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Aono

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[54] **APPARATUS FOR AND METHOD OF CONTROLLING AIR-FUEL MIXTURE IN A CARBURETOR OF AN AUTOMOTIVE INTERNAL COMBUSTION ENGINE**

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[21] Appl. No.: **505,540**

[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** ..... **123/119 R**; 123/32 EA; 123/103 R; 261/72 R; 261/121 B; 261/19; 261/39 R; 261/DIG. 67

[51] **Int. Cl.²**.. **F02B 32/00**; F24F 3/14; F02D 11/08

[58] **Field of Search** .... 123/32 EA, 32 AE, 119 R, 123/103 R; 261/72 R, 121 B, 19, 39 R

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Primary Examiner—Charles J. Myhre
Assistant Examiner—Ronald B. Cop

[57] **ABSTRACT**

The richness of an air-fuel mixture produced by a carburetor of an internal combustion engine of an automotive vehicle, by increasing the pressure of air behind the fuel in a fuel discharge circuit for enrichment of the air-fuel mixture if the mixture is found excessively lean or injecting pressurized air into the fuel flowing in the fuel discharge circuit for leaning out the mixture if the mixture is found excessively rich. Increasing the air pressure behind the fuel in the fuel discharge circuit gives rise to an increase in the flow rate of the fuel to be discharged and injection of pressurized air into the fuel flowing in the fuel discharge circuit is causative of reduction of density of the fuel to be discharged and accordingly contribute to reduction of the flow rate of the fuel discharged from the circuit.

38 Claims, 20 Drawing Figures

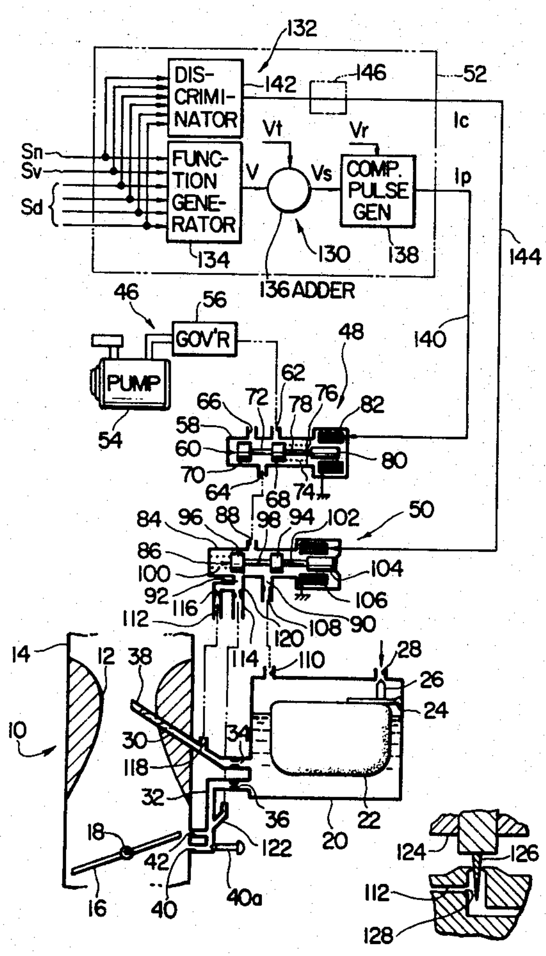


FIG. 1 PRIOR ART

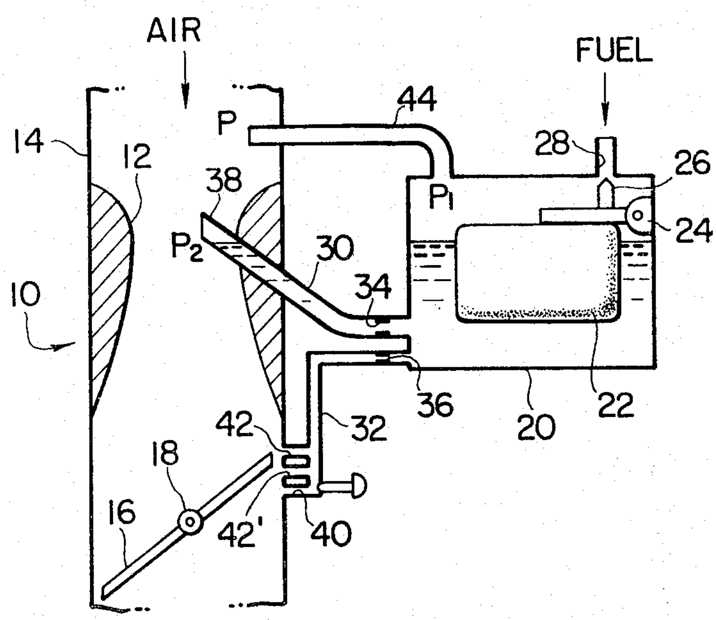


FIG. 2

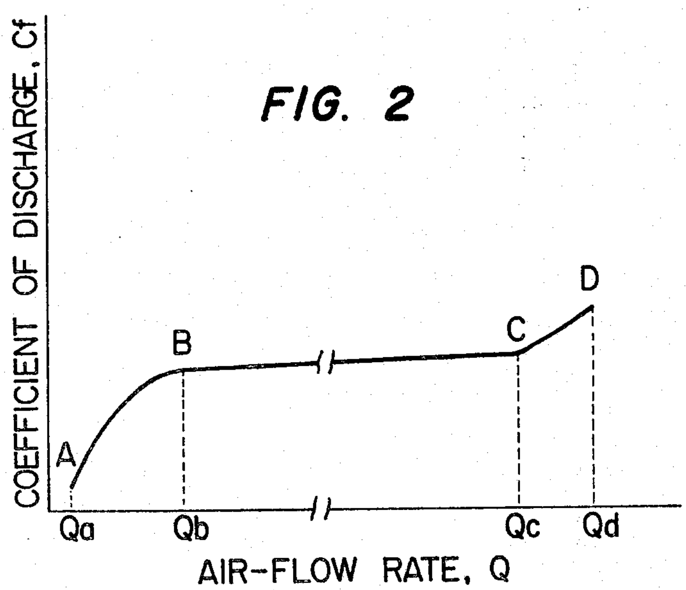
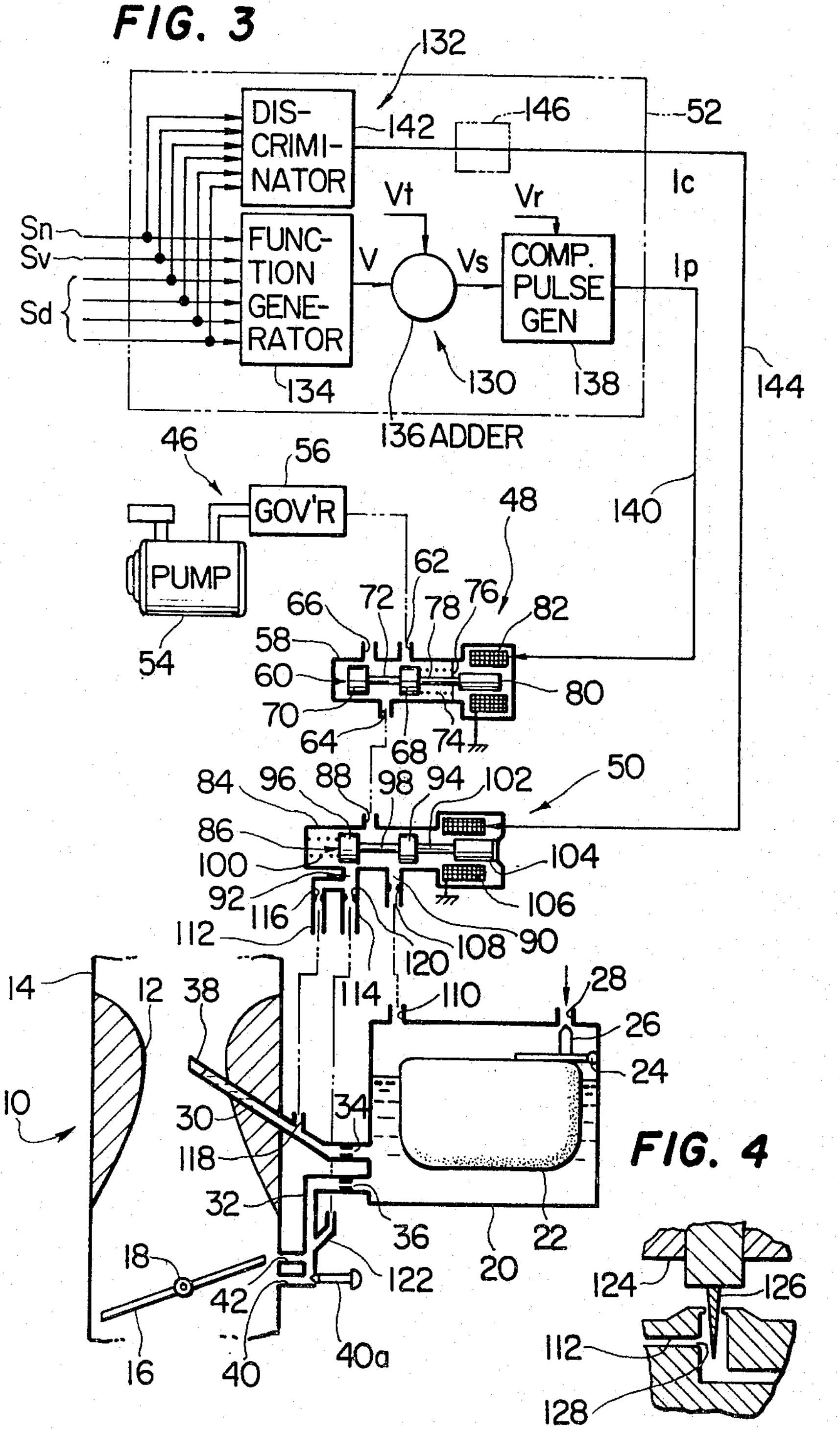


