

Nov. 19, 1957

J. M. WHITE ET AL
FUEL INJECTION SYSTEM

2,813,522

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4 Sheets-Sheet 1

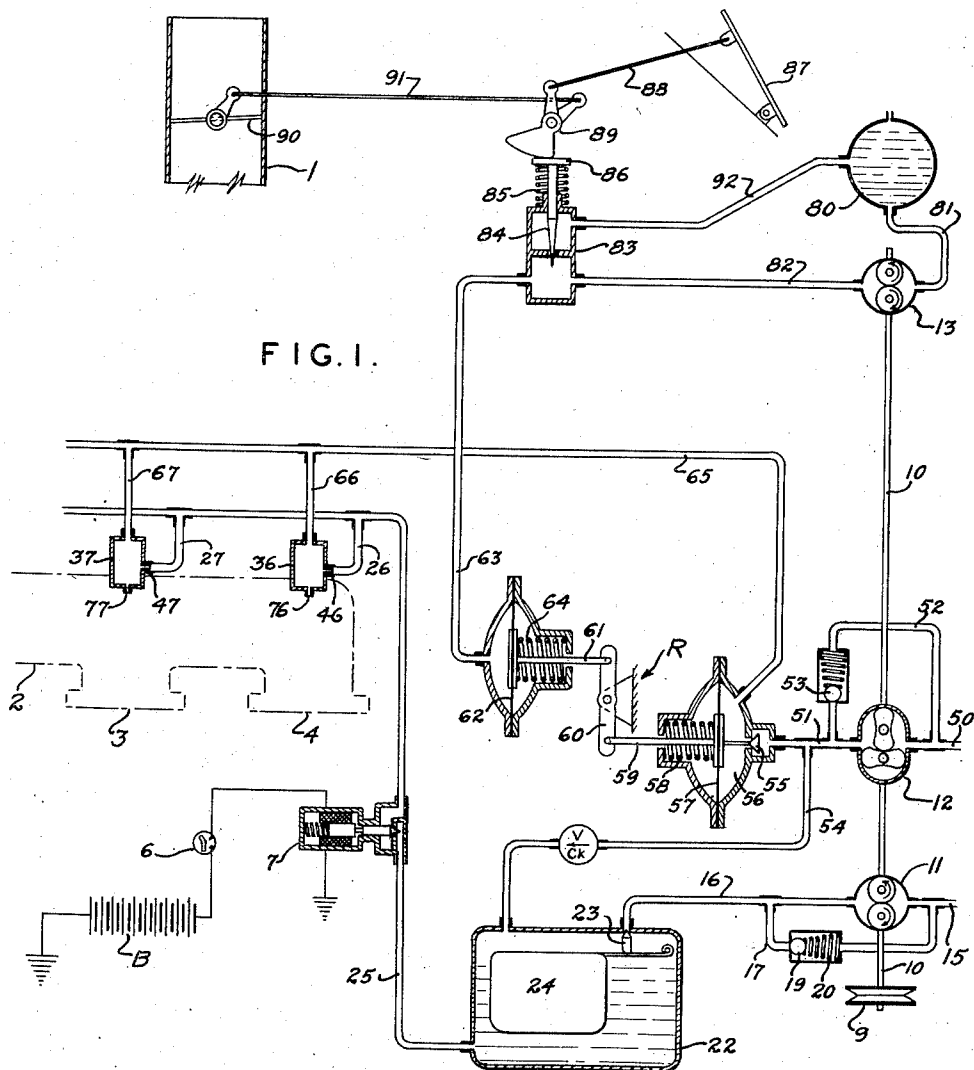


FIG. 1.

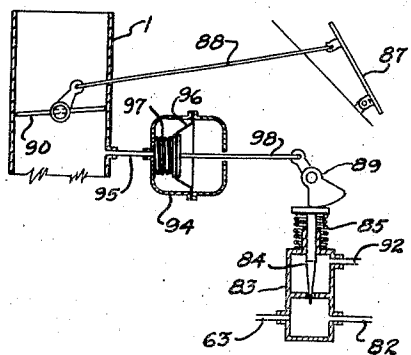


FIG. 2.

