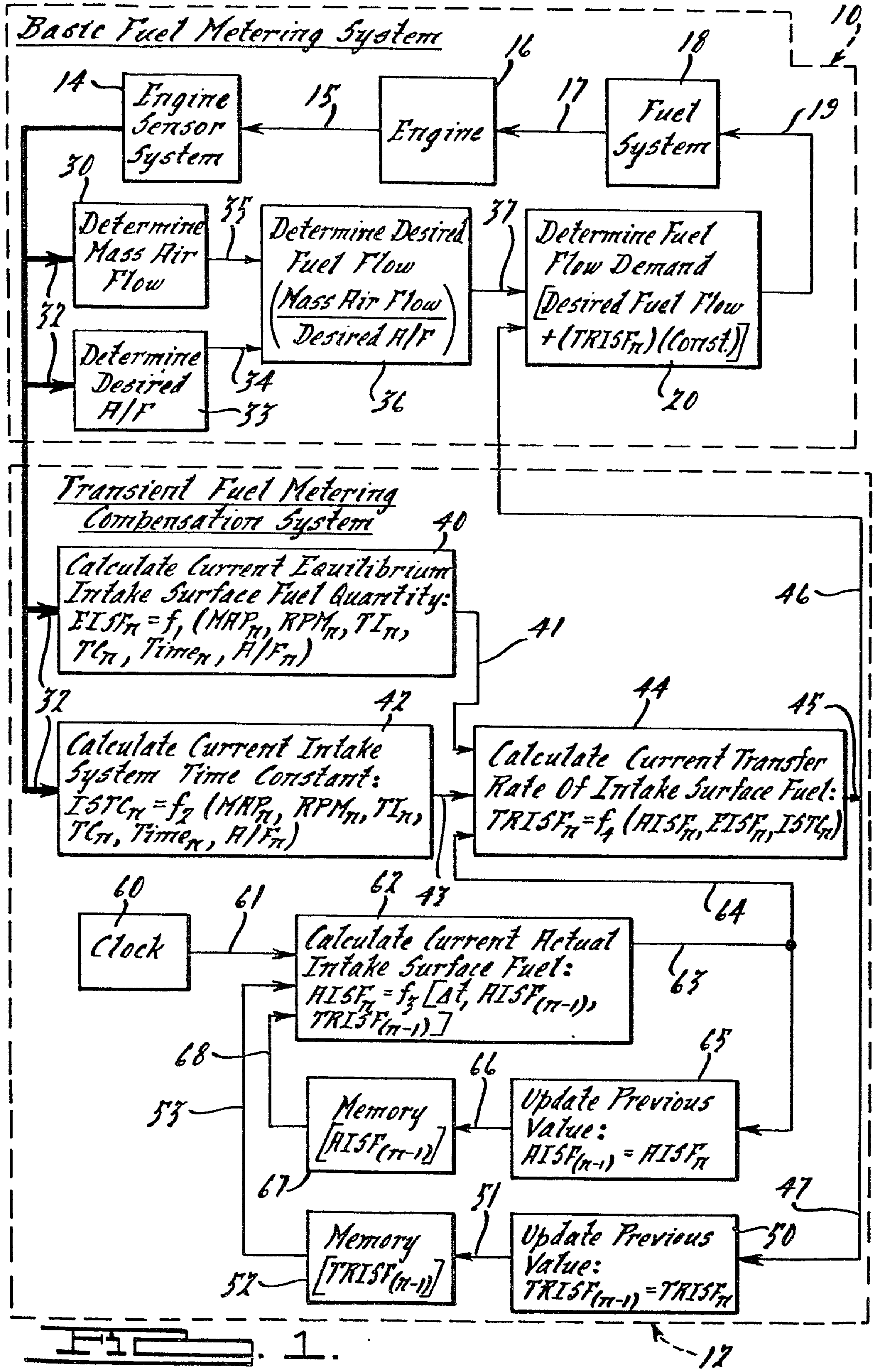
Basic Fuel Metering System
10
14
Engine Sensor System
15
16
Engine
17
18
Fuel System
19
30
Determine Mass Air Flow
35
Determine Desired Fuel Flow (Mass Air Flow / Desired A/F)
37
Determine Fuel Flow Demand [Desired Fuel Flow + (TRISFn)(Const.)]
32
Determine Desired A/F
34
33
36
20
Transient Fuel Metering Compensation System
40
Calculate Current Equilibrium Intake Surface Fuel Quantity: EISFn = f1 (MAPn, RPMn, TIn, TCn, Timen, A/Fn)
46
41
32
42
44
45
Calculate Current Intake System Time Constant: ISTCn = f2 (MAPn, RPMn, TIn, TCn, Timen, A/Fn)
Calculate Current Transfer Rate Of Intake Surface Fuel: TRISFn = f4 (AISFn, EISFn, ISTCn)
60
61
62
43
64
Clock
Calculate Current Actual Intake Surface Fuel: AISFn = f3 [Δt, AISF(n-1), TRISF(n-1)]
63
68
66
65
53
Memory [AISF(n-1)]
Update Previous Value: AISF(n-1) = AISFn
67
51
47
Memory [TRISF(n-1)]
Update Previous Value: TRISF(n-1) = TRISFn
50
52
12

