United States Patent

O'Neill

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[45] **Sept. 5, 1972**

[54] **MASS FLOW METERED FUEL INJECTION SYSTEM**

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[73] Assignee: **Physics International Company,** San Leandro, Calif.

[22] Filed: **April 30, 1970**

[21] Appl. No.: **33,376**

[52] **U.S. Cl.**.....**123/32 EA,** 123/119 R, 123/140 MC, 123/139 AW

[51] **Int. Cl.**..........................**F02b 3/00,** F02m 51/06

[58] **Field of Search**..........123/119 R, 139.17, 32 EA, 140.3,123/139 AW, 140 MC

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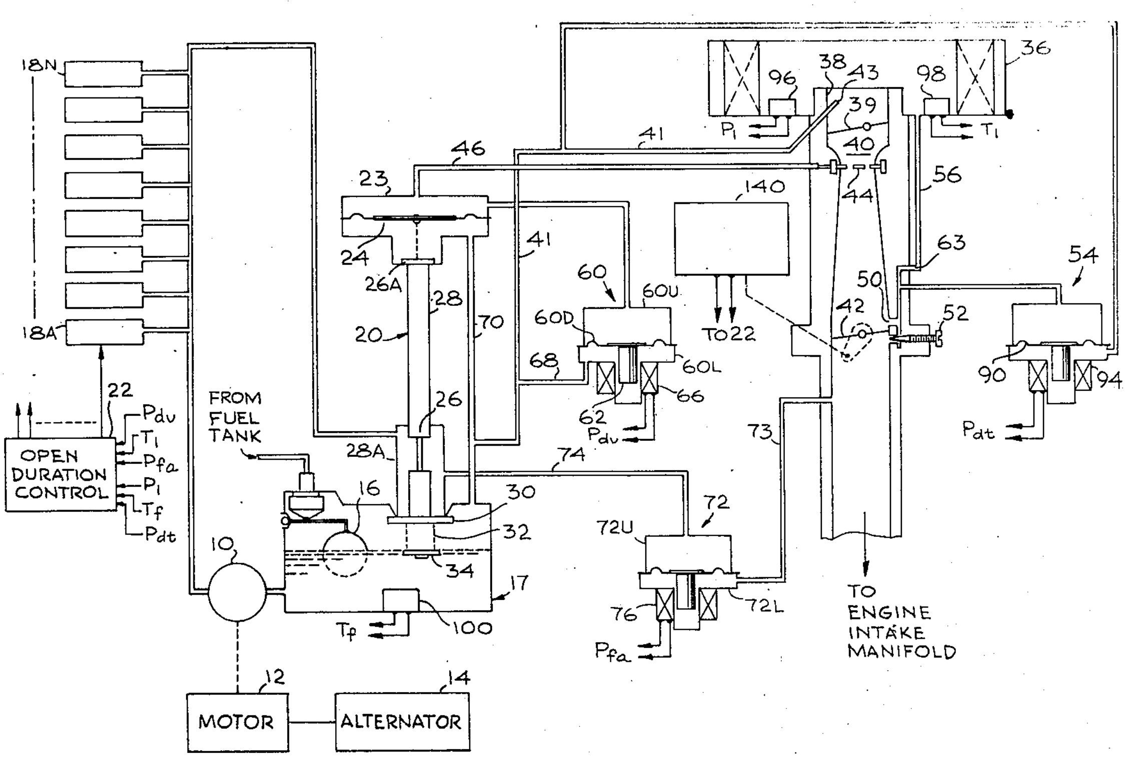
[57] **ABSTRACT**

A mass flow, timed fuel injection system is provided, wherein fuel flow is maintained at all times in a predetermined relation to air mass flow actually entering the engine at any instant, and the fuel injection valve is maintained open for an interval corresponding to a constant crank angle. This interval is corrected to compensate for any error which may have occurred because of inaccuracies introduced by the venturi through which air is metered and to compensate for the variations in discharge nozzle downstream pressure that occur in the induction ports.

15 Claims, 7 Drawing Figures



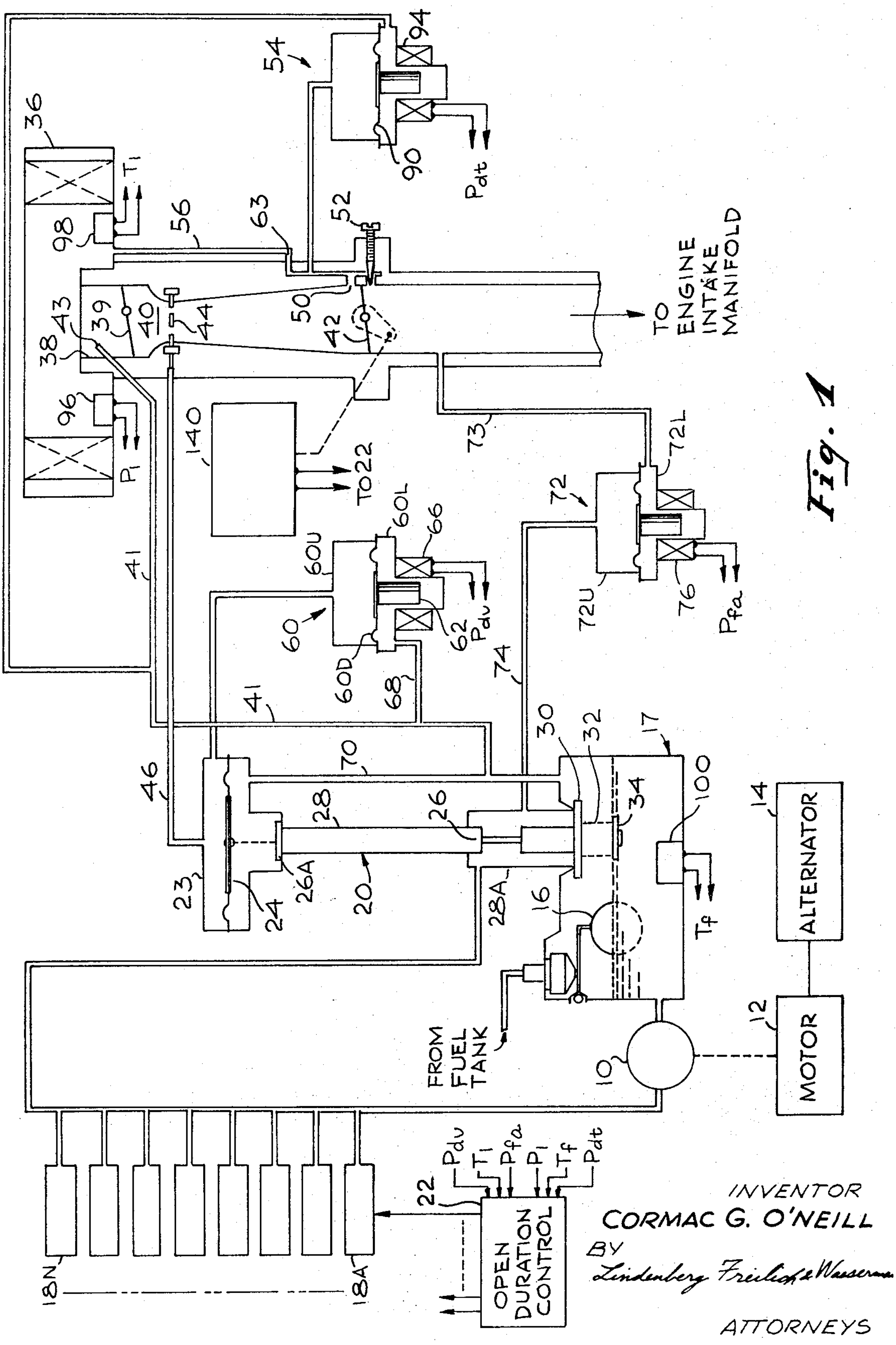


Fig. 1
TO ENGINE INTAKE MANIFOLD
TO 22
FROM FUEL TANK
ALTERNATOR
MOTOR
OPEN DURATION CONTROL
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ATTORNEYS