FIG. 3


DIS-
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Sn
Sv
Sd
V
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Vs
Vr
Ic
Ip

FIG. 4

FIG. 5a

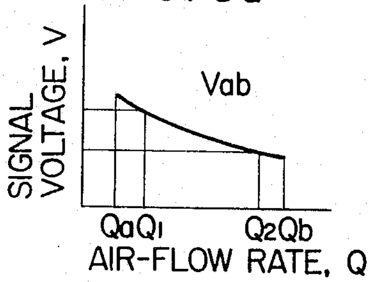


FIG. 5b

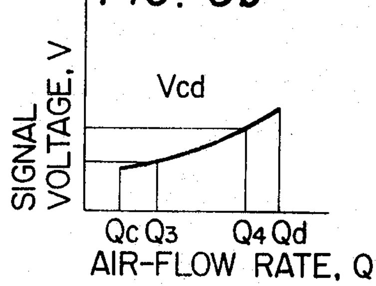


FIG. 5c

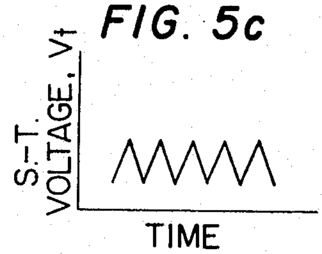


FIG. 5d

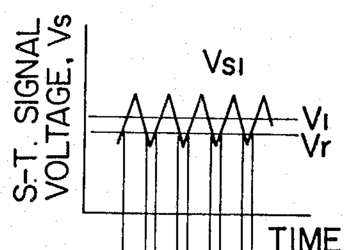


FIG. 5e

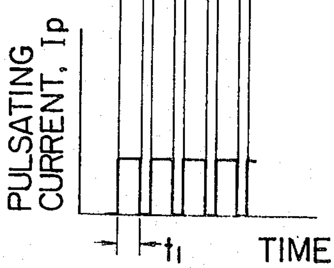


FIG. 5f

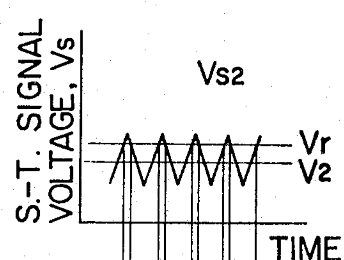
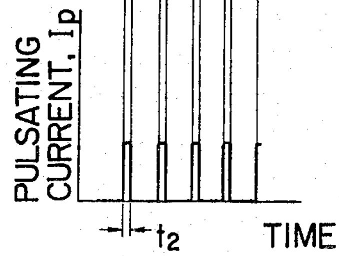


FIG. 5g



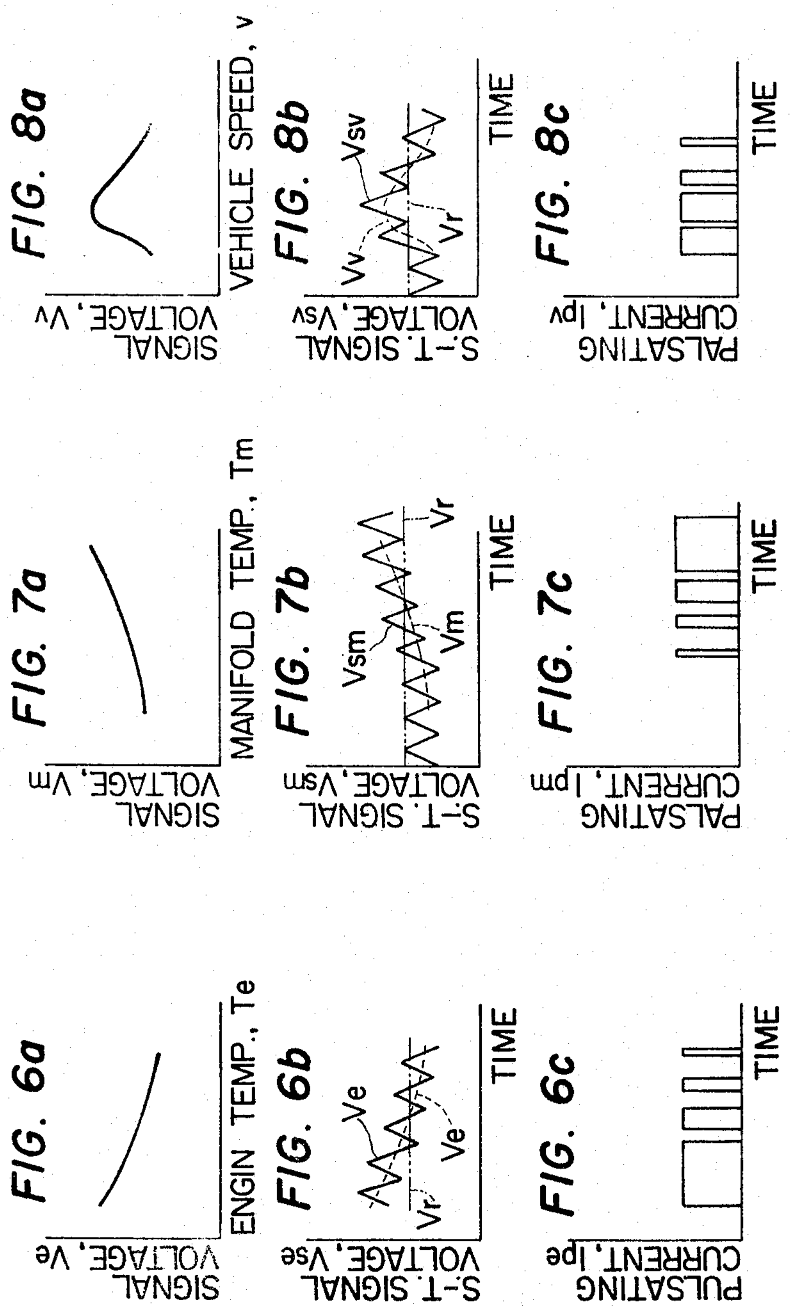


FIG. 8a
SIGNAL VOLTAGE, Vv
VEHICLE SPEED, v
FIG. 8b
S-T. SIGNAL VOLTAGE, Vsv
Vsv
Vv
Vr
TIME
FIG. 8c
PALSATING CURRENT, Ipv
TIME
FIG. 7a
SIGNAL VOLTAGE, Vm
MANIFOLD TEMP., Tm
FIG. 7b
S-T. SIGNAL VOLTAGE, Vsm
Vsm
Vm
Vr
TIME
FIG. 7c
PALSATING CURRENT, Ipm
TIME
FIG. 6a
SIGNAL VOLTAGE, Ve
ENGIN TEMP., Te
FIG. 6b
S-T. SIGNAL VOLTAGE, Vse
Ve
Ve
Vr
TIME
FIG. 6c
PULSATING CURRENT, Ipe
TIME

APPARATUS FOR AND METHOD OF CONTROLLING AIR-FUEL MIXTURE IN A CARBURETOR OF AN AUTOMOTIVE INTERNAL COMBUSTION ENGINE

The present invention relates generally to internal combustion engines of automotive vehicles and, particularly, to mixture induction systems such as carburetors of the automotive internal combustion engines. More specifically, the present invention is concerned with an apparatus for and a method of controlling the richness, or an air-to-fuel ratio, of an air-fuel mixture to be supplied from the carburetor to the combustion chambers of the engine.

It is well known in the art of the carburetors of the automotive internal combustion engines that the flow rate of fuel into the carburetor varies with the rate of flow of air through the carburetor and is causative of formation of an excessively lean or excessively rich air-fuel mixture responsive to a relatively high or low flow rate of air through the carburetor. Various attempts have thus far been made to compensate for the excessive richness or leanness of the air-fuel mixture but none of such attempts have proved completely successful.

An object of the present invention is to provide an apparatus for and a method of controlling the air-to-fuel ratio of an air-fuel mixture produced in a carburetor of an automotive internal combustion engine so that the air-fuel mixture supplied to the engine is proportioned to an optimum richness throughout the varying operating conditions of the vehicle.