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4 Sheets-Sheet 2

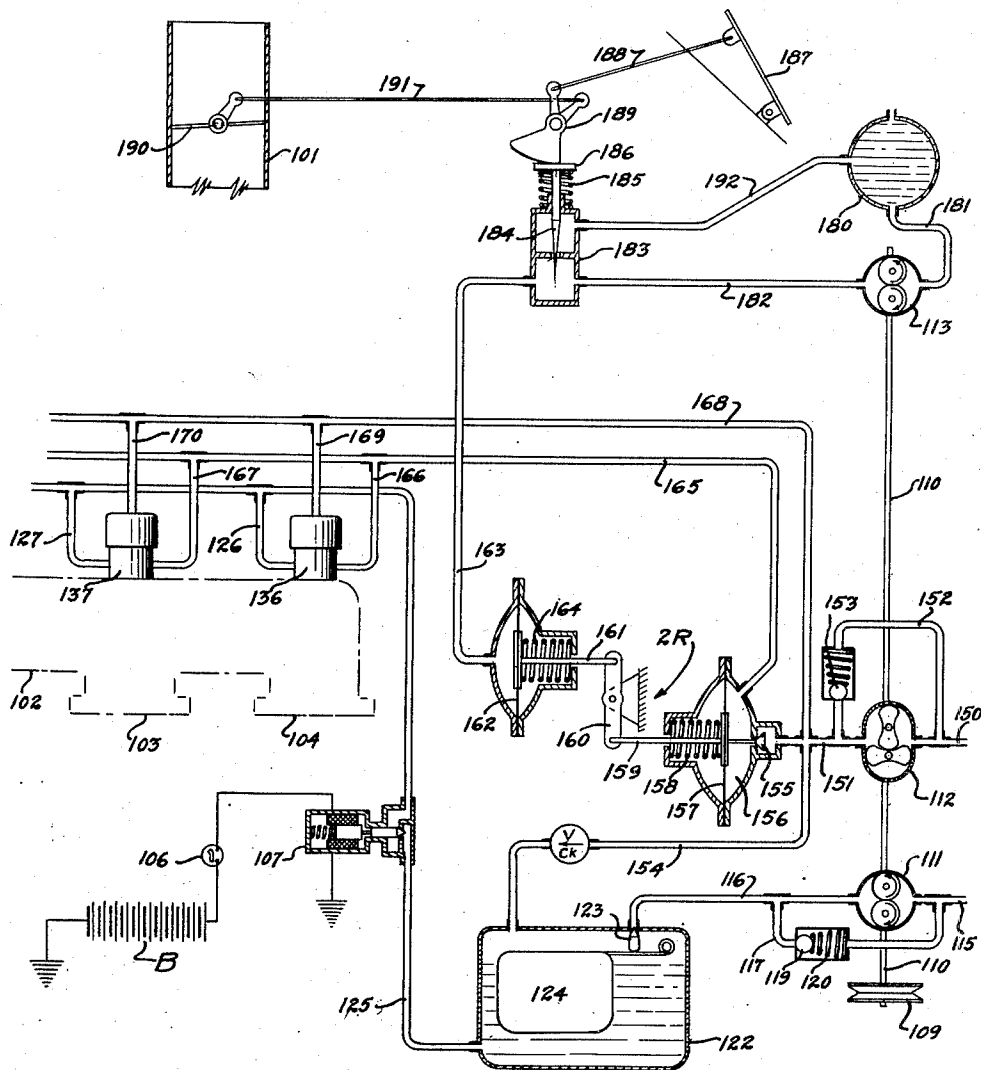


FIG. 3.

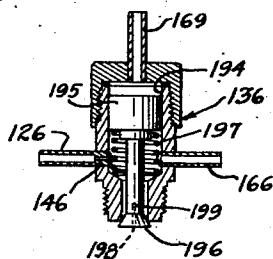


FIG. 4.

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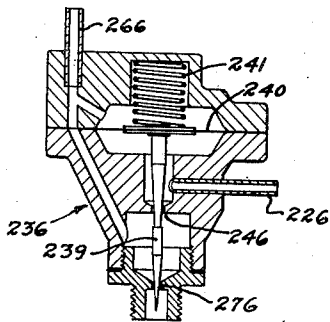


FIG. 6.