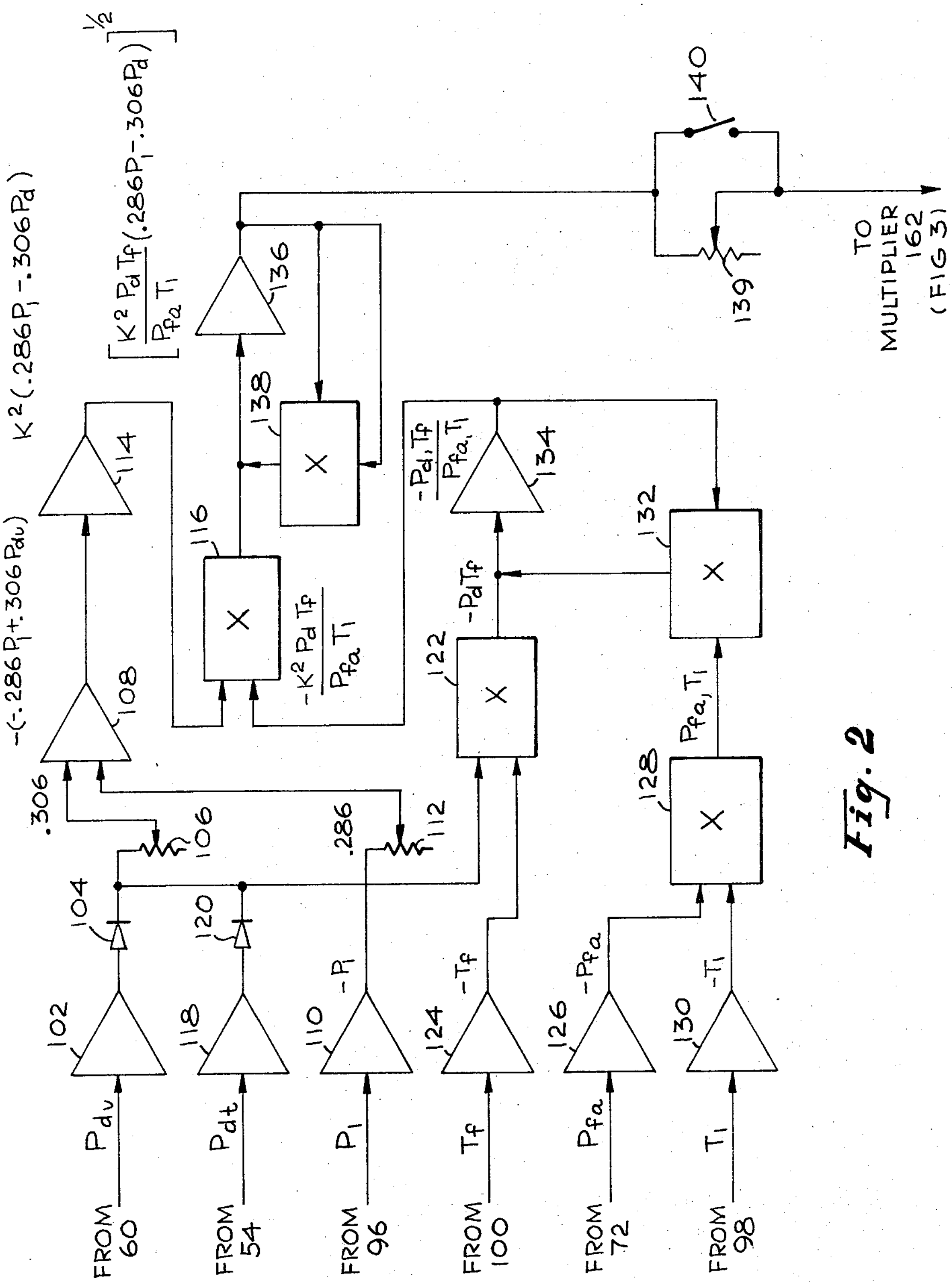

Fig. 2

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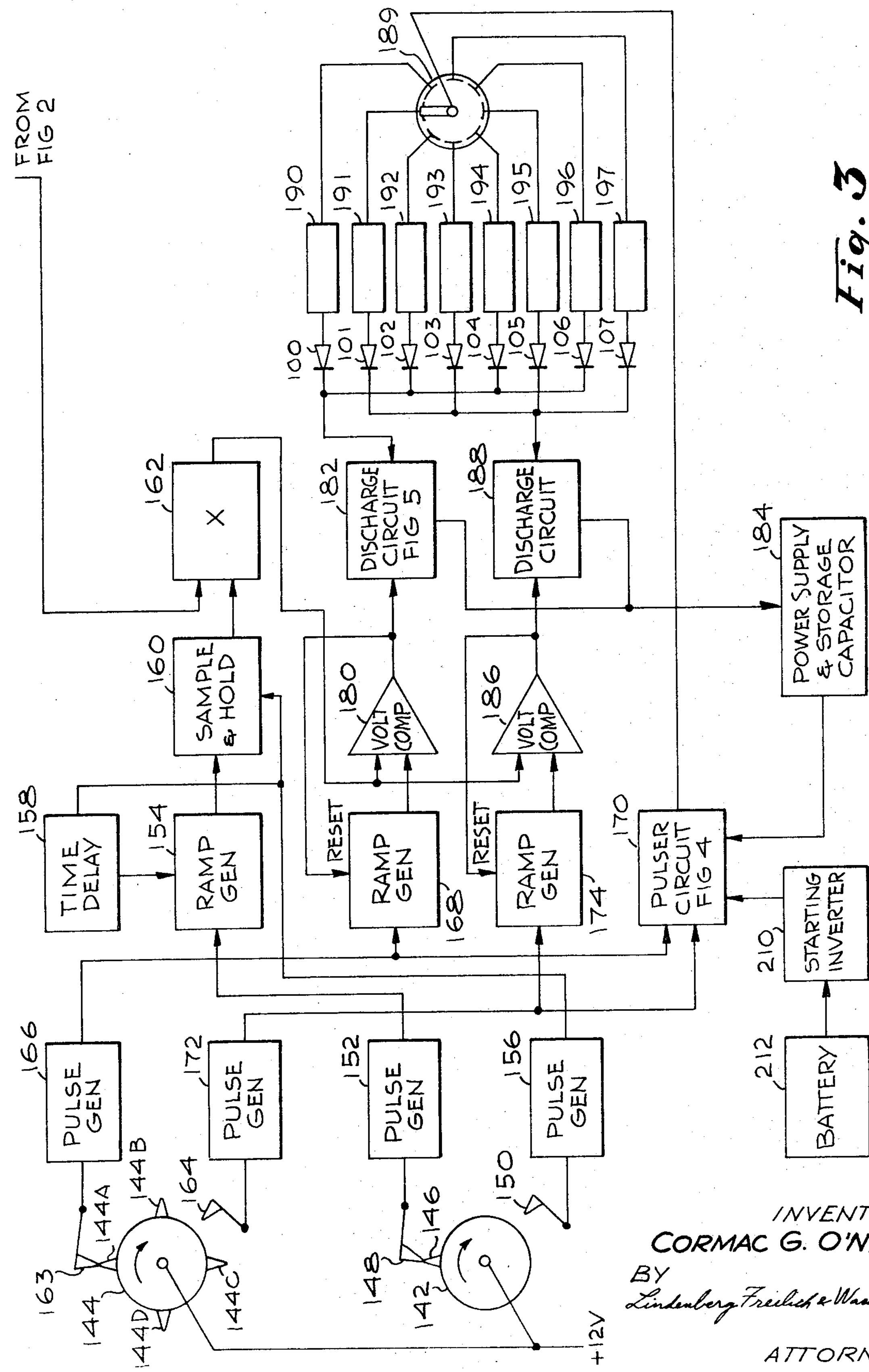

Fig. 3

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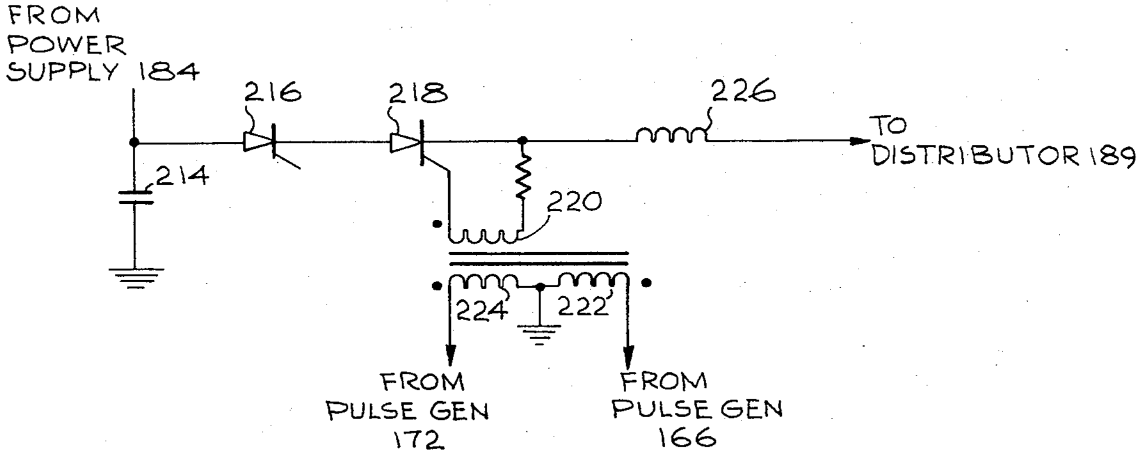