In accordance with one important aspect of the present invention, such an object will be accomplished basically in an apparatus which comprises first passage means having an outlet end open into a substantially closed space behind the fuel in a fuel discharge circuit of the carburetor where the pressure difference between the fuel outlet and the float chamber become larger; second passage means having an outlet end open into the fuel discharge circuit; a source of pressurized air; air-flow regulator valve means in communication with the source of pressurized air and operative to regulate the flow rate of pressurized air through the valve means when actuated; air-flow shift valve means having a first operative condition providing communication between the air-flow regulator valve means and the first passage means and a second operative condition providing communication between the air-flow regulator valve means and the second passage means; and an electric control unit responsive to predetermined operating conditions of the vehicle and operative to supply a first control signal to the air-flow regulator valve means for varying the flow rate of pressurized air through the regulator valve means in accordance with the operating conditions of the vehicle and a second control signal to the air-flow shift valve means for holding the air-flow shift valve in the first operative condition when the vehicle operating conditions are representative of an excessively lean condition of the air-fuel mixture being produced in the carburetor or in the second operative condition when the vehicle operating conditions are representative of an excessively rich condition of the air-fuel mixture. The electric control unit may be responsive to the rate of flow of atmospheric air in the carburetor and operative to produce the first control signal which is effective to decrease the rate of flow of pressurized air through the air-flow regulator valve means when the rate of flow of atmospheric air in the carburetor increases in a range lower than a first predetermined level and to increase the rate of flow of pressurized air through the regulator valve means when the rate of flow of atmospheric air in the carburetor increases in a range higher than a second predetermined level and the second control signal which is effective to hold the air-flow shift valve means in the first operative condition when the rate of flow of atmospheric air in the carburetor is lower than the first predetermined level and in the second operative condition when the rate of flow of atmospheric air in the carburetor is higher than the first predetermined level. Or otherwise, the electric control unit may be so arranged as to be responsive to variation in engine temperature lower than a predetermined level and operative to produce the first control signal which is effective to decrease the rate of flow of pressurized air through the air-flow regulator valve means as the engine temperature rises toward the predetermined level and the second control signal which is effective to hold the air-flow shift valve means in the first operative condition thereof in response to the engine temperature lower than the predetermined level. Where desired, the electric control unit may be so arranged as to be responsive to variation of the temperature in the intake manifold of the engine and to idling condition of the engine and operative to produce the first control signal which, in this instance, is effective to increase the rate of flow of pressurized air through the air-flow regulator valve means as the temperature of the intake manifold increases beyond a predetermined level and the second control signal which is effective to hold the air-flow shift valve means in the second operative condition thereof during idling of the engine. Or still otherwise, the electric control unit forming part of the apparatus according to the present invention may be so arranged as to be responsive to change in the vehicle speed and operative to produce the first control signal which is effective to abruptly increase the rate of flow of pressurized air through the air-flow regulator valve means during an incipient stage of change of the vehicle speed and the second control signal which is effective to hold the air-flow shift valve in the first operative condition thereof in response to an increase in the vehicle speed and in the second operative condition in response to a decrease in the vehicle speed. The air-flow regulator valve means may comprise an air-inlet port in communication with the source of the pressurized air, an air-outlet port in communication with the air-flow shift valve, a valve member which is movable between a first position providing communication between the air-inlet port and the air-outlet port and a second position interrupting the communication between the air-inlet port and the air-outlet port, and electromagnetically operated actuating means responsive to the previously mentioned first control signal for actuating the valve member between the first and second positions thereof when energized and de-energized by the first control signal. Likewise, the air-flow shift valve means may comprise an air-inlet port in communication with the air-outlet port of the air-flow regulator valve means, a first air-outlet port in communication with the previously mentioned first passage means, a second air-outlet port in communication with the previously mentioned second passage means, a valve member movable between a first position providing communication between the air-inlet port and the first air-outlet port and a second position providing communication between the air-inlet port and the second air-outlet port, and electromagnetically operated actuating means responsive to the second control signal for actuating the valve member into the first or second position thereof when the actuating means is energized or de-energized.

In accordance with another important aspect of the present invention, there will be provided a method of controlling the richness of an air-fuel mixture in a carburetor of an internal combustion engine, comprising producing a first control signal which is responsive to predetermined operating conditions of the vehicle, a second control signal responsive to an unduly rich or lean condition of the air-fuel mixture being produced in the carburetor, producing a flow of pressurized air, varying the rate of flow of the pressurized air by the first control signal, and injecting the pressurized air into a substantially closed space behind the fuel in a fuel discharge circuit of the carburetor in response to the excessively lean condition of the air-fuel mixture or into the fuel flowing in the fuel discharge circuit in response to the excessively rich condition of the air-fuel mixture in accordance with the second control signal.

While it has been stated in the above description that the richness of the air-fuel mixture to be produced in the carburetor is controlled in accordance with the rate of flow of atmospheric air through the carburetor, the temperature in the engine, the temperature of the cooling water of the engine under idling condition, or the change in the vehicle speed (viz., the accelerating or decelerating condition of the vehicle, the richness of the mixture may be varied in accordance with other operating variables of the vehicle such as the altitude of a road on which the vehicle is running, the temperature in the exhaust system, and/or the concentration or concentrations of one or more specific compounds contained in the exhaust gases.

The features of the apparatus and method according to the present invention will become more apparent from the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic sectional view which shows a representative example of an arrangement including a carburetor and a fuel discharge circuit of an ordinary automotive internal combustion engine;

FIG. 2 is a graph indicating a general tendency of airflow characteristics of a usual carburetor such as the carburetor illustrated in FIG. 1;

FIG. 3 is a schematic sectional view, partly in a block diagram, of a preferred embodiment of the apparatus according to the present invention;

FIG. 4 is a fragmentary sectional view showing part of a fuel discharge circuit of a variable-area venturi of a constant-vacuum carburetor having incorporated therein a modification of the embodiment illustrated in FIG. 3;

FIGS. 5*a* to 5*g* are graphs which indicate various waveforms of signals produced in an electrical arrangement forming part of the embodiment illustrated in FIG. 3;

FIGS. 6*a* to 6*c* are graphs which indicate waveforms of signals which may be produced in the electrical arrangement of the embodiment illustrated in FIG. 3 where it is desired that the device embodying the present invention is so arranged as to be responsive to engine temperature;

FIGS. 7*a* to 7*c* are graphs which are similar to those of FIGS. 6*a* to 6*c*, respectively, but which show waveforms of signals which may be further produced in the electrical arrangement of the embodiment illustrated in FIG. 1 where it is desired that the device embodying the present invention is so arranged as to be responsive to the temperature in the intake manifold of the engine; and d

FIGS. 8*a* and 8*c* are also similar to FIGS. 6*a* to 6*c*, respectively but now show waveforms of signals which may be produced where it is desired that the device embodying the present invention is so arranged as to be responsive to accelerating and decelerating conditions of the vehicle.

Referring to the drawings, first to FIG. 1, a carburetor 10 is shown to have a fixed-area venturi 12 which is located downstream of an air horn 14 and upstream of a carburetor throttle valve 16 which is rotatable on a shaft 18 between a closed-throttle position illustrated and a full-throttle position. A float chamber or fuel reservoir 20 has positioned therein a float 22 which is pivotally cantilevered as at 24 to the side wall of the float chamber 20. The float 22 carries thereon a needle valve 26 which is movable into or out of a fuel inlet port 28 formed in, for example, the top wall of the float chamber 20 as shown. The fuel inlet port 28 of the float chamber 20 is in constant communication with an outlet port of a fuel pump (not shown) that delivers fuel to the float bowl 20 when the needle valve 26 is withdrawn from the fluid inlet port 28 of the bowl 22 as shown. From the bottom portion of the float bowl 20 do extend a main fuel discharge circuit 30 and an idle and low-speed fuel discharge circuit 32 through a main fuel metering jet 34 and an idle and low-speed fuel metering jet 36, respectively. The main fuel discharge circuit 30 terminates in a fuel discharge nozzle 38 which is open in the venturi 12 while the idle and slow-speed fuel discharge circuit 32 terminates in an idle port 40 and slow-speed ports 42 and 42′ bypass the venturi 12 and the throttle valve 16. The carburetor 10 herein shown is assumed to be of the "balanced" type and, thus, the float chamber 20 is vented to the atmosphere through a venting passageway 44 which opens into the air horn 14 located upstream of the venturi 12. The construction of the carburetor per se is well known in the art and, therefore, further detailed description thereof will not be herein incorporated.

In the carburetor thus constructed and arranged, the fuel in the float chamber 20 is injected from the fuel discharge nozzle 38 into the venturi 12 by a motivating force which results from a differential pressure which is developed across the venturi 12 due to a vacuum created in the intake manifold of the engine when the engine is in operation. The flow rate per unit time of the liquid fuel to be injected from the discharge nozzle 38 into the venturi 12 is, as is well known, given by a formula:

$$\text{Flow Rate} = C_f.S. \sqrt{2g.d.(P_1 - P_2)},$$

where C_f is a constant herein called the "coefficient of discharge" of liquid fuel, S is the cross sectional area of the fuel discharge nozzle 38, g is the acceleration due to gravity, d is the density of the liquid fuel, P_1 is the absolute pressure prevailing in the air horn 14 or upstream of the venturi 12 of the carburetor 10, and P_2 is the pressure developed immediately downstream of the venturi 12. In the shown carburetor 10 in which the float chamber 20 is vented to the air horn 14 through the venting passageway 44, the pressure P_1 is equal to the pressure which is developed atop the liquid fuel in the float chamber **20** and is, thus, representative of the air pressure obtains behind the liquid fuel to be injected into the venturi **12** through the main fuel discharge circuit **30.**

FIG. **2** illustrates the variation of the above mentioned coefficient of discharge C_f in terms of the rate of flow of air Q across the venturi **12** in the carburetor **10** illustrated in FIG. **1.** As will be evident from FIG. **2,** the coefficient of discharge C_f increases with a generally exponential curve A to B as the air-flow rate Q increases from Q_a to Q_b through a range of relatively low level and with a curve C to D as the air-flow rate Q increases from Q_c to Q_d through a range of relatively high level, although the coefficient of discharge C_f remains substantially constant throughout the range indicated by a curve B to C. From the curves illustrated in FIG. **2** and from the previously shown mathematic relation between the coefficient of discharge C_f and the mass flow of the fuel, it will be apparent that the mass flow of the fuel to be injected into the venturi **12** of the carburetor **12** varies in a non-linear relation which follows the curve A to B and the curve C to D as the air-flow rate Q across the venturi **12** varies in the range between Q_a amd Q_b or the range between Q_c and Q_d. As a result of such a non-linear variation of the flow rate of the fuel to be injected into the venturi **12** of the carburetor, the air-fuel mixture produced in the carburetor will be excessively leaned out if the air-flow rate Q falls within the range between Q_a and Q_b and excessively enriched if the air-flow rate Q falls within the range between Q_c and Q_d.