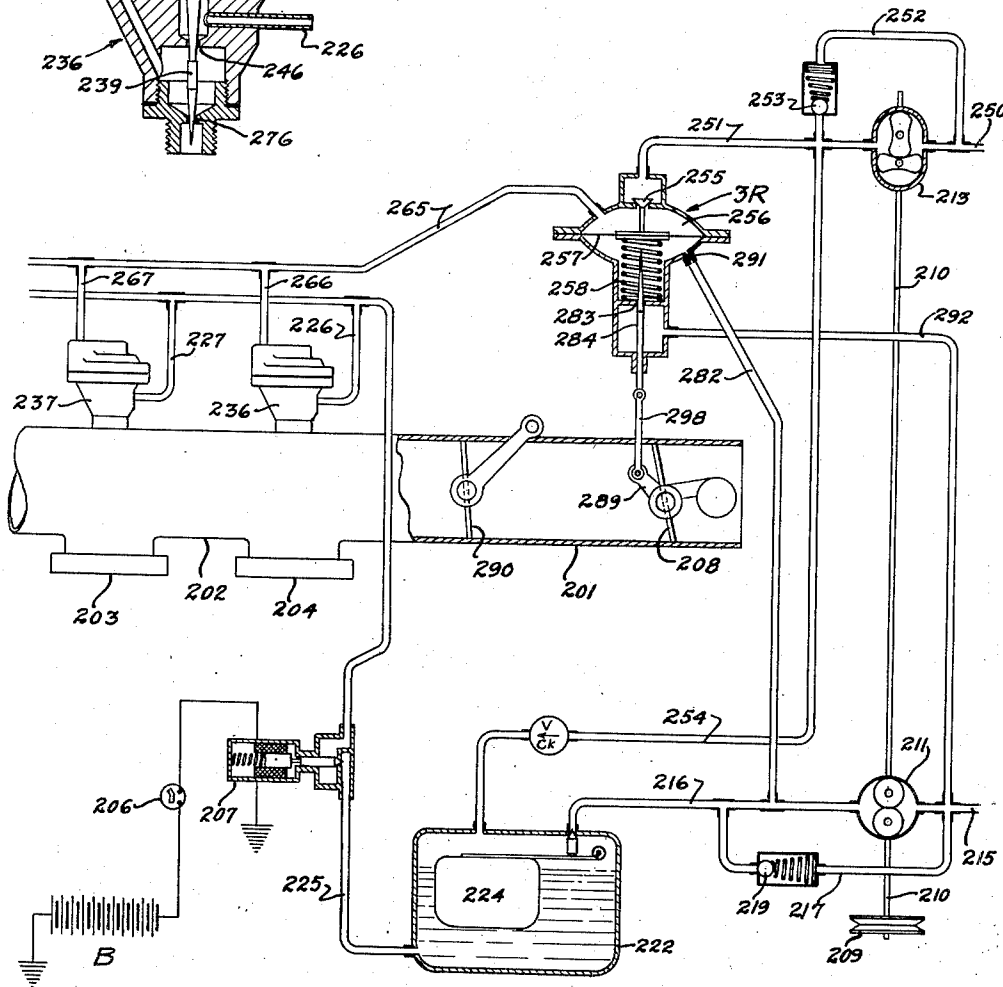


FIG. 5.

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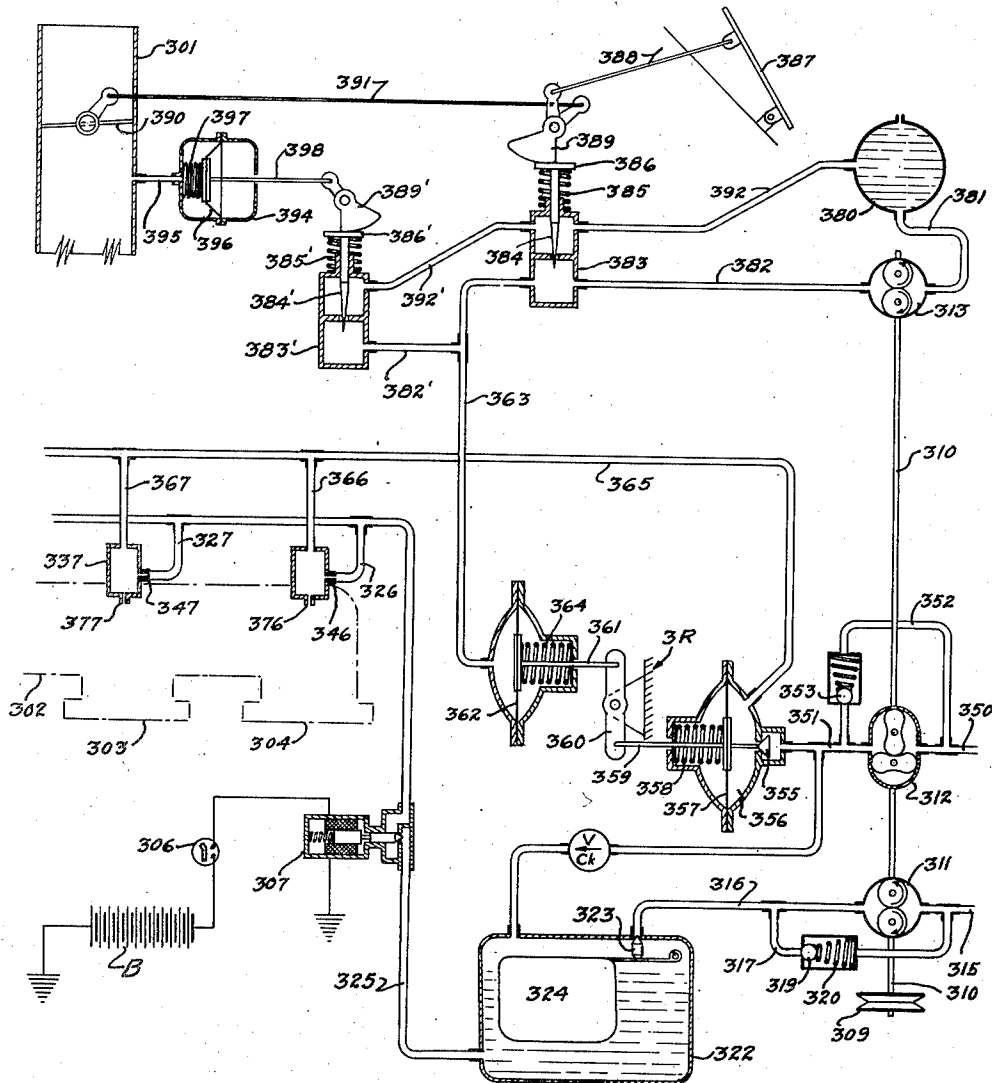