Fig. 4

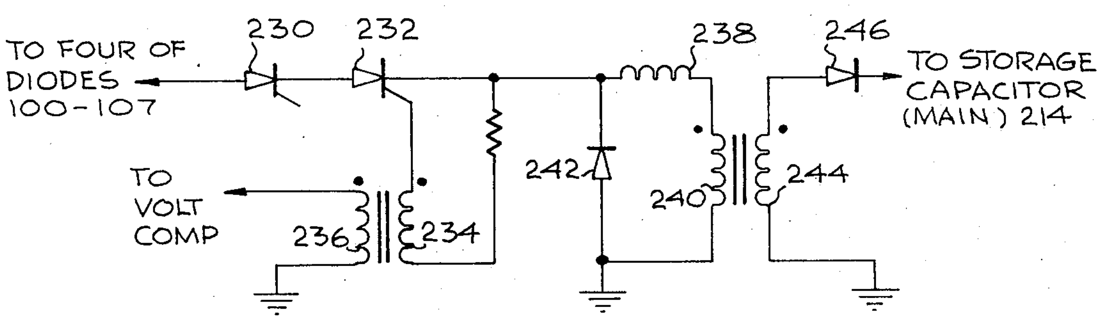

Fig. 5

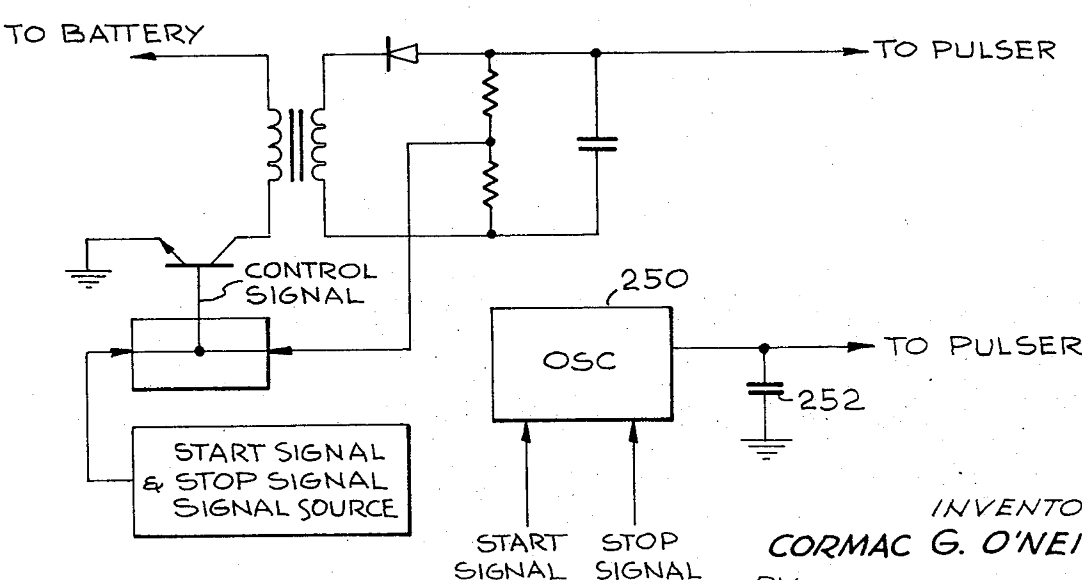

Fig. 6

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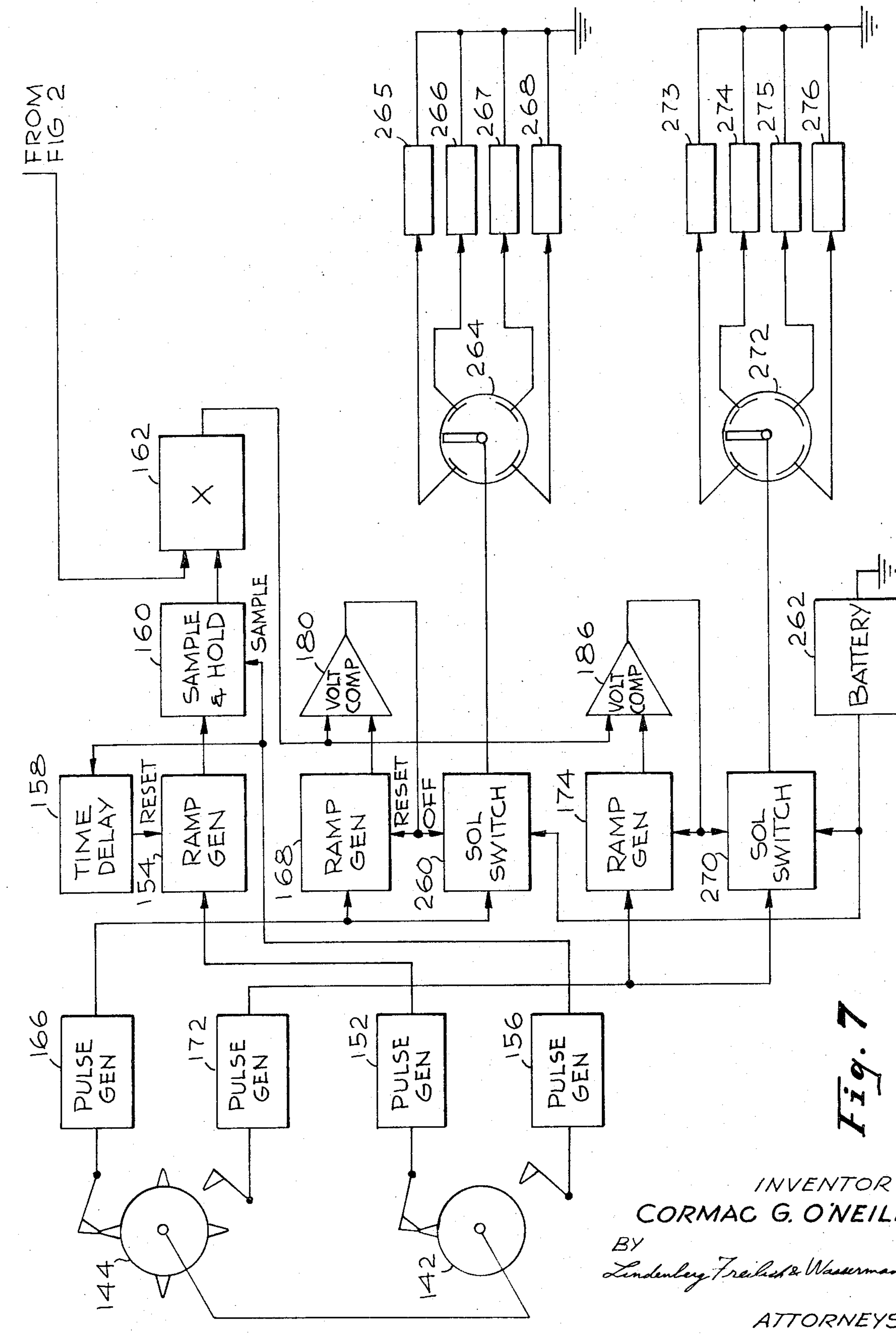

Fig. 7

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MASS FLOW METERED FUEL INJECTION SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to fuel injection systems for internal combustion systems and more particularly to improvements therein.

In an application for patent entitled "Fuel Injection and Control System," filed Sept. 17, 1969, Ser. No. 858,717, now abandoned, by this inventor, which is assigned to a common assignee, there is described a common rail fuel delivery system for an internal combustion engine wherein the pressure at which fuel is applied to the fuel injection valves in the system, is in proportion to the mass air flow, information for which is derived using a venturi. The duration of each of the fuel injection valve open times is varied inversely with engine speed. To avoid the formation of vapor at low engine output, together with inadequate atomization, fuel pressure is prevented from falling below a predetermined minimum value which is preselected. At all operating power levels below this minimum value fuel pressure, it is apparent that mixture strength would be too rich. To maintain correct mixture strength under these conditions, a correction in fuel delivery valve open duration time is introduced that shortens the duration of injection in the relationship:

$$T_a = T_s \sqrt{P_v/P_a}$$

where T_a is actual injection valve open duration, T_s is injection valve open duration derived from fixed crank angle, P_v is a fuel injection pressure derived from mass air flow signal, and P_a is actual fuel injection pressure. For these purposes, the actual fuel injection pressure used is taken as the pressure differential between the fuel supply line and intake manifold pressure.

To avoid the problems produced by using constant time per injection, the open time of each of the injection valves per cycle is in inverse proportion with speed, (or, the injection valve is open for a constant crank angle when fuel injection pressure exceeds some predetermined level, such as 20 p.s.i.)

The system described briefly, employs a venturi depression signal to modulate the common rail feed fuel pressure. While the system operates satisfactorily, improvement is noted when certain factors which occur under specific operating conditions of the venturi are taken into consideration. One of these is the fact that velocity and pressure pulsations that alter in phase can cause the venturi meter to produce a false measurement of air flow. To avoid this problem efforts are made to attenuate pulsation at the venturi. The venturi is positioned upstream of an air surge damping capacity, remote from the engine ports and, since no fuel is required to be fed through it, problems of fuel transport and deposition are avoided.

A second error occurs in mass air flow measurements made by venturi meters at high throat vacuum, when the expansion of the air mass creates a depression signal that does not follow a "squared" law. The error increases in magnitude as a result of variations in ambient temperature and ambient pressure. Accordingly, in order to avoid the error in air mass flow measurement by a venturi meter, which is caused by these factors, some arrangement must be found to measure these error causing factors and make the proper corrections for them.

OBJECTS AND SUMMARY OF THE INVENTION

An object of this invention is to provide in a fuel injection system of the type wherein fuel injection pressure is determined by air mass flow as measured by a venturi meter, an arrangement for compensating for certain inaccuracies introduced in the measurement of said air mass flow by said venturi meter.

Yet another object of this invention is the provision of an air mass flow timed fuel injection system which compensates for errors caused in air mass flow measurement by a venturi meter by ambient temperature and pressure variations and to provide accurate fuel mixture control at all altitudes.