To compensate for the excessive leanness or richness of the air-fuel mixture, a variety of attempts have thus far been made. Provision of the bypass ports including the idle port **40** and the slow-speed ports **42** and **42'** in the carburetor **10** as shown in FIG. **1** is one of such attempts. Another attempt is to provide two or more venturi tubes as in double or tripple venturi carburetors so that the flow characteristics resulting from the non-linear variation of the mass flows of the fuel into the individual venturi tubes are cancelled or moderated by each other. None of the attempts thus far made has, however, succeeded in providing linearly varying fuel flow characteristics of the carburetor and, for this reason, only practical compromise has been to design and engineer a carburetor that will exclusively match the inherent performance characteristics of an engine of a particular make. Such a compromise will apparently give rise to reduction in the production efficiency and an increase in the production cost of the carburetor.

The present invention proposes to control the flow rate of the liquid fuel to be injected into the carburetor by varying the air pressure P_1 behind the liquid fuel or the density *d* of the liquid fuel in accordance with various operational variables of the automotive vehicle such as the air-flow rate in the carburetor, the vacuum developed in the intake manifold of the engine, the revolution speed of the engine, the engine temperature, the combination of the temperature in the engine intake manifold and the carburetor throttle opening, the accelerating or decelerating conditions of the vehicle, the altitude of a road on which the vehicle is running, the temperature of exhaust gases from the engine, and/or the concentration or concentrations of a specific compound or compound in the exhaust gases.

Reference will now be made to FIG. **3** which illustrates the preferred embodiment of the air-fuel mixture control apparatus according to the present invention, wherein the parts and units which have their counterparts in the carburetor shown in FIG. **1** are designated by like reference numerals. The apparatus embodying the present invention as shown in FIG. **3** largely consists of a source **46** of pressurized air, a solenoid-operated air-flow regulator valve unit **48,** a solenoid-operated air-flow shift valve unit **50** and an electric control unit which is designated in its entirety by reference numeral **52.**

The source **46** of pressurized air may be constructed and arranged in any desired manners but is herein shown, by way of example, as consisting of an air-feed pump **54** which is operative to pump out pressurized air from its discharge port and a pressure governor **56** which has an inlet port in communication with the discharge port of the air-feed pump **54** and which is adapted to deliver a substantially constant air pressure from its outlet port. The air-feed pump **54** is usually driven by the power output of the engine (not shown).

The solenoid-operated air-flow regulator valve unit **48** comprises an elongate valve housing **58** and a spool valve member **60** which is axially movable in the valve housing **58.** The valve housing **58** is formed with an air-inlet port **62,** an air-outlet port **64** and a vent **66** which is open to the atmospheric air. The air-inlet port **62** of the valve housing **58** is in communication with the outlet port of the pressure governor **56.** On the other hand, the spool valve member **60** is formed with axially spaced first and second lands **68** and **70** and a circumferential groove **72** which is located between the lands **68** and **70.** The spool valve member **60** is movable between a first axial position having the first land **68** located to uncover the air-inlet port **62** and the second land **70** located to cover the vent **66** and a second axial position having the first land **68** located to cover the air-inlet port **62** and the second land **70** located to uncover the vent **66** as seen in FIG. **3.** The circumferential groove **72** of the spool valve member **60** is in constant communication with the air-outlet port **64** irrespective of the axial position of the spool valve member **60** relative to the valve housing **58** so that the air-outlet port communicates through the circumferential groove **72** with the air-inlet port **62** when the spool valve member **60** is in the first axial position thereof and with the vent **66** when the spool valve member **60** is in the second axial position thereof. The spool valve member **60** is biased toward the second axial position thereof by means of a preload spring **74** which is shown to be seated at one end on an outer end face of the first land **68** of the valve member **60** and at the other end on an annular spring seat member **76** which is secured to or integral with the inner peripheral surface of the valve housing **58.** The spool valve member **60** further has an axial extension **78** projecting from the outer end face of the first land **68** thereof and has carried at the leading end of the axial extension **78** an armature core **80** which is coaxially surrounded by an exciting coil **82.** The armature core **80** and the exciting coil **82** constitute, in combunation, a solenoid to actuate the spool valve member **60** when the exciting coil **82** is energized. When, thus, the exciting coil **82** of the solenoid is energized from an external source as will be discussed in more detail, then the armature core **80** is driven to axially move from its initial position illustrated and, in turn, drives the spool valve member **60** from the second axial position illustrated in FIG. **3** to the first axial position. Thus, the solenoid-operated air-flow regulator valve unit **48** has a first condition providing communication between the air-inlet port **62** and the air-outlet port **64** thereof with the exciting coil **82** of the solenoid energized and a second condition interrupting the communication between the ports **62** and **64** and providing communication between the air-outlet port **64** and the vent **66** with the exciting coil **82** of the solenoid de-energized.

The solenoid-operated air-flow shift valve unit **50** is constructed largely similarly to the above described air-flow regulator valve unit **48** and comprises an elongate valve housing **84** and a spool valve member **86** which is axially movable in the valve housing **84**. The valve housing **84** is formed with an air-inlet port **88**, a first air-outlet port **90** and a second air-outlet port **92**. The air-inlet port **88** is in communication with the air-outlet port **64** of the air-flow regulator valve unit **48**. On the other hand, the spool valve member **86** is formed with axially spaced lands **94** and **96** and a circumferential groove **98** which is located between the lands **94** and **96**. The spool valve member **86** thus constructed is movable between a first axial position having the first land **94** located to uncover the first air-outlet port **90** and the second land **96** located to cover the second air-outlet port **92** as illustrated in FIG. 3 and a second axial position having the first land **94** located to cover the first air-outlet port **90** and the second land **96** located to uncover the second air-inlet port **92**. The air-inlet port **88** is in constant communication with the circumferential groove **98** in the spool valve member **86** so that the air-inlet port **88** communicates through the circumferential groove **98** with the first air-inlet port **90** when the spool valve member **86** is, as shown, in the first axial position thereof and with the second air-outlet port **92** when the spool valve member **86** is in the second axial position thereof. The spool valve member **86** is biased toward the first axial position by means of a preload spring **100** which is shown to be seated at one end on an outer end face of the second land **96** of the valve member **86** and at the other end on an end wall of the valve housing **94**. The spool valve member **86** has an axial extension **102** projecting from an outer end face of the first land **94** of the valve member **86** and has carried at leading end of the axial extension **102** an armature core **104** which is coaxially surrounded by an exciting coil **106**. The armature core **104** and the exciting coil **106** constitute in combination a solenoid to actuate the spool valve member **86** when the coil **106** is energized. When the exciting coil **106** is thus energized from an external power source, then the armature core **104** is driven to axiallly move from its initial position illustrated and, in turn, drives the spool valve member **86** from the first axial position to the second axial position. The air-flow shift valve unit **50** has a first operative condition providing communication between the air-inlet port **88** and the first air-outlet port **90** with the exciting coil **106** de-energized and a second operative condition providing communication between the air-inlet port **88** and the second air-outlet port **92** with the exciting coil **106** energized.

The first air-outlet port **90** of the air-flow shift valve unit **50** communicates through a restriction or orifice **108** with an air-inlet port **110** which is formed in the top wall of the float bowl **20**. On the other hand, the second air-outlet port **92** of the shift valve unit **50** is branched into main and auxiliary air passageways **112** and **114**, respectively. The main air passageway **112** is led through a restriction or orifice **116** to a main air bleed **118** which is open into the previously mentioned main fuel discharge circuit **30** terminating at the fuel discharge nozzle **38**. Likewise, the auxiliary air passageway **114** is led through a restriction or orifice **120** to an auxiliary air bleed **122** which is open into the idle and low-speed fuel discharge circuit **32**. The idle and low-speed fuel discharge circuit **32** is herein shown as terminating in the idle port **40** and only one low-speed port **42**. Designated by **40***a* is an idle adjustment screw for adjusting the rate of discharge of the fuel from the idle port **40**.

The carburetor has been assumed to be of the constant-choke type having a fixed venturi area. If desired, however, the apparatus embodying the present invention may be incorporated into a carburetor of the constant-vacuum type having a variable-area venturi which comprises, as shown in FIG. **4**, a piston **124** movable in a direction perpendicular to the path of carburetor air and a needle valve **126** projecting from the leading end of the piston **124** and movable back and forth in a fuel jet **128** leading from a main fuel discharge circuit of the carburetor. With the variable-area venturi thus constructed, the main air passageway **112** leading from the second air-outlet port **92** of the air-flow shift valve unit **50** of the apparatus shown in FIG. **3** may open into the fuel jet **128**.