FIG. 1.

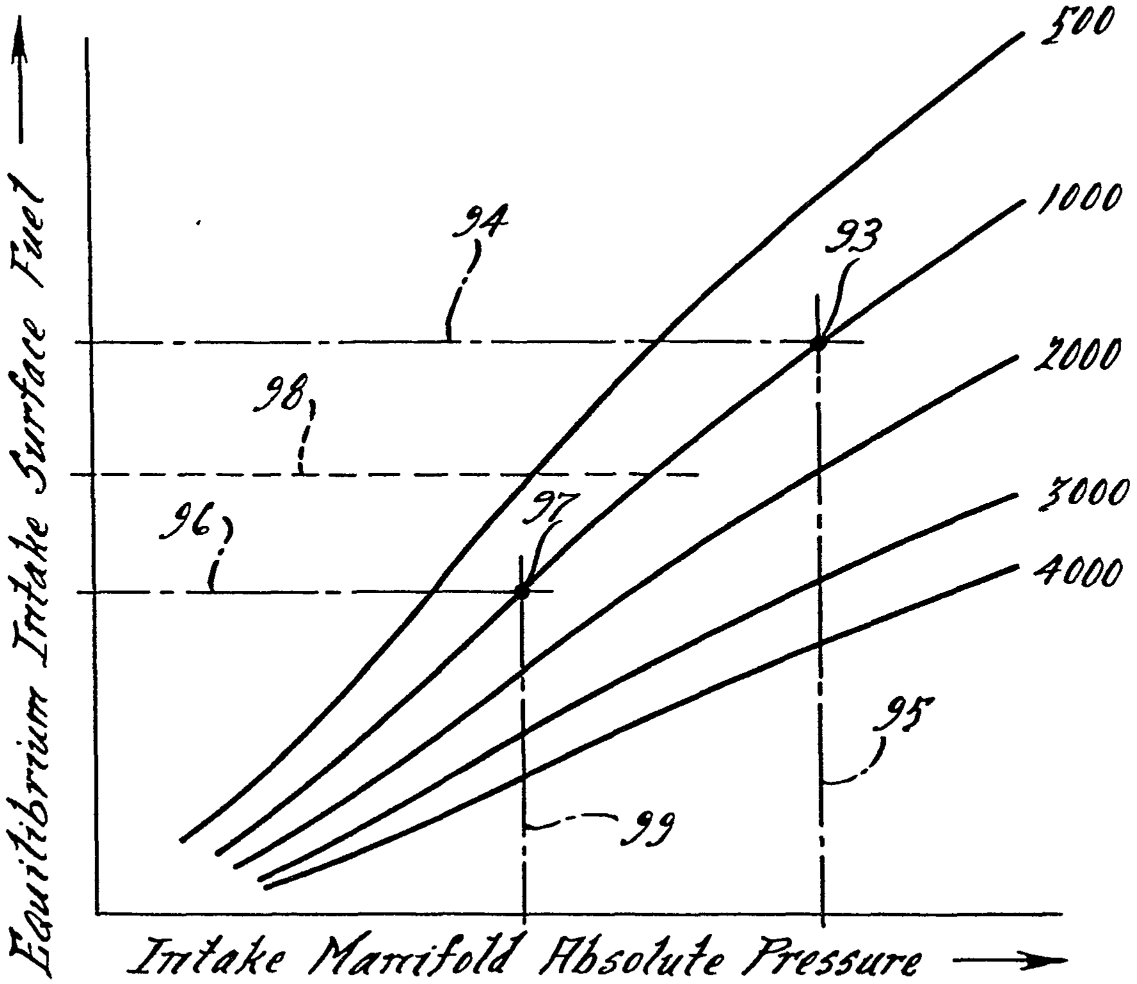
500
1000
2000
3000
4000
94
93
98
96
97
95
99
Equilibrium Intake Surface Fuel
Intake Manifold Absolute Pressure

FIG. 2.