Still another object of the present invention is the provision of a novel and improved fuel injection system.

These and other objects of the invention may be achieved in a common rail fuel delivery system of the type described briefly above, wherein an analog electrical circuit has applied thereto signals from several sensors which respectively measure the ambient temperature, the fuel temperature, atmospheric pressure, the pressure drop between the fuel supply pressure line and the manifold, the depression in the venturi throat below atmospheric pressure, and the depression below atmospheric pressure in the idling control channel which is down stream of the venturi, and from all these signals, the analog circuit produces a resultant analog electrical signal which is used to shorten the duration of the constant crank angle open time of the fuel injection valve, whereby any error in the measurement of the air mass flow is compensated.

The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description, when read in conjunction with the accompany drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic arrangement illustrative of where the various sensors required with this invention are placed.

FIG. 2 is a schematic diagram of an analog computer used to calculate the venturi meter error signal in accordance with this invention.

FIG. 3 is a schematic circuit diagram of a fuel injection valve control circuit.

FIG. 4 is a pulser circuit diagram which is employed with this invention.

FIG. 5 is a discharge circuit diagram which is employed with this invention.

FIG. 6 is a circuit diagram of a starting inverter which is employed with this invention, and

FIG. 7 is a schematic diagram of another embodiment of the fuel injection valve control circuit which may be employed in accordance with this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

There follows a derivation resulting in an equation which is implemented by analog circuits to provide the reduction in the "open" time of fuel injection valves which compensates for any errors introduced into the mass air flow fuel metering system as a result of the use of the venturi for determining mass air flow. From the equation which expresses fuel flow in pounds per second in an interrupted flow system, and from an equation which approximates air flow in a continuous flow system through a venturi, there is derived a "correction" factor which can be used to correct the crank angle signal which represents the interval over which the fuel injection valve is to be maintained open, whereby compensation is provided for the error in the measurement of mass air flow through the venturi meter.

First there will be shown the derivation of an approximation for air flow through a venturi which is then employed with the equation expressing fuel flow through a venturi, for obtaining the crank angle correction factor.

Air flow through a venturi follows the law

$$W=\left(agCdvP_1\sqrt{\frac{2\gamma}{\gamma-1}\frac{1}{gRT_1}}\right)\sqrt{\left(\frac{P_2}{P_1}\right)^{2/\gamma}-\left(\frac{P_2}{P_1}\right)\frac{\gamma+1}{\gamma}}$$

where

Cdv = Coefficient of discharge of venturi
W = flow rate
a = throat area (in.^{2})
g = units conversion factor
P_1 = ambient pressure
T_1 = ambient temperature
P_2 = throat pressure
R = gas constant
γ = gamma law gas factor

In order to build a simple electrical analog computer to compute W, it is necessary to approximate this function using only the operations of addition, subtraction, multiplication, division, and the evaluation of a square root.

The quantity in parenthesis involves only these operations, so it is now necessary to find an approximation to

$$G=\sqrt{\left(\frac{P_2}{P_1}\right)^{2/\gamma}-\left(\frac{P_2}{P_1}\right)\frac{\gamma+1}{\gamma}}$$

This can also be expressed as

$$G=\sqrt{\left(\frac{P_2}{P_1}\right)^{1/\gamma}\left[\left(\frac{P_2}{P_1}\right)^{1/\gamma}-\frac{P_2}{P_1}\right]}$$

Let $P_0=P_1-P_2$
so that $P_2/P_1=1-(P_0/P_1)$
with this substitution, G becomes

$$G=\sqrt{\left(1-\frac{P_D}{P_1}\right)^{1/\gamma}\left[\left(1-\frac{P_D}{P_1}\right)^{1/\gamma}-\left(1\frac{P_D}{P_1}\right)\right]}$$

For this particular application which is carburetion system, the only valves of h and P_1 of interest are in the ranges

$0 \leq P_0 \leq 6$ inches of Hg
$15 \leq P_1 \leq 31$ inches of Hg

so that the range of the dimensionless ratio P_0/P_1 is

$0 \leq (P_0/P_1) \leq (6/15) = 0.4$

The smallness of the ratio P_0/P_1 suggests that

$$\left(1-\frac{P_D}{P_1}\right)^{1/\gamma}$$

be expanded in a Taylor series about $P_0/P_1=0$ to get an approximate expression for G. Thus, using

$$\left(1-\frac{P_D}{P_1}\right)^{1/\gamma}\cong 1-\frac{1}{\gamma}\left(\frac{P_D}{P_1}\right)+\frac{1}{2\gamma}\left(\frac{1}{\gamma}-1\right)\left(\frac{P_D}{P_1}\right)^2$$

and neglecting all terms higher than second order in P_0/P_{ay}, gives

$$G\cong\sqrt{\frac{\gamma-1}{\gamma}\frac{P_D}{P_1}-\frac{3(\gamma-1)}{2\gamma^2}\left(\frac{P_D}{P_1}\right)^2}$$

or

$$\sqrt{\frac{P_D}{P_1}\left(.286-.306\frac{P_D}{P_1}\right)}$$

With this approximation for G, one finally has

$$W=agP_1\sqrt{\frac{2\gamma}{\gamma-1}\frac{1}{gRT_1}}$$

$$W=Cdv\,Av\sqrt{\frac{2\gamma}{\gamma-1}\cdot\frac{g}{R}}\cdot\frac{P_1}{\sqrt{T_1}}\cdot\left(\frac{P_D}{P_1}0.286-0.306\frac{P_D}{P_1}\right)$$

This approximate formula for W is very accurate in the ranges of P_0 and P_1 that is under consideration. The table on the next page shows the accuracy of the approximation when $\gamma = 1.4$ (air).

Accuracy of the Approximation to W for γ =**1.4**

Range of P_0/P_1	Maximum Relative Error in W = Exact-Approximation/Exact × 100%
0 to .4	−0.06% when $P_0/P_1 = .15$
0 to .5	+0.1% when $P_0/P_1 = .5$

Assume now that Adiabatic conditions $\gamma = 1.4$. The Fuel flow lb/sec (interrupted flow) for an interval combustion engine may be expressed as

$$Lf=A_N V_f \rho_f tN=A_N C_{DN}\sqrt{2gh_f\rho_f}tN$$

$$L_f=A_N C_{dN}\sqrt{2g\rho_f P_f}\,t\times N \qquad (1)$$

where

A_N = Nozzle orifice area
C_{DN} = Nozzle coefficient of discharge
ρ_f = Fuel density
h_f = Head loss across nozzle
P_f = Pressure drop across nozzle (psi)
t = Duration of injection (sec)
N = Number of injections/sec
a = Area of venturi throat (in.^{2})
P_1 = Ambient pressure (psi)
T_1 = Ambient temperature (°R)
P_0 = Venturi throat depression (psi)
C_{dv} = Coefficient of discharge of venturi

It was previously shown that an approximation of Air flow, lb/sec (continuous flow) through a venturi may be approximately expressed as

$$W=C_{d\cdot a}\sqrt{\frac{2\gamma}{\gamma-1}\frac{g}{R}}\frac{P_1}{\sqrt{T_1}}\left(\frac{P_D}{P_1}0.286-0.306\frac{P_D}{P_1}\right)^{1/2} \qquad (2)$$

If $W = B\,Lf$ where B = air/fuel ratio, then equating B × Equation (1) with Equation (2)

$$B A_N C_{dN} tN\sqrt{2g\rho_f}\cdot\sqrt{P_f}=$$

$$C_{dv}a\sqrt{\frac{2\gamma}{\gamma-1}\cdot\frac{g}{R}}\cdot\frac{P_1}{\sqrt{T_1}}\sqrt{\left(\frac{P_d}{P_1}0.286-0.306\frac{P_d}{P_1}\right)}$$

$$K_1B=\frac{P_1}{\sqrt{T_1}}\sqrt{\frac{0.286-0.306\frac{P_D}{P_1}}{P_1}}\sqrt{\frac{P_D}{P_f}}\frac{1}{tN}$$

where

$$K_1=\frac{A_N}{a}\frac{C_{dN}}{C_{dv}}\sqrt{\frac{(\gamma-1)}{\gamma}R_{\rho f}}$$

$$K_1B=\sqrt{\frac{(0.286P_1-0.306P_D)}{T_1}}\sqrt{\frac{P_D}{P_f}}\frac{1}{t\cdot N} \qquad (3)$$

If P_f is controlled through a force balance linkage such that $P_f = W\,P_d$ where W is a constant ratio.

Then

$$B=\frac{1}{tN}\sqrt{\frac{(0.286P_1\ 0.306P_D}{T_1}}\cdot K_2 \qquad (4)$$

where

$$K_2=\frac{a}{A_N}\,\frac{C_{dv}}{C_{dN}}\sqrt{\frac{\gamma}{(\gamma-1)R}\cdot\frac{1}{\rho_f W}}$$

If the opening duration t is controlled electronically so that:

$$Nt\sqrt{\frac{T_1}{(0.286P_1-0.306P_d}}=\text{a constant } K_3$$

$$t=\frac{K_3}{N}\sqrt{\frac{(0.286P_1-0.306P_D}{T_1}} \qquad (5)$$

Therefore substituting for t in Equation (4)

$$B=\frac{\sqrt{\frac{(0.286P_1-0.306P_D)}{T_1}}\cdot K_2}{\frac{N}{K_3 N}\cdot\sqrt{\frac{(0.286P_1-0.306P_D)}{T_1}}}$$

$$=\frac{K_2}{K_3}$$

i.e., fuel/air ratio is independent of P_1, T_1 and venturi signal level.