The two valve units **48** and **50** above described are controlled by the electric control unit **52**. The control unit **52** consists of a flow control circuit **130** to control the rate of flow of air through the air-flow regulator valve unit **48** and a flow-shift control circuit **132** to control the direction of flow of air through the air-flow shift valve unit **50**. The flow control circuit **130** comprises a function generator **134** having a plurality of input terminals which are respectively connected to sensors (not shown) to detect various operating conditions of the vehicle such as the air-flow rate through the carburetor, the vacuum developed in the intake manifold of the engine, the revolution speed of the engine, the temperature in the engine intake manifold, the carburetor throttle opening, the vehicle speed, the altitude of a road on which the vehicle is running, the temperature of the exhaust gases from the engine, and the concentration or concentrations of a compound or compounds contained in the exhaust gases. The function generator **134** is operative to produce at its output terminal a signal voltage V which is representative of a certain function which is determined from any combination of these operating conditions of the vehicle, examples of the waveforms of the signal voltage V being indicated in FIGS. 5*a* and 5*b*. The signal voltage V is fed to an adding circuit **136** which is constantly biased with a voltage V_t having a steady-state saw-tooth waveform as indicated in FIG. 5*c*. The signal voltage V is thus added with the saw-tooth voltage V_t in the adding circuit **136** which therefore produces at its output terminal a saw-tooth signal voltage V_s which is higher than the saw-tooth voltage V_t a value corresponding to the signal voltage V, as will be seen in FIG. 5*d* or 5*f*. The output terminal of the adding circuit **136** is connected to a combination comparator and pulse-generator **138** on which a fixed reference voltage V_r is constantly impressed. The combination comparator and pulse-generator **138** is thus operative to compare the saw-tooth signal voltage V_s supplied from the adding circuit **136** with the reference voltage V_r and to produce a pulsating current I_p when the former is higher than the latter as will be seen in FIG. 5*e* or 5*g*. The combination comparator and pulse generator **138** has an output terminal connected through a line **140** to the exciting coil **82** of the solenoid of the air-flow regulator valve unit **48** so that the coil **82** is energized cyclically by the pulsating current I_p delivered from the combination comparator and pulse generator **138.**

On the other hand, the flow-shift control circuit **130** comprises a discriminator **142** which has a plurality of input terminals which are common to those of the function generator **134** and are thus supplied with signals representative of the previously mentioned various operating conditions of the vehicle. The discriminator **142** is operative to detect from these signals a condition in which the air-fuel mixture being produced in the carburetor is unduly rich or lean for the sensed operating conditions of the vehicle, producing a control signal when such a condition is detected. In the present context, the discriminator **142** is assumed, by way of example, to be so arranged as to produce a control current I_c responsive to an unduly rich air-fuel mixture condition and to produce no output voltage responsive to an unduly lean air-flow mixture condition. The discriminator **142** has an output terminal which is connected through a line **144** to the exciting coil **106** of the solenoid of the air-flow shift valve unit **50.** The air flow shift valve **50** is, thus, held in the first operative condition providing the communication between the air-inlet port **88** and the first air-outlet port **90** thereof in the absence of the control current I_c at the output terminal of the discriminator **142** and is actuated into the second operative condition providing the communication between the air-inlet port **88** and the second air-outlet port **92** thereof in the presence of the control current I_c at the output terminal of the discriminator **142.** Designated by reference numeral **146** is a capacitor which may be connected between the output terminal of the discriminator **142** and the exciting coil **106** of the air-flow shift valve unit **50** for the reason to be explained later.

Operation of the mixture control apparatus thus constructed and arranged will now be described with reference to FIG. **3** and concurrently to FIGS. **5***a* to **5***g*.

As the signals to be fed to the control unit **52,** various kinds of variables may be used which are representative of the previously mentioned operating conditions of the vehicle. For the simplicity of description, however, it will be pro tempore assumed that the control unit **52** is arranged to be responsive to the rate of air flow Q through the carburetor. Description will be thereafter made as to the cases in which other variables representative of, for example, the engine temperature, the temperature in the engine intake manifold, the carburetor throttle opening, the vehicle speed or the like.

The air-flow rate Q in the carburetor may be directly measured by a flow meter positioned anywhere in the carburetor. In the embodiment illustrated in FIG. **3,** however, the air-flow rate Q is assumed to be approximated from a signal S_n representative of the revolution speed of the crankshaft of the engine and a signal S_v representative of the vacuum which is developed in the intake manifold of the engine.

When, now, the signals S_n and S_v are fed to the function generator **134** of the control unit **52,** the function generator **134** of the control unit **52,** the function generator **134** produce a signal voltage V which has a waveform V_{ab} shown in FIG. **5***a* if the air-flow rate Q approximated by the function generator **134** from input signals S_n and S_v falls within the range between Q_a and Q_b indicated in FIG. **2** or which has a waveform V_{cd} shown in FIG. **5***b* if the approximated air-flow rate Q falls within the range between Q_c and Q_d. As seen in FIG. **5***a*, the signal voltage V_{ab} droops as the air-flow rate Q increases from Q_a to Q_b whereas, as seen in FIG. **5***b* the signal voltage V_{cd} gradually rises as the air-flow rate Q increases from Q_c to Q_d.

when, thus, the signal voltage V of the waveform V_{ab} is delivered from the function generator **134** and if the air-flow rate Q is at a level Q_1 (which is assumed to be on a lower side of the range Q_a–Q_b as seen in FIG. **5***a*), the voltage V will be at a level indicated by V_1 in FIG. **50***a* so that the adding circuit **136** supplied with the steady-state saw-tooth voltage V_t shown in FIG. **5***c* produces a signal voltage V_s which has a saw-tooth waveform V_{s1} indicated in FIG. **5***d*. The signal voltage V_s thus produced from the adding circuit **136** is similar in waveform to the initially supplied saw-tooth voltage V_t and is higher then the saw-tooth voltage V_t by a value equal to the level V_1 of the output voltage V from the function generator **134.** The saw-tooth signal voltage V_s delivered from the adding circuit **136** is supplied to the combination comparator and pulse generator **138** and is compared with the fixed reference voltage V_r (FIG. **5***d*). The combination comparator and pulse generator **138** produces a pulsating current I_p having pulse-widths t_1 (FIG. **5***e*) which correspond to the intervals in which the saw-tooth signal voltage V_s is higher than the reference voltage V_r as will be seen from FIGS. **5***d* and **5***e*. The pulsating current thus delivered from the flow control circuit **130** is fed through the line **140** to the exciting coil **82** of the solenoid of the air-flow regulator valve unit **48.** The exciting coil **82** is consequently energized in cycles that correspond to the repetition frequency of the pulses P and cyclically actuates the spool valve member **60** into the first axial position thereof, providing communication between the air-inlet port **62** and the air-outlet port **64** at a frequency substantially equal to the pulsating cycles of the current supplied to the coil **106.** Pressurized supplied from the air-feed pump **54** through the pressure governor **56** is in this manner passed through the air-flow regulator valve unit **48** to the air-flow shift valve **50** at a frequency and at time intervals which are dictated by the train of pulses P indicated in FIG. **5***e*. Simultaneously as the pulsating current I_p is thus produced from the flow control circuit **130,** the discriminator **142** of the flow shift control circuit **132** forming part of the electric control unit **52** is operative to detect the richness of the air-fuel mixture being produced in the carburetor and delivers the control current I_c provided the air-fuel mixture is found to be unduly rich. Under the condition in whch the air-flow rate Q is in the range of between Q_a and Q_b, however, the air-fuel mixture produced in the carburetor is unduly lean and, as a consequence, the discriminator **142** remains inoperative to proudce the control current I_c. The exciting coil **106** of the air-flow shift valve unit **50** is therefore kept de-energized so that the spool valve member **86** of the valve unit **50** is maintained in the first axial position illustrated in FIG. **3,** providing communication between the air-inlet port **88** and the first air-outlet port **90.** Pressurized air which has been passed through the air-flow regulator valve unit **48** is now passed through the air-flow shift valve unit **50** to the air-inlet port **110** of the float bowl **20** and is admitted into the top of the liquid fuel stored in the bowl **20,** thereby giving rise to an increase in the air pressure P_1 behind the liquid fuel to be discharged. As will be understood from the previously shown mathematic relation, the increase in the pressure P_1 behind the fuel to be discharged results in an increase in the mass flow of the fuel injected from the main fuel discharge nozzle **38** into the venturi **12** (or the variable-area venturi shown in FIG. **4**) and is thus effective to enrich the air-fuel mixture produced in the carburetor. The rate of increase in the mass flow of the fuel discharged from the fuel discharge nozzle **38** is largely proportional to the square root of the rate of increase in the pressure of air in the float bowl **20** and the increasing rate of the air pressure P_1 is, in turn, dictated by the pulsewidths and the pulse repetition frequency of the pulsating current I_p produced from the flow control circuit **130** and accordingly by the waveform V_{ab} (FIG. **5***a*) of the signal voltage V produced by the function generator **134**. If, thus, the approximated rate of air flow Q through the carburetor is at a level Q_2 which is on a higher side of the range of between Q_a and Q_b so that the signal voltage V delivered from the function generator **134** is at a level V_2 which is lower than the previously mentioned level V_1 as seen in FIG. **5***a*, the adding circuit **136** will produce a signal voltage V_s having a saw-tooth waveform indicated by V_{s2} in FIG. **5***f* and as a consequence the pulsating current I_p produced from the combination comparator and pulse generator **138** will be such that is shown in FIG. **5***g*, having pulsewidths t_2 which are smaller than the pulsewidths t_1 of the pulsating current C_p produced when the air-flow rate Q is lower than Q_2. From this, it will be apparent that, when the air-flow rate Q is at a relatively high level in the range of between Q_a and Q_b, the pressure P_1 of air behind the liquid fuel to be discharged into the venturi of the carburetor stepped up at a relatively low rate and accordingly the air-fuel mixture produced in the carburetor is enriched at a moderate rate.

When, on the other hand, the flow rate Q of air through the carburetor is within the range of between Q_c and Q_d indicated in FIG. **2**, then the function generator **134** delivers a signal voltage V which now has a waveform V_{cd} which increases as the air-flow rate Q increases from Q_c to Q_d indicated in FIG. **5***d*. If, in this instance, the air-flow rate Q is at a level Q_3 which is on a lower side of the range between Q_c and Q_d, the signal voltage V will be at a level indicated by V_3 in FIG. **5***b* so that the signal voltage V_s produced from the adding circuit **136** has a saw-tooth waveform which is similar to the waveform V_{s2} shown in FIG. **5***f*. The saw-tooth signal voltage V_s thus produced from the adding circuit **136** is compared with the reference voltage V_r in the combination comparator and pulse generator **138**, which produces a pulsating current I_p composed of a train of pulses which are similar to those shown in FIG. **5***g*. The air-flow regulator valve unit **48** is consequently actuated into the previously mentioned first condition repeatedly in cycles and at time intervals which are dictated by the pulse repetition frequency and the pulsewidths of the pulses constituting the pulsating current I_p. Simultaneously as the pulsating current I_p is in this manner supplied from the flow control circuit **130**, the discriminator **142** of the flow shift control circuit **132** of the electric control unit **52** is operative to detect the air-to-fuel ratio of the air-fuel mixture being produced in the carburetor. When the air-flow rate Q in the carburetor falls within the range of between Q_c and Q_d, the air-fuel mixture produced in the carburetor is unduly rich for the operating conditions of the vehicle as previously mentioned and, for this reason, the discriminator **142** delivers the control current I_c so that the exciting coil **106** of the solenoid of the air-flow shift valve unit **50**. The armature core **104** is consequently driven to axially move from its initial position illustrated and, in turn, drives the spool valve member **86** to move from the first axial position to the second axial position thereof against the opposing force of the preload spring **100**. The communication which has been established between the air-inlet port **88** and the first air-outlet port **90** of the valve unit **50** with the second air-outlet port **90** closed by the first land **94** of the spool valve member **86** and, instead, communication is provided between the air-inlet port **88** and the second air-outlet port **92** of the valve unit **50** through the circumferential groove **98** in the valve member **86** with the second land **96** of the spool valve member **86** moved off the second air-outlet port **92**. Pressurized air cyclically passed through the air-flow regulator valve unit **48** is now directed through the air-flow shift valve **50** to the previously mentioned first and second air passageways **112** and **114**. Air under pressure is consequently injected through the main and auxiliary air bleeds **118** and **122** leading, in the embodiment shown in FIG. **3**, from the first and second air passageways **112** and **114**, respectively, into the main fuel discharge circuit **30** and the idle and low-speed fuel discharge circuit **32**. The liquid fuel in the main fuel discharge circuit **30** or the idle and low-speed fuel discharge circuit **32** is thus mixed with air under pressure on its way to the main fuel discharge nozzle **38** or the idle port **40** and the low-speed port **42**. The fuel to be ejected from the main fuel discharge nozzle **38** or the idle port **40** and the low-speed port **42** is in an emulsified state with pressurized air injected thereinto and as a consequence reduces its viscosity and accordingly the density thereof. As will be understood from the previously shown mathematical relation, the reduction in the density of the fuel results in a decrease in the mass flow of the fuel injected into the carburetor and gives rise to an increase in the art-to-fuel mixture produced in the carburetor. The air-fuel mixture is in this manner leaned out to an optimum richness when the air-flow rate Q through the carburetor is at the level Q_3 in the range of between Q_c and Q_d. The rate of decrease in the mass flow of the fuel discharged from the main fuel discharge nozzle **38** is largely proportional to the square root of the rate of decrease of the density *d* of the fuel and, in turn, the decreasing rate of density *d* of the fuel is dictated by the pulsewidths and the pulse repetition frequency of the pulsating current I_p supplied to the solenoid of the air-flow regulator valve unit **48**. If, thus, the approximated rate of air flow Q computed by the function generator **134** is at a level Q_4 which is on a higher side of the range between Q_c and Q_d so that the signal voltage V delivered from the function generator **134** is at a level V_4 which is higher than the previously mentioned voltage level V_3 as seen in FIG. **5***b*, the saw-tooth voltage V_t produced by the adding circuit **136** will have a waveform which is similar to that indicated in FIG. **5***d* with the result that the pulsating current I_p delivered from the combination comparator and pulse generator **138** will be such that is illustrated in FIG. **5***e*. From this it will be understood that the air-fuel mixture produced in the carburetor when the air-flow rate Q in the carburetor is in the range of between Q_c and Q_d is leaned out at a rate which decreases as the air-flow rate Q increases from the level Q_c to the level Q_d in accordance with the waveform V_{cd} of the signal voltage V delivered from the function generator **134**. The waveforms of the signal voltage V produced by the function generator **134** may be selected and varied in a manner to match the specific performance characteristics of the engine, particularly, the carburetor therefor so that the air-to-fuel mixture supplied to the engine is at all times maintained optimum for the varying operating conditions of the vehicle. Major considerations that should be taken into account in determining the waveforms to be produced by the function generator **134** may include the relative positions of the main fuel discharge nozzle **38**, the idle port **40** and the low-speed port **42** and the ratio between the discharge rates of the nozzle **38** and the idle and low-speed ports **40** and **42** so that the fuel discharged from the discharge nozzle **38** is prevented from sticking to the throttle valve **16** and failing to be sufficiently atomized in the carburetor especially when the throttle valve **16** is in a closed-throttle or part-throttle position.

The engine may malfunction transiently when the flow of pressurized air is shifted in the air-flow shift valve unit **50** by the switching action of the flow shift control circuit **48**. Such a temporary malfunction of the engine can be prevented if the capacitor **146** is connected between the output terminal of the discriminator **142** of the flow shift control circuit **132** and the exciting coil **106** of the air-flow shift valve unit **48** as indicated by phantom lines in FIG. **3** so that the control current I_c is gradually increased or decreased when the control current is initially delivered from the discriminator **142** or the supply of the current therefrom is interrupted.

Although, moreover, the air-flow regulator valve unit **48** has been described as being electrically energized by a train of pulses, such is merely by way of example and, therefore, the regulator valve unit **48** may be energized by a current having any other waveform insofar as the valve unit **48** is operable to pass the flow of pressurized air at a rate which is dictated by the waveform produced by the function generator **134**. The cyclic operation of the air-flow regulator valve unit **48** by the pulsating current I_p is, however, conductive to reducing the static friction between the inner peripheral surface of the valve housing **58** and the lands **68** and **70** of the spool valve member **60** and will thus guarantee the sensitive and accurate response of the valve unit **48** to the signal produced by the function generator **134**. The dithering motions of the spool valve member **60** of the air-flow regulator valve unit **48** may create pulsations of the pressure of air directed to the float bowl **20** or the fuel discharge circuits **30** and **32**. Where this is an important consideration, the frequency of the saw-tooth voltage V_t impressed on the adding circuit **136** may be raised to an appropriate level and/or the orifices **108, 112** and **114** and/or the air passageways leading from these orifices may be calibrated to have appropriate cross sectional areas with a view to cancelling the pulsations of the air pressure.

While the embodiment illustrated in FIG. **3** has been described as being operative in responsive to the air-flow rate Q in the carburetor or, more specifically, the revolution speed of the engine crankshaft and the vacuum developed in the intake manifold of the engine, this is solely for the pupose of illustration of the apparatus and the method according to the present invention and, thus, the electric control unit **52** may be supplied, in addition to the signals S_n and S_v representative of the engine crankshaft revolution and the intake manifold vacuum, with any other signals which are commonly designated by S_d in FIG. **3.**

As one of the additional input signals S_d which may be impressed on the function generator **134** and the discriminator **132,** a variable representing the temperature of the engine may be used so as to cope with the cold starting of the engine. In this instance, the function generator **134** may be so arranged as to produce a signal voltage V_e which gradually decreases as the engine temperature T_e rises in a relatively low range as indicated in FIG. **6***a*. The drooping signal voltage V_e is added with the previously mentioned steady-state saw-tooth voltage V_t (FIG. **5***c*) and is formed into a saw-tooth signal voltage V_{se} indicated in FIG. **6***b*. The saw-tooth signal voltage V_{se} delivered from the adding circuit **136** is compared with the predetermined reference voltage V_r by the combination comparator and pulse generator **138,** which thus produces a pulsating current I_{pe} composed of a train of pulses indicated in FIG. **6***c* when the input voltage V_{se} is higher than the reference voltage V_r. On the other hand, the signal representative of the temperature of the engine being started from cold disables the discriminator **142** from producing the control current I_c. The exciting coil **106** of the solenoid-operated air-flow shift valve unit **50** is consequently held in the first operative condition thereof providing communication between the air-inlet port **88** and the first air-outlet port **90** as shown. Pressurized air delivered from the air-feed pump **54** is thus directed through the valve units **48** and **50** into the float bowl **20** at rate which is dictated by the pulse repetition frequency and the pulsewidths of the pulsating current I_{pe} fed to the exciting coil **82** of the air-flow regulator valve unit **48.** The air-fuel mixture produced in the carburetor is enriched by reason of the increased air pressure P_1 behind the fuel to be discharged from the main fuel discharge circuit **30** and the idle and low-speed fuel discharge circuit **32** during cold starting of the engine. The rae of injection of pressurized air into the float bowl **20** is diminished and accordingly the air-to-fuel ratio of the mixture is reduced (viz, the air-fuel mixture is made leaner) as the engine temperature T_e increases toward an ordinary operating level as will be understood from the pulse train shown in FIG. **6***c*.