We must now adopt datum conditions from which to apply the radical as a "correction" for t.

The following conditions have been adopted arbitrarily with the intention only of maintaining the correction less than unity:

$T_1 = 440°R$

$P_1 = 31$ in. Hg $\equiv$ 15.2 psi

$P_D = 0.5$ in. Hg $\equiv$ 0.245 psi

Therefore

$$K_3=Nt\sqrt{\frac{440}{0.286\times15.2-0.306\times0.245}}=Nt\sqrt{\frac{440}{4.275}} \qquad (6)$$

Without "correction"

$$t=\frac{\alpha}{60\text{ r.p.m.}}\text{ sec.}$$

where α = injection duration in crank angle degrees.

$$K_3=N\frac{\alpha}{60\text{ r.p.m.}}\sqrt{\frac{440}{(4.275)}}$$

$$t=\frac{\alpha}{60\text{ r.p.m.}}\sqrt{\frac{440}{T_1}\cdot\frac{0.286P_1-0.306P_D}{4.275}} \qquad (7)$$

or

$$t=\frac{K_4}{\text{r.p.m.}}\sqrt{\frac{0.286P_1-0.306P_D}{T_1}}$$

where

$$K_4=\frac{\alpha}{60}\sqrt{\frac{440}{4.275}}$$

In Equation (7) the correction factor is:

$$\sqrt{\frac{440}{T_1}\cdot\frac{0.286P_1-0.306P_D}{4.275}}$$

A second correction factor that acknowledges the use of an incorrect fuel pressure must also be used. In Equation (3) the term $\sqrt{P_D/P_f}$ assumed P_f, the pressure drop across the nozzle, to be the same as the pressure drop across the spill valve. However it sometimes differs from nozzle pressure and the substitution of $W\cdot P_D$ in Equation (4) is not valid at all times. We must therefore multiply by $\sqrt{W\,P_D/P_{FA}}$ where P_{FA} is the sensed difference between fuel pressure and manifold pressure.

This additional term gives a total correction factor that can be applied to valve opening duration:

Correction factor

$$=\sqrt{\frac{P_D}{P_{FA}T_1}\cdot\frac{440W}{4.275}\cdot\frac{(0.286P_1-0.306P_D)}{1}}$$

or

$$\text{Correction factor}=K_5\sqrt{\frac{P_D}{P_{FA}T_1}(0.286P_1-0.306P_D)}$$

where $K_5^2 = (440\ W/4.275)$ (8)

The "correction" factor is

$$K_5\left(\frac{P_D}{P_{FA}T_1}\right)^{1/2}(0.286P_1-0.306P_D)^{1/2} \qquad (8A)$$

PFA difference between fuel pressure and manifold pressure is obtained electrically from three sensors and an analog circuit. An electrical signal proportional to the full $\alpha°$ injection event is obtained from a ramp generator. This signal is reduced by multiplying it by the "correction" factor and the resultant signal is employed to terminate injection at a crank angle duration correspondingly less than $\alpha°$.

Reference is now made to FIG. **1** of the drawings. This FIG. **1** resembles FIG. 1 of application Ser. No. 858,717 referred to above, except modifications required for the purpose of this invention. Thus, three additional sensors are provided, one of which is a barometric pressure sensor, the second an ambient pressure sensor, and the third a fuel temperature sensor. This drawing also shows the presence of other structures which are used in accordance with this invention.

A high pressure pump **10** is driven in approximately constant relationship to engine speed, either by direct coupling, or preferably, by an induction motor **12** which is powered directly from the AC output of the vehicle alternator **14**. The pump **10**, which may be a positive displacement pump, pumps fuel from a conventional float bowl **17**. A float **16** enables fuel to be transferred into the float bowl **17** from the fuel tank, when the level of the fuel in the float bowl drops below a predetermined value.

The fuel is pumped to a plurality of injection valves **18A**, . . . **18N**, one to each cylinder, which are fed from a common passage. The fuel is then circulated to a spill valve unit **20**, and from the spill valve unit back to the float bowl **17** then to the injection valves. Each of the injection valves may be of an electro mechanical type that open and close very rapidly in response to an electrical signal, which is provided by "open duration" control system **22**. The injection valve may also be of a hydraulically actuated type which responds to hydraulic pressures from the opening duration control **22**. Each valve contains a calibrated orifice through which the fuel must pass before it can be discharged.

The spill valve unit **20** includes a cylindrical chamber **23** having a diaphragm **24** mounted therein. The diaphragm is attached to a poppet valve stem **26** which is supported in a guide bore **28**. The lower part of the guide bore **28A** is enlarged and the larger bore terminates in a narrow seating upon which the poppet valve **30** can seat. The poppet valve is free to slide on its stem but is urged toward the closed or seated position by a spring **32** mounted on the stem between the poppet and a snap ring or collar **34**. To prevent the spring from drawing the stem downward and thus distorting the diaphragm, a collar **26A** is formed at the upper end of the valve stem that abuts the spill valve housing when the diaphragm is in the lowest permitted position.

The air silencer and cleaner **36** is supported on one end of the air intake **38** which leads to a common plenum chamber or manifold (not shown) which distributes air to the intake ports of the engine. A venturi structure **40** is located in this intake. A throttle valve **42** is located between the venturi and the engine. Tappings in the throat of the venturi, **44**, are connected via a tube **46**, to the diaphragm chamber **23** of the spill valve unit **20**, to apply vacuum to the upper side of the diaphragm **24**, depending upon the flow of air through the venturi. The greater the flow of air, the greater the pull on the poppet valve, the less fuel can get by it and therefore the higher the back pressure of the fuel on the injection valves. The lower the flow of air through the venturi, the lower the pull on the diaphragm and the poppet valve, the more fuel can get by the poppet valve into the float chamber, and therefore the lower the pressure of the fuel on the injection valves.

A progression system and idling port **50**, with a volume control tapered screw **52**, and an air bleed from atmosphere **53**, which are conventionally used in carburetors, are provided in the throttle body and the channel linking, idling and progression holes is connected to a third or idling pressure sensor **54**, which will be described later herein. An air bleed line **56** is used to vent the idling port **50**.

A mode switch **58**, which will be explained in more detail in FIG. **2**, responds to an indication from the throttle valve that an optimum output is required. That is, when the fuel mixture needs to be altered from say, a cruising air fuel ratio of 16:1 to a full power ratio of 12:1. The mode switch then signals the control circuits **22** to lengthen the fuel injection interval.

A first pressure sensor **60**, comprises an upper chamber **60U** which is separated from the lower chamber **60L** by a diaphragm **60D**. The diaphragm carries a magnetic core **62**. A winding **66** senses the position of the core **62**. At this point, it is desired to emphasize that the foregoing pressure sensor construction is merely exemplary not only of pressure sensor **60**, but others to be described herein. Other well known pressure sensing transducers may be employed, such as the strain gauge type, without departing from the spirit and scope of this invention.

The upper chamber of the first pressure sensor **60** is connected to the upper side of the spill valve diaphragm chamber. The lower chamber of the first pressure sensor is connected via a pipe **68** to the lower side of the spill valve diaphragm chamber. The lower side of the spill valve diaphragm chamber also communicates via the pipe **70** with the float bowl. The first pressure sensor thus provides an electrical output, designated as *Pdv* and applied to control **22**, which is representative of the difference in pressure across the diaphragm which is proportional to the intake air (mass flow)^2 or to the fuel pressure that is being signalled to the injection valves. A tube **41** also extends from the air intake **38** to the tube **68** and then to the tube **70**. An impact tube **43** is placed at the junction between tube **41** and air intake **38** to sense stagnation pressure in the intake passage.

A second pressure sensor **72** has a similar construction to the first pressure sensor. Its lower chamber **72L** is connected via a tube **73** to the intake manifold downstream of the throttle valve **42**. The upper chamber **72U** is connected via a pipe **74** to the fuel passage in the spill valve unit **20** which is upstream of the poppet valve **30**. An inductive pickup **76** on the second pressure sensor **72** senses the position of the diaphragm therein.

The electrical signal output of the second pressure sensor, designated as *Pfa*, is applied to the control **22** and represents the actual fuel pressure difference applied across the calibration in the injection valves which is to be described later.

The idling pressure sensor **54** may be called the third pressure sensor and is connected so that the idling and progression channel **50** is in communication with the upper side of the diaphragm **90** which is carried by the third pressure sensor, while the lower side of the diaphragm is vented to the air intake horn between the air silencer and the venturi by being connected to tube **41**. An electrical pickup **94** senses the displacement of the diaphragm. The electrical signal output of the third pressure sensor designated as PDT, is applied to control **22** and indicates (air mass flow)^2 over periods of light engine operation when the flow through the venturi **40** falls into a laminar flow regime and indicates flow erroneously.

The third pressure sensor output is used to indicate when the fuel pressure would fall below a predetermined value, for example below 20 lbs. per sq. in. If the determination of fuel pressure remained solely under the control of mass air flow in the venturi, at low engine output there would be a low fuel pressure and vapor would be formed and there would be inadequate atomization. The spring **32** establishes a minimum fuel pressure which avoids the effects of low fuel pressure. However, at engine operating levels below this minimum value fuel pressure the mixture strength could become too rich. A correction is made by the open duration control **22**, in the time duration the fuel delivery valve is open, that shortens fuel injection time and thereby compensates and maintains the correct fuel mixture strength. The barometric pressure sensor **96** and the ambient temperature sensor **98**, are both placed in the air cleaner. In this way the barometric pressure sensor takes into account the additional pressure loss due to filter element resistance. The output of the barometric pressure sensor is an electrical signal designated as P_1, representative of the barometric pressure. The ambient temperature sensor produces as its output an electrical signal, designated as T_1, representative of the ambient temperature. There is also a fuel temperature sensor **100**, which is placed in the bowl **17** and which produces as its output a signal T_f representative of fuel temperature. All of the foregoing signals are applied to the Open Duration Control Circuits **22**.

When the engine is first started, the choke valve **39** placed just before the venturi is turned to block the passage of air. This causes an increase in the differential air pressure across the diaphragm **24**. The result is an upward pull on the diaphragm which pulls upon on the spill valve. This results in increased pressure and fuel flow to the fuel injection valves, a desirable condition during cold starting.

Reference is now made to FIG. 2 which is a block schematic diagram of an analog circuit which implements equation 8A. This is the equation for the correction factor by which it is required to reduce the constant crank angle fuel injection interval.

The output of the pressure sensor **60**, which senses a venturi pressure, and which is designated as P_{dv} is applied to an amplifier **102**. The output of this amplifier, which is non-inverting, is applied to a diode **104**. The output of the diode is applied to an attenuating potentiometer **106**, which multiplies the value P_{dv} by 0.306. Thereafter, the attenuator output is connected to a summing amplifier **108** input.

The output of the ambient temperature sensor **96**, which is designated as P_1, is applied to an inverting amplifier **110**. Its output, represented by $-P_1$, is applied to an attenuating potentiometer **112**, which attenuates it by the factor 0.288. The output of the potentiometer **112** is applied to the summing amplifier **108** as its second input.

The output of the summing amplifier, which now comprises $-(-0.286P_1+0.306\ P_{dv})$ is applied to an amplifier **114**, which multiplies it by a gain factor K^2. The output of the amplifier **114** is applied as one input to a multiplier circuit **116**.

The output from pressure sensor **54**, which derives a signal from the idling control channel, and which is represented by P_{dt}, is applied to a noninverting amplifier **118**. The output of this amplifier is applied to a diode **120**. The output from diodes **104** and **120** are connected together and serve as one input to a multiplier circuit **122**. The signal that is applied to the multiplier **122** will be the larger of the two signals applied to the diodes **104** and **120**, since this larger signal will bias off the other diode. Thus, the signal applied to the multiplier **122** represents either the idling air pressure or the off idling air pressure.

The other input to the multiplier **122** is a correction factor which is derived from the fuel temperature sensor **100**, and is represented by the signal T_f. This is applied to an inverting amplifier **124**. The output of this amplifier is applied as a second input to the multiplier **122**.

The fuel pressure sensor **72**, represented by the signal P_{fa} is applied to an inverting amplifier **126**. The output of this amplifier is applied at one input to a multiplier **128**. The other input to the multiplier is the ambient temperature sensor **98** output, T_1, which is applied to an inverting amplifier **130**. The output of amplifier **130** is the second input to multiplier **128**.

The reason for the correction for fuel temperature provided by the signal T_f, is that the variation in fuel gravity is approximated by a straight line relationship of 7 percent mass flow reduction for 100° F. fuel temperature increase. The purpose of the fuel temperature sensor **100** is to produce a signal which increases injection duration with rise in temperature to compensate for this effect.

The output of the multiplier **128**, consisting of the quantity P_{fa},T_1 is one input to a multiplier **132**. This multiplier **132** is in the negative feedback path of the amplifier **134**. This negative feedback is applied to the multiplier **132** as its second input. The output of the multiplier **132** is summed with the output of multiplier **122** and applied to the input of amplifier **134** As a result, the output of amplifier **134**represents the output of multiplier **122** divided by the output of multiplier **132**, or $(-P_d,\ T_f)/(P_{fa},T_1)$.

The output of amplifier **134**s applied to the multiplier **116** as its second input. The output of the multiplier **116**, consisting of the product of its two input terms, is applied to an inverting amplifier **136**. This amplifier has its output connected as two inputs to a multiplier **138**, whereby the output of the amplifier constitutes the square root of its input.

A switch **140**, responsive to movement of the throttle control pedal, is fitted so that the output of amplifier **136** may be directly passed to a multiplier **162** when the switch is closed (throttle full open) or may be reduced by the voltage dividing action of a potentiometer **139** when the switch is open (throttle partially closed). The action of the switch, when it is open, is to reduce the voltage applied to multiplier **162** and thus to reduce fuel supply by shortening the injection interval when the throttle is less than fully open.

The setting of the potentiometer **139** is done at the factory. It is determined by the fuel/air ratio needs of a particular engine, i.e., at normally cruising ranges this potentiometer enables the fuel/air mixture to be made as lean as can be tolerated and yet still be under control of the analog computer. When large engine power or a high speed is needed, the switch **140** is operated. The signal applied to the multiplier **142** is an unattenuated output of the analog computer circuit, which is of course larger than the attenuated signal. This, as will be seen subsequently herein, results in the interval over which the fuel injection valves are maintained open, being greater and therefore the fuel mixture which is injected being richer, whereby the requirement for increased engine power is met. However, the valve open interval is still modified by the correction signal computed by the analog computer described.

FIG. 3 is a block schematic diagram of an arrangement for generating an electrical signal representing a fixed crank angle interval, which is multiplied with the correction signal to produce a resultant signal for correcting fuel injection valve open interval at the particular speed of operation. In essence this constitutes a correction in the fuel delivery valve open interval which shortens the duration of injection in the relationship $T_a = T_s$ (correction factor), where T_a is the actual injection valve open duration, and T_s is injection valve open duration derived from a fixed crank angle. Two shafts respectively **142**, **144** are driven by the engine crankshaft at engine speed. Shaft **142** carries a single contact **146** which, in the course of rotation successively touches contacts **148** and **150**. When the connection between contacts **146** and **148** is made, a pulse generator **152** is enabled to generate a pulse which is applied to a ramp generator **154** causing it to commence to generate a ramp. When contact **146** connects with contact **150**, a second pulse generator **156** is enabled to apply a pulse to a time delay circuit **158**, which after a predetermined interval resets the ramp generator **154**. This interval is determined by the time required for the output of pulse generator **156** to enable a sample and hold circuit **160** to sample the output of the ramp generator at that time. As a result, sample and hold circuit **160** has an electrical signal whose amplitude represents the fixed crank angle interval between the contacts **148** and **150** at the particular speed of rotation.

The output of the sample and hold circuit **160** is applied as one input to a multiplier **162**, whose other input is the correction factor signal derived from the output of the amplifier **136** in FIG. **2**.

The shaft **144** has four contacts respectively **144A**, B, C, and D positioned at four quadrants. These will successively connect with a contact **162** as the shaft rotates, and also with a contact **164**. When the contacts on shaft **144** connect with contact **162**, they cause a pulse generator **166** to apply a pulse to a ramp generator **168** enabling it to commence to generate a ramp voltage signal, and is also applied to a pulse circuit **170**, enabling it to produce an output in response thereto.

Similarly, contact **164**, when connected to the successive contacts **144A** through D, enables the pulser generator **172** to generate a pulse whereby ramp generator **174** is enabled to commence generating a ramp voltage and pulser **170** is caused to generate an output pulse.

The output of the ramp generator **168** is applied to a voltage comparator **180**, which functions to compare the ramp voltage with the output of the multiplier **162**. When the ramp voltage equals the multiplier voltage, then the voltage comparator **180** provides an output signal which resets the ramp generator **168** and which enables a discharge circuit **182** to discharge a voltage which may be across any one of the respective injection valves respectively **190**, **192**, **194**, or **196**. The discharge circuit thereby closes any one of these valves which may have been open. The discharge circuit discharges into the power supply, **184**, for the system thereby conserving energy.

The output of the ramp generator **174** is applied to a voltage comparator **186**, whose other input is the output of the multiplier **162**. When the ramp generator voltage equals the multiplier voltage, then the voltage comparator **186** produces an output which resets the ramp generator and which enables a second discharge circuit **188** to discharge any voltages into the power supply **184**, which may be across any one of the injection valves **191**, **193**, **195**, or **197**. Thereby, which ever one of the valves was open at this time, is discharged. The operation of the system described in FIG. **3**, is as follows: The contact **150** is spaced at a location relative to contact **148**, which represents the maximum number of crankshaft degrees over which injection is required to occur. The ramp generator **154** is energized when contact **146** connects with contact **148** and generates a ramp voltage over the interval required for contact **146** to travel the indicated crankshaft angle until it connects with contact **150**. At this time the sample and hold circuit **160** is energized and the ramp generator **154** is reset. The sample and hold signal then holds a signal whose amplitude represents the time taken for the shaft to rotate the predetermined crankshaft angle. From a time standpoint, this is also representative of the maximum time that the fuel injection valves should remain open. This voltage signal is renewed for every rotation of the shaft **142**.