It is well known that the engine fails to operate properly if the air-fuel mixture supplied thereto is unduly enriched when the temperature in the intake manifold of the engine is increased to cause reduction in the density of the mixture flowing into the combustion chambers of the engine, especially during idling of the engine. For the purpose of preventing this condition from being invited in the engine, the additional signals S_d to be supplied to the function generator **132** and the discriminator **142** of the electric control circuit **52** may include a signal representative of the temperature in the intake manifold of the engine and a signal representative of the idling condition of the engine. In this instance, the function generator **132** is responsive to the signal representative of the temperature T_m of the engine intake manifold and is thus operative to produce a signal voltage V_m which has a waveform gradually increasing as the temperature T_m of the engine intake manifold increases as indicated in FIG. **7***a*. As will be understood from the previous discussion, the signal voltage V_m thus delivered from the function generator **132** is added with the saw-tooth voltage V_t in the adding circuit **134** and is formed into a saw-tooth signal voltage V_{sm} shown in FIG. **7***b*. The saw-tooth signal voltage V_{sm} is then compared with the predetermined reference voltage V_r in the combination comparator and pulse generator **138** so that, when the former is higher than the latter, a pulsating current I_{pm} is produced which is composed of a train of pulses indicated in FIG. 7*c*. On the other hand, the discriminator **142** is responsive to the signal representative of the idling condition of the engine and is operative to produce the control current I_c. The exciting coil **106** of the solenoid-operated air-flow shift valve unit **50** is energized by the control current I_c so that the shift valve unit **50** is actuated from the first operative condition into the second operative condition thereof, providing communication between the air-inlet port **88** and the second air-inlet port **92** of the valve unit **50.** Pressurized air is now injected into the main fuel discharge circuit **30** and the idle and low-speed fuel discharge circuit **32** through the main and auxiliary air bleeds **118** and **122,** respectively. Under the idling condition of the engine, only the idle and low-speed fuel discharge circuit **32** is operative to discharge the fuel from the idle port **40** with the main fuel discharge nozzle **38** and the low-speed port **42** kept inoperative. The fuel on its way to the idle port **40** is thus mixed with pressurized air injected through the auxiliary air bleed **122** into the low-speed fuel discharge circuit **32.** The density of the fuel discharged from the idle port **40** is thus reduced and accordingly the air-fuel mixture resulting from the fuel is leaned out to an air-to-fuel ratio which is optimum for the idling operating of the engine with the intake manifold of the engine at an elevated temperature. As will be understood from the variation of the pulsewidths of the pulsating current I_{pm} indicated in FIG. 7, the air-fuel mixture produced in the carburetor is leaned out at a rate that increases as the temperature T_m in the engine intake manifold rises during the idling condition of the engine.

The richness of the air-fuel mixture to be supplied to the engine may be increased or descreased when the vehicle is accelerated or decelerated, respectively. To achieve this end, a change of vehicle speed may be used as one of the additional signals S_d to be supplied to the function generator **132** and the discriminator **142.** In this instance, the function generator **132** may be so arranged as to produce a signal voltage V_r having an upwardly convex waveform having a relatively steep tail ramp or, in other words, a relatively short rise-time and a gradually disclining leading ramp or a relatively long fall-time as indicated in FIG. **8***a*. A saw-tooth signal voltage V_{sr} shown in FIG. 8*b* is obtained in the adding circuit **134** from this signal voltage V_r so that, upon comparision with the predetermined reference voltage V_r in the combination comparator and pulse generator **138,** a pulsating current I_{pr} composed of a train of pulses formed as indicated in FIG. 8*c* is produced and applied to the exciting coil **82** of the solenoid-operated air-flow regulator valve unit **48.** On the other hand, the discriminator **142** of the flow shift control circuit **132** is responsive to the signal representative of the change in the vehicle speed and produces the control current I_c is the signal is indicative of a decrease in the vehicle speed, viz., a decelerating condition of the vehicle. When, thus, the vehicle is decelerated during normal cruising, the solenoid-operated air-flow shift valve unit **50** is energized by the control current I_c from the discriminator **142** and is actuated from the first operative condition into the second operative condition thereof. Pressurized air is in this manner injected into the fuel being directed toward the main fuel discharge nozzle **38** and the idle and low-speed ports **40** and **42** with a consequent decrease in the richness of the air-fuel mixture produced in the carburetor at an incipient stage of the decelerating condition of the vehicle. The signal voltage V_r produced by the function generator **132** steeply rises in response to the initial decrease of the vehicle speed as will be seen in FIG. **8***a* so that the air-fuel mixture produced in the carburetor is leaned out for a short while during the initial stage of the deceleration. When, however, the vehicle is accelerated during normal cruising, the air-flow shift valve unit **50** remains de-energized in the absence of the control current I_c from the discriminator **142** and is maintained in the first operative condition. Pressurized air is therefore directed into the float bowl **20** and enriches the air-fuel mixture produced in the carburetor during an incipient stage of the acceleration of the vehicle.

Besides the additional signals S_d above described, signals representative of the altitude of a road on which the vehicle is running, the temperature of the exhaust gases and/or the concentration or concentrations of one or more specific compounds contained in the exhaust gases may be impressed on the electric control unit **52** of the embodiment illustrated in FIG. **3.**

While a few embodiments of the apparatus according to the present invention have been herein described and shown, there are simply illustrative of the gist of the present invention and, as such, such embodiments may be changed or modified in numerous manners and applied to carburetors of any types other than those which have been described and shown herein.

What is claimed is:

1. An apparatus for controlling the richness of an air-fuel mixture produced by a carburetor of an internal combustion engine of an automotive vehicle, comprising first passage means having an outlet end open into a substantially closed space behind the fuel in a fuel discharge circuit of the carburetor; second passage means having an outlet end open into said fuel discharge circuit; a source of pressurized air; air-flow regulator valve means in communication with the source of pressurized air and operative to regulate the flow rate of pressurized air through the valve means when actuated; air-flow shift valve means having a first operative condition providing communication between said air-flow regulator valve means and said first passage means and a second operative condition providing communication between said air-flow regulator valve means and said second passage means; and an electric control unit responsive to predetermined operating conditions of the vehicle and operative to supply a first control signal to said air-flow regulator valve means for varying the flow rate of pressurized air through the regulator valve means in accordance with said operating conditions of the vehicle and a second control signal to said air-flow shift valve means for holding the air-flow shift valve in said first operative condition when the vehicle operating conditions are representative of an excessively lean condition of the air-fuel mixture being produced in the carburetor or in said second operative condition when the vehicle operating conditions are representative of an excessively rich condition of the air-fuel mixture.

2. An apparatus as claimed in claim **1,** in which said electric control unit is responsive to the rate of flow of atmospheric air in said carburetor and is operative to produce said first control signal which is effective to decrease the rate of flow of pressurized air through said air-flow regulator valve means when the rate of flow of atmospheric air in the carburetor increases in a range lower than a first predetermined level and to increase the rate of flow of pressurized air through the regular valve means when the rate of flow of atmospheric air in the carburetor increases in a range higher than a second predetermined level and said second control signal which is effective to hold said air-flow shift valve means in said first operative condition when the rate of flow of atmospheric air in the carburetor is lower than said first predetermined level and in said second operative condition when the rate of flow of atmospheric air in the carburetor is higher than said first predetermined level.

3. An apparatus as claimed in claim **2,** in which said electric control unit comprises a flow control circuit responsive to the rate of flow of atmospheric air in the carburetor and operative to produce a train of pulses having pulsewidths which are decreased as the rate of flow of atmospheric air in the carburetor increase in the range lower than said first predetermined level and which are increased as the rate of flow of atmospheric air in the carburetor decrease in the range higher than said second predetermined level, said train of pulses constituting said first control signal.

4. An apparatus as claimed in claim **3,** in which said air-flow regulator valve means comprises electromagnetically operated actuating means electrically connected to said flow control circuit for being energized by said train of pulses and actuating the air-flow regulator valve means into open condition in cycles which are dictated by said pulses produced by said flow control circuit.

5. An apparatus as claimed in claim **3,** in which said air-flow shift valve means comprises electromagnetically operated actuating means electrically connected to said electric control unit for being energized by said second control signal for actuating the shift valve means between said first and second operative conditions thereof.

6. An apparatus as claimed in claim **4,** in which said flow control circuit comprises function generating means operative to produce a signal voltage having a waveform which gradually declines as the rate of flow of atmospheric air in the carburetor increases in the range lower than said first predetermined level and which gradually increases as the rate of flow of atmospheric air in the carburetor increases in the range higher than said second predetermined level, adding means for adding a steady-state saw-tooth voltage to the signal voltage delivered from said function generating means for producing a saw-tooth signal voltage, and comparing and pulse generating means for comparing said saw-tooth signal voltage with a predetermined reference voltage and producing said train of pulses when the saw-tooth signal voltage is higher than said reference voltage.

7. An apparatus as claimed in claim **1,** in which said electric control unit is responsive to variation in engine temperature lower than a predetermined level and is operative to produce said first control signal which is effective to decrease the rate of flow of pressurized air through said air-flow regulator valve means as the engine temperature rises toward said predetermined level and said second control signal which is effective to hold said air-flow shift valve means in said first operative condition thereof in response to the engine temperature lower than said predetermined level.

8. An apparatus as claimed in claim **7,** in which said electric circuit comprises a flow control circuit responsive to the variations in the engine temperature lower than said predetermined level and operative to produce a train of pulses having pulsewidths which are decreased as the engine temperature rises toward said predetermined level, said train of pulses constituting said second control signal.

9. An apparatus as claimed in claim **8,** in which said air-flow regulator valve means comprise electromagnetically operated actuating means electrically connected to said flow control circuit for being energized by said train of pulses and actuating the air-flow regulator valve means into open condition in cycles which are dictated by said pulses produced by said flow control circuit when the engine temperature is lower than said predetermined level.

10. An apparatus as claimed in claim **8,** in which said air-flow shift valve means comprises electromagnetically operated actuating means electrically connected to said flow shift control circuit for being energized by said second control signal for actuating the shift valve means between said first and second operative conditions thereof.

11. An apparatus as claimed in claim **9,** in which said flow control circuit comprises function generating means operative to produce a signal voltage having a waveform which gradually declines as the engine temperature rises toward said predetermined level, adding means for adding a steady-state saw-tooth voltage to said signal voltage for producing a saw-tooth signal voltage, and comparing and pulse generating means for comparing said saw-tooth signal voltage with a predetermined reference voltage and producing said train of pulses when the saw-tooth signal voltage is higher than the reference voltage.