The output of the sample and hold circuit **160** is reduced by an amount determined by the correction factor signal generated by the analog computer shown in FIG. **2**. This signal is a voltage amplitude less than 1. As soon as it attains the value 1, then the interval that the fuel injection valve remains open is determined solely by the time required for the engine to rotate through the predetermined crank angle.

Ramp generator **168** is energized at four successive times during the rotation of the shaft **144**. Ramp generator **174** is also energized at four successive times during the rotation of the shaft **144**. Each time each one of these ramp generators is energized, pulser **170** is energized. Accordingly, pulser **170** delivers eight successive output pulses to a distributor **189**. The distributor successively applies these output pulses to the respective fuel injection valves **190** through **197**.

A suitable fuel injection valve, which may be electrically controlled by the output of the pulser circuit, may be valves of the type described for example, in a patent by N. Kattchee (application Ser. No. 676,458), U.S. Pat. No. 3,465,732 or a patent by G. Benson (application Ser. No. 671,065), U.S. Pat. No. 3,501,099. The nature of the piezoelectric material used in the fuel injection valves is that upon the application of a voltage pulse thereto, it moves and thereby enables fuel to be injected into an intake post. The piezoelectric material will remain in its moved condition, acting as a capacitor storing the electrical energy supplied thereto. The energization of the discharge circuits **182** or **188** removes the voltage from across the piezoelectric material enabling the piezoelectric fuel injection valve to be closed.

The purpose of the respective diodes **100** through **107** which are connected between the respective piezoelectric valves **190** and **197** and the respective discharge circuits **182** and **188**, is to prevent a voltage being applied to one valve such as **190** to cause it to open, from also being applied to the other three valves, respectively **192**, **194** and **196**, with which it makes a common connection.

The power supply **184** includes an AC alternator and a regulator normally used with an internal combustion engine, and in addition contains a storage capacitor at its output, into which the discharge circuit voltages may be dumped in order to conserve energy. A starting inverter circuit **110**, which is shown in FIG. **6**, is energized by the battery **112**, energizes the pulser circuit until the engine starts whereby its alternator can supply the required energy.

FIG. **4** is a circuit diagram of the pulser circuit **170**, which may be employed with this invention. A capacitor **214** is charged up from the power supply **184**. The capacitor is connected in series with two matched silicon controlled rectifiers respectively **216** and **218**. The control electrode of silicon control rectifier **218** is connected to the secondary winding **220** of a transformer, having a split primary winding respectively **222**, **224**. The cathode of the silicon control rectifier **218** is also connected to an inductor **226** whose other end is connected to the distributor **189**. The ends of the respective primary winding **222** and **224** are respectively connected to the pulse generators **166** and **172**.

In the presence of a pulse from either pulse generator **166** or **172**, the silicon control rectifier **218** is enabled to conduct. The voltage across the storage capacitor **214** at this time is sufficient to break down the silicon controlled rectifier **216** which then acts as a diode. A voltage pulse is then applied to the distributor **189**.

The discharge circuit is shown in FIG. **5**. Two of these are used. The anode ends of four of the diodes **100** through **107** are connected to two series connected matched silicon control rectifiers, respectively **230**, **232**. The control electrode of the silicon control rectifier **232** is connected to a secondary winding **234** of a transformer. The primary winding of the transformer **236** is connected to the output of one of the voltage comparators **180** or **186**. The cathode of silicon control rectifier **232** is connected in series with a damping inductor **238**. The other end of the damping inductor is connected to the primary winding **240** of a transformer. A free wheeling diode **242** is connected between the first end of the inductor and ground. The secondary winding **244** of the transformer is connected through a locking diode **246** to the storage capacitor **214**.

When a voltage comparator produces an output, it enables silicon control rectifier **232** to conduct whereby the voltage which was applied across one of the fuel injection valves is enabled to be discharged into the primary winding of the transformer **240**, inducing a voltage in the secondary winding **244** which is dumped into the storage capacitor **214**. The purpose of the diode **242** is to prevent a reverse current flow through transformer primary winding **240**. The diode **246** prevents a negative voltage swing at the fuel injection valve.

FIG. **6** is a circuit diagram illustrative of a starting inverter circuit, which may be employed with the embodiment of the invention. This includes effectively an oscillator circuit **250**, which is energized when a start signal, is applied thereto. The start signal may be initiated from the battery when the ignition key is turned. The oscillator oscillates and builds up a charge across a capacitor **252**, which is applied to the pulser circuit **170** enabling it to function for starting the car engine. Once the engine has fired, a stop signal is applied to the oscillator to discontinue its operation.

FIG. **7** illustrates an embodiment of the invention which may be employed with electrical solenoid fuel injection type valves instead of piezoelectric type valves. In this arrangement, the rotating shafts and the contact arrangements associated therewith, the ramp generators and sample and hold circuits are the same as was described in connection with FIG. **3** and therefore similar functioning structure will bear the same reference numerals. However, since substantial current must be applied to the solenoid type fuel injection valves, it is necessary to employ some type of a switching device to maintain battery current applied to these valves. Accordingly, the output of pulse generator **166** turns on a solenoid switch **260** whereby current can be applied from a battery or power supply **262**, to a distributor **264**. The distributor distributes current successively to four fuel injection valves respectively **265**, **266**, **267** and **268**. When the output of the voltage comparator **180** occurs, it resets ramp generator **168** and turns off solenoid switch **260** thereby discontinuing current from the battery **262**.

In the presence of an output from pulse generator **172**, solenoid switch **270** is energized enabling current to flow from the battery **262** to a distributor **272**. This distributor controls the application of current to each of the four valves respectively **273**, **274**, **275** and **276**. In the presence of an output from voltage comparator **186**, the solenoid switch is rendered inoperative thereby preventing further current flow from the battery **262** to the distributor **272**.

It should be appreciated that the correction signal generated by circuit arrangement of FIG. **2** may also be employed with a hydraulic fuel injection valve control system as described in FIGS. **3** through **10** of the application for patent Ser. No. 858,717, by this inventor which has been mentioned previously.

There has accordingly been shown and described above a fuel injection system wherein fuel injection valve opening time occupies a constant crank angle at all engine speeds and the common rail feed pressure is modulated in proportion to a venturi depression signal, with provisions further being made for correction of the valve opening interval for errors introduced by the venturi. During those periods when the operation of the engine is at light loads fuel pressure is fixed. Corrections are applied to the valve opening interval during these periods to prevent too rich a fuel mixture from occurring. The corrections applied are generated by an analog computer which may be termed a duration control computer. This computer responds to the error in fuel flow produced by the spill valve system when responding to a signal from the venturi throat. It also senses the error in fuel flow produced bythe actual pressure drop across the fuel nozzle compared with the pressure drop across the spill valve.

The first of these errors results from air compressibility. As venturi depression increases, ambient pressure reduces or ambient temperature increases, the relationship between air flow and throat depression undergoes a change from a squared law to a higher index. The computer senses these parameters and determines a correction factor.

The second error rises when either (a) manifold pressure falls significantly below atmospheric and/or (b) the spill valve collar contacts the housing upsetting the force balance between fuel pressure and venturi depression. The computer senses fuel pressure drop across the discharge nozzle and in combination with venturi depression it produces a second correction factor in proportion to the pressure error existing.

These corrections are multiplied together and the resultant correction is employed to adjust the duration of injection.

What is claimed is:

1. A system for controlling the amount of fuel introduced into the combustion chambers or ports of an internal combustion engine by fuel injection valves fed from a common rail, each fuel injection valve being opened for fuel injection over an interval required for said engine to rotate through a fixed crank angle, said engine having an air intake with air flowing through a venturi meter, the improvement comprising:

valve means for maintaining fuel pressure applied to said common rail from falling below a predetermined value despite engine output falling below a level required for maintaining said predetermined value,

means for controlling said valve means for varying fuel pressure applied to said common rail above said predetermined pressure value as a function of the air mass flow to said engine flowing through said venturi meter, electrical analog means coupled to said internal combustion engine for generating a correction signal representative of errors introduced into the air mass flow function due to air compressibility and for errors occurring when said fuel pressure is maintained at said constant value, and

means responsive to said correction signal to modify said crank angle fuel injection interval over which said injection valves are held open to compensate for said errors.

2. A system as recited in claim **1** wherein there is included means for establishing a crank angle signal representative of the interval over which said fuel injection valves should remain open,

said means for modifying the fixed crank angle interval over which said fuel injection valves are open includes means for multiplying said crank angle signal with the output of said analog means to produce a resultant signal representative of the duration for which said fuel injection valves should remain open.

3. A system as recited in claim **1** wherein there is included an idling control channel which follows said venturi meter, and said air flowing through said venturi meter thereafter flows through said idling control channel, and said means coupled to said internal combustion engine for generating a correction signal includes means for measuring air pressure at said venturi and producing a first signal representative thereof,

means for measuring air pressure in said idling control channel and generating a second signal representative thereof,

means for measuring ambient temperature and providing a third signal representative thereof,

means for sensing barometric pressure and producing a fourth signal representative thereof,

means for determining which of said first and second signals is the larger,

means for modifying said larger signal with said third and fourth signals to provide a modified signal representative of the substantially correct air mass flow through said venturi.

4. A system as recited in claim **3** wherein there is included a means for measuring fuel pressure applied to said fuel intake manifold and establishing a fuel pressure signal representative thereof,

said valve means is a spill valve having a predetermined valve area,

a diaphragm is coupled to said venturi meter and to said spill valve to move said spill valve in accordance with the air pressure variations at said venturi meter,

means for increasing the amplitude of said modified signal by a constant determined by the ratio of the area of said diaphragm to the area of said spill valve to produce an amplified modified signal,

means for determining the ratio of said fuel pressure signal and said amplified modified signal to produce a sixth signal representative thereof,

means for determining the square root of said sixth signal and producing a correction signal representative thereof.

5. In a system as recited in claim **1** wherein there is included mode switch means for altering the amplitude of said correction signal responsive to predetermined load requirements on said internal combustion engine.

6. In a system for controlling the amount of fuel introduced into the combustion chambers or ports of an internal combustion engine by fuel injection valves fed from a common rail, each of said fuel injection valves being opened for fuel injection over an interval determined by the time required for said engine to traverse a predetermined crank angle, said engine having an air intake through a venturi meter followed by an idlying control channel, the improvement comprising:

valve means for maintaining fuel pressure applied to said common rail from falling below a predetermined value despite engine output falling below the level required to maintain said value,

means for controlling said valve means for varying fuel pressure of fuel applied to said common rail above said predetermined pressure value as a function of the mass air flow to said engine flowing through a venturi meter and thereafter through an idling control channel,

means for varying said crank angle interval over which said injection valves are held open to compensate for errors introduced into the air mass flow function because of air compressibility and for errors occurring when said fuel pressure is maintained at said predetermined value, including

means for measuring air pressure at said venturi and generating a first signal representative thereof,

means for measuring air pressure in the idling control channel and generating a second signal representative thereof,

means for sensing fuel injection pressure to said common rail and providing a third signal representative thereof,

means for measuring ambient temperature and providing a fourth signal representative thereof,

means for sensing the barometric pressure and providing a fifth signal representative thereof,

means for sensing the fuel temperature and producing a sixth signal representative thereof, and

electrical analog means responsive to said first, second, third, fourth, fifth and sixth signals for generating a correction signal representative of an amount said fixed crank angle interval should be altered to compensate for errors introduced in the mass air flow function because of air compressibility and for errors occurring when said fuel pressure is maintained at said predetermined value caused by low engine output, and

means for reducing the fixed crank angle interval over which said fuel injection valves are open responsive to said electrical analog means output.

7. In a system as recited in claim **6** wherein there is included means for establishing a crank angle signal representative of the interval over which said fuel injection valves should remain open,

said means for reducing the fixed crank angle interval over which said fuel injection valves are open includes means for multiplying said crank angle signal with the output of said analog means to produce a resultant signal representative of the duration for which said fuel injection valves should remain open.

8. In a system as recited in claim **6** wherein there is included mode switch means for altering the amplitude of said electrical analog means output responsive to predetermined load requirements on said internal combustion engine.

9. In a system as recited in claim 6 wherein said electrical analog means comprises means for establishing which ever of said first and second signals is the larger and producing a seventh signal representative thereof,

means for combining said fifth and seventh signals for producing an eighth signal representative thereof,

means for increasing said eighth signal by a predetermined gain to produce an eighth signal representative thereof,

means for multiplying said seventh and sixth signals to produce a ninth signal representative thereof,

means for multiplying said third and fourth signals to produce a 10th signal representative thereof,

means for dividing said ninth signal by said tenth signal to produce an 11th signal representative thereof,

means for multiplying said eighth signal and said 11th signal to produce a 12th signal representative thereof, and

means for taking the square root of said 12th signal to produce a 13th signal representative of a correction factor for correcting the interval during which the fuel injection valve should be held open.

10. In a system for controlling the amount of fuel introduced into the combustion chambers or ports of an internal combustion engine by fuel injection valves fed from a fuel intake manifold, each fuel injection valve being opened for fuel injection over a crank angle interval required for the engine to rotate through a predetermined crank angle, and the pressure above a predetermined threshold at which said fuel is applied to each said injection valve is varied as a function of the air mass flow to said engine through a venturi meter and thereafter through an idling control channel, means for correcting the interval over which said fuel injection valve remains open to compensate for errors in fuel pressure which occur due to errors introduced by the use of a venturi meter for measuring air mass flow to said engine, and to control the richness of the fuel mixture when said fuel pressure attains its predetermined threshold value comprising:

first means for sensing the pressure of air at said venturi throat and establishing a first signal representative thereof,

second means for sensing the air pressure in the idling control channel which is downstream of said venturi throat and producing a second signal representative thereof,

third means for sensing fuel pressure applied to a fuel intake manifold and producing a third signal representative thereof,

fourth means for sensing ambient temperature and producing an electrical signal representative thereof,

fifth means for sensing the barometric pressure and producing a fifth signal representative thereof,

sixth means for sensing the fuel temperature and producing a sixth signal representative thereof,

means for establishing whichever is the larger of said first and second signals and producing a seventh signal representative thereof,

means for combining said fifth and seventh signals for producing an eighth signal representative thereof,

means for increasing said eighth signal by a predetermined gain to produce an enlarged eighth signal representative thereof,

means for multiplying said seventh and sixth signals to produce a ninth signal representative thereof,

means for multiplying said third and fourth signals to produce a 10th signal representative thereof,

means for dividing said ninth signal by said 10th signal to produce an 11th signal representative thereof,

means for multiplying said enlarged eighth signal and said eleventh signal to produce a 12th signal representative thereof,

means for taking the square root of said 12th signal to produce a 13th signal representative of a correction factor for correcting the interval during which the fuel injection valves should be held open,

means for generating an electrical signal representative of said crank angle interval,

means for modifying said crank angle representative electrical signal with said 13th signal to produce a corrected signal representative of the interval during which said fuel injection valves should be maintained open.

11. Apparatus for substantially accurately measuring the air mass flow through the throat of a venturi meter used with an internal combustion engine wherein air for said engine is taken through a venturi meter comprising:

means for measuring air pressure at said venturi and producing a first signal representative thereof,

means for measuring air pressure in said idling control channel and generating a second signal representative thereof,

means for measuring ambient temperature and providing a third signal representative thereof,

means for sensing barometric pressure and producing a fourth signal representative thereof,

means for determining which of said first and second signals is the larger,

means for modifying said larger signal with said third and fourth signals to provide a modified signal representative of the substantially correct air mass flow through said venturi.

12. A system for controlling the amount of fuel introduced into the combustion chambers or ports of an internal combustion engine by fuel injection valves fed from a common rail, said engine having a shaft driven thereby and an air intake through a venturi meter followed by an idling control channel,, the improvement comprising:

valve means for maintaining fuel pressure applied to said intake manifold from falling below a predetermined pressure value despite engine output falling below a level required for maintaining said predetermined fuel pressure value,

means for controlling said valve means for varying fuel pressure applied to said common rail above said predetermined fuel pressure value as a function of the air mass flow to said engine flowing through said venturi meter and thereafter through said idling control channel,

electrical analog means coupled to said engine for generating a correction signal representative of errors introduced into the air mass flow function due to air compressibility and due to errors occurring when said fuel pressure is maintained at said predetermined fuel pressure value,

means for generating a crank angle signal representative of the interval required for said shaft to rotate through a predetermined angle,

means for modifying said crank angle signal with said correction signal to produce a corrected signal representative of the interval over which said fuel injection valves should remain open and

means for applying said corrected signal to said fuel injection valves to hold them open over an interval represented by said corrected signal.

13. A system as recited in claim 12 wherein said means for applying said corrected signal to said fuel injection valves includes:

a source of operating potential for opening said fuel injection valves,

solenoid switch means,

a distributor,

means connecting said distributor to said fuel injection valves,

means for applying operating potential to said distributor through said solenoid switch means when said solenoid switch means is rendered operative, and

means for rendering said solenoid switch means operative over an interval represented by said corrected signal.

14. A system as recited in claim 12 wherein said means for applying said corrected signal to said fuel injection valves includes a pulse generating circuit,

a distributor connected to said pulse generating circuit,

means connecting said distributor to said fuel injection valves,

a discharge circuit connected to said fuel injection valves,

means for establishing a time interval responsive to said corrected signal having a duration represented by said corrected signal,

means for causing said pulse generating circuit to generate a pulse at the start of said time interval whereby a fuel injection valve connected to said pulse generating circuit at that time is opened and maintained open by the voltage of said pulse, and

means for causing said discharge circuit to discharge the voltage of said pulse at the end of said time interval to close said fuel injection valve.

15. A system as recited in claim 12 wherein said electrical analog means coupled to said engine for generating a correction signal includes an adjustable attenuator for adjusting the correction signal amplitude in accordance with the engine characteristics,

a normally open switch connected across said attenuator, and

means for closing said switch to short out said attenuator responsive to predetermined load requirements on said engine.

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