12. An apparatus as claimed in claim **1,** in which said electric control unit is responsive to variation in the temperature in the intake manifold of the engine and to idling condition of the engine and is operative to produce said first control signal which is effective to increase the rate of flow of pressurized air through said air-flow regulator valve means as the intake manifold temperature rises beyond a predetermined level and said second control signal which is effective to hold said air-flow shift valve means in said second operative condition thereof during idling of the engine.

13. An apparatus as claimed in claim **12,** in which said electric control unit comprises a flow control circuit responsive to the variation in the temperature in the engine intake manifold and operative to produce a train of pulses having pulsewidths which are increased as the intake manifold temperature rises beyond said predetermined level, said train of pulses constituting said first control signal, and a flow shift control circuit responsive to the idling condition of the engine and operative to produce a control current when the engine is in the idling condition, said control current constituting said second control signal.

14. An apparatus as claimed in claim **13,** in which said air-flow regulator valve means comprise electromagnetically operated actuating means electrically connected to said flow control circuit for being energized by said train of pulses and actuating the air-flow regulator valve means into open condition in cycles which are dictated by said pulses produced by said flow control circuit when the intake manifold temperature is higher than said predetermined level.

15. An apparatus as claimed in claim 13, in which said air-flow shift valve means comprises electromagnetically operated actuating means electrically connected to said electric control unit for being energized by said control current for actuating the shift valve means between said first and second operative conditions thereof.

16. An apparatus as claimed in claim 14, in which said flow control circuit comprises function generating means operative to produce a signal voltage having a waveform which gradually increases as the cooling water temperature rises beyond said predetermined level, adding means for adding a steady-state saw-tooth waveform to said signal voltage for producing a saw-tooth signal voltage, and comparing and pulse generating means for comparing said saw-tooth signal voltage with a predetermined reference voltage and producing said train of pulses when the saw-tooth signal voltage is higher than the reference voltage.

17. An apparatus as claimed in claim 1, in which said electric control unit is responsive to change in the vehicle speed and is operative to produce said first control signal which is effective to abruptly increase the rate of flow of pressurized air through said air-flow regulator valve means during an incipient stage of change of the vehicle speed and said second control signal which is effective to hold said air-flow shift valve means in said first operative condition thereof in response to an increase in the vehicle speed and in said second operative condition thereof in response to a decrease in the vehicle speed.

18. An apparatus as claimed in claim 17, in which electric control unit comprises a flow control circuit responsive to the change in the vehicle speed and operative to produce a train of pulses having pulse-widths which are abruptly increased at said incipient stage of the change of the vehicle speed, said train of pulses constituting said first control signal, and a flow shift control circuit responsive to an increase and a decrease in the vehicle speed and operative to produce a control current when the vehicle speed is increased or decreased, said control current constituting said second control signal.

19. An apparatus as claimed in claim 18, in which said air-flow regulator valve means comprise electromagnetically operated actuating means electrically connected to said flow control circuit for being energized by said train of pulses and actuating the regulator valve means into open condition in cycles which are dictated by said pulses produced by said flow control circuit during the incipient stage of the change of the vehicle speed.

20. An apparatus as claimed in claim 18, in which said air-flow shift valve comprise electromagnetically operated actuating means electrically connected to said flow shift control circuit for being energized by said control current and actuating said air-flow shift valve between said first and second operative conditions thereof.

21. An apparatus as claimed in claim 19, in which said flow control circuit comprises function generating means operative to produce a signal voltage having a waveform with a relatively short risetime in response to a change in the vehicle speed, adding means for adding a steady-state saw-tooth voltage to said signal voltage for producing a saw-tooth signal voltage, and comparing and pulse generating means for comparing said saw-tooth voltage with a predetermined reference voltage for producing said train of pulses when the saw-tooth signal voltage is higher than said reference voltage.

22. An apparatus as claimed in claim 1, in which said air-flow regulator valve means comprise an air-inlet port in communication with said source of pressurized fluid, an air-outlet port in communication with said air-flow shift valve means, a valve member which is movable between a first position providing communication between the air-inlet port and the air-outlet port and a second position interrupting the communication between the ports, and electromagnetically operated actuating means responsive to said first control signal for actuating said valve member between said first and second positions when energized and de-energized by the first control signal.

23. An apparatus as claimed in claim 22, in which said electric control unit comprises a flow control circuit responsive to said operating conditions of the vehicle and operative to produce a train of pulses having pulsewidths dictated by the vehicle operating conditions whereby said actuating means is energized in cycles by said pulses produced from the flow control circuit, said train of pulses constituting said first control signal.

24. An apparatus as claimed in claim 1, in which said air-flow shift valve means comprises an air-inlet port in communication with said air-flow regulator valve means, a first air-outlet port in communication with said first passage means, a second air-outlet port in communication with said second passage means, a valve member which is movable between a first porition providing communication between said air-inlet port and said first air-outlet port and a second position providing communication between said air-inlet port and said second air-outlet port, and electromagnetically operated actuating means responsive to said second control signal for actuating said air-flow shift valve between said first and second operative conditions when energized and de-energized by said second control signal.

25. An apparatus as claimed in claim 24, in which said electric control unit comprises a flow shift control circuit responsive to said operating conditions of the vehicle and operative to produce a control current responsive to an excessively rich or lean condition of the air-fuel mixture produced in the carburetor whereby said actuating means is energized or de-energized in accordance with the excessively rich or lean condition of the air-fuel mixture.

26. A method of controlling the richness of an air-fuel mixture produced by a carburetor of an internal combustion engine of an automotive vehicle, comprising producing a first control signal responsive to predetermined operating conditions of the vehicle, a second control signal responsive to an excessively rich or lean condition of the air-fuel mixture being produced in the carburetor, producing a flow of pressurized air, varying the rate of flow of pressurized air by said first control signal, and injecting the pressurized air into a substantially closed space behind the fuel in a fuel discharge circuit of the carburetor in response to the excessively lean condition of the air-fuel mixture or into the fuel flowing in the fuel discharge circuit in response to the excessively rich condition of the air-fuel mixture in accordance with said second control signal.

27. A method as claimed in claim 26, in which said operating conditions of the vehicle include the rate of flow of atmospheric air in the carburetor.

28. A method as claimed in claim 27, in which said first control signal is effective to decrease the rate of injection of said pressurized air as the rate of flow of atmospheric air in the carburetor increases in a range lower than a first predetermined level and to increase the rate of injection of the pressurized air as the rate of flow of atmospheric air increases in a range higher than a second predetermined level and in which said second control signal is effective to direct the flow of pressurized air into said space responsive to the unduly lean condition of the air-fuel mixture and into the fuel flowing in the fuel discharge circuit in response to the unduly rich condition of the air-fuel mixture.

29. A method as claimed in claim 28, in which said first control signal is produced by producing a signal voltage having a waveform which gradually decreases as the rate of flow of atmospheric air in the carburetor increases in the range lower than said first predetermined level and which gradually increases as the rate of flow of atmospheric air increases in the range higher than said second predetermined level, adding a steady-state saw-tooth voltage to said signal voltage for producing a saw-tooth signal voltage, comparing said saw-tooth signal voltage with a predetermined reference voltage and producing a train of pulses as said first control signal when the saw-tooth signal voltage is higher than said reference voltage, said train of pulses constituting said first control signal.

30. A method as claimed in claim 26, in which said operating conditions of the vehicle include the temperature of the cooling water the engine and idling condition of the engine.

31. A method as claimed in claim 30, in which said first control signal is effective to increase the rate of injection of said pressurized air as the cooling water temperature increases beyond a predetermined level and in which said second control signal is effective to direct the flow of the pressurized air into the fuel flowing in said fuel discharge circuit in response to the idling condition of the engine.

32. A method as claimed in claim 31, in which said first control signal is produced by producing a signal voltage having a waveform which gradually increases as the cooling water temperature rises beyond said predetermined level, adding a steady-state saw-tooth voltage to said signal voltage for producing a saw-tooth signal voltage, comparing the saw-tooth signal voltage be added to the signal voltage with a predetermined reference voltage and producing a train of pulses as said first

control signal when the saw-tooth signal voltage is higher than said reference voltage.

33. A method as claimed in claim 26, in which said operating conditions of the vehicle include the engine temperature.

34. A method as claimed in claim 33, in which said first control signal is effective to decrease the rate of injection of said pressurized air as the engine temperature increases in a range lower than a predetermined level and in which said second control signal is effective to direct the flow of said pressurized air into said space behind the fuel in the fuel discharge circuit in response to the engine temperature lower than said predetermined level.

35. A method as claimed in claim 34, in which said first control signal is produced by producing a signal voltage having a waveform which gradually decreases as the engine temperature rises toward said predetermined level, adding a steady-state saw-tooth voltage to said signal voltage for producing a saw-tooth signal voltage, comparing the saw-tooth signal voltage with a predetermined reference voltage and producing a train of pulses as said first control signal when the saw-tooth signal voltage is higher than the reference voltage.

36. A method as claimed in claim 26, in which said operating conditions of the vehicle include change in the vehicle speed.

37. A method as claimed in claim 36, in which said first control signal is effective to abruptly increase the rate of injection of said pressurized air during an incipient stage of change of the vehicle speed and said second control signal is effective to direct the flow of said presssurized air into said space behind the fuel in the fuel discharge circuit in response to an increase in the vehicle speed and into the fuel flowing in the fuel discharge circuit in response to a decrease in the vehicle speed.

38. A method as claimed in claim 37, in which said first control signal is produced by producing a signal voltage having a waveform which has a relatively short resetime responsive to the change in the vehicle speed, adding a steady-stage saw-tooth voltage to said signal voltage for producing a saw-tooth signal voltage, comparing the saw-tooth signal voltage with a predetermined reference voltage, and producing a train of pulses as said first control signal when the saw-tooth signal voltage is higher than the reference voltage.

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