FIG. 7.

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FUEL INJECTION SYSTEM

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Application July 2, 1956, Serial No. 595,410

24 Claims. (Cl. 123—119)

This invention relates to a system for feeding fuel under pressure to an internal combustion engine and, more specifically, to a system of this type wherein the fuel flow to the engine is metered by varying either the fuel pressure differential across one or more fuel flow metering restrictions or the area of these restrictions in proportion to or in accordance with the rate of air flow to the engine, which can, in turn, be measured directly or regarded as a parameter determined by one or more of the engine variables—density, engine speed, and throttle opening.

According to this invention, the engine is supplied with air through a suitable air induction system, the entrance of which is controlled by a manually operated throttle valve. If the engine has a plurality of cylinders, which is usually the case, a manifold with a plurality of outlets connects with the inlet ports of the several cylinders. The fuel is supplied from a substantially constant pressure source, which may be a closed reservoir, and flows through a fuel passage to one or more nozzles opening into the air induction passage adjacent the engine inlet port or ports. Between this source and the nozzle inlet is a fuel flow metering restriction.

A source of air under constant pressure connects with the fuel source to urge the fuel to flow through the fuel passages and the flow metering restriction. Another connection from the air pressure source to the fuel passage downstream of the metering restriction and upstream of the nozzle outlet tends to retard the flow of fuel through the flow metering restriction. The air pressure in this connection is controlled to vary in accordance with variations in air density posterior of the throttle valve or by engine speed and the degree of throttle opening.

It will be readily apparent that in such a system any differential between the fuel pressure at the fuel source and the air pressure downstream of the fuel flow metering restriction will cause the fuel to flow at a rate proportional to the square root of the pressure differential across the fuel flow metering restriction or orifice. When this pressure differential is suitably controlled, fuel flow can be maintained substantially proportional to air flow through the engine induction system.

A separate hydraulic circuit having a variable output pressure acting on an air pressure regulator controls the air pressure differential applied to the fuel by variably controlling the air pressure supplied downstream of the fuel flow metering restriction.

The hydraulic circuit includes a constant displacement pump driven at engine speed, a direct pressure connection between this pump and the air pressure regulator, and a by-pass hydraulic circuit around the pump, including a variable area orifice suitably operated by either throttle opening and/or manifold pressure posterior of the throttle valve. For any given setting of the orifice in this hydraulic circuit, the output pressure imposed on the air pressure regulator will vary as a square function of engine speed.

The action of the air pressure regulator responds to this output pressure from the hydraulic circuit to produce

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changes in air pressure which are inversely proportional to the pressure changes in the hydraulic circuit.

As an alternative to the above-described arrangement for regulating the air pressure differential, a modification 5 contemplates a structure in which a separate hydraulic circuit connects with the air pressure regulator by way of a metering restriction. The hydraulic pressure in the regulator is varied according to variations in air flow to the engine by a controlled outlet downstream of the metering restriction in a discharge line leading to the intake 10 of the pump. The controlled outlet may be a variable orifice such as a tapered needle in a restriction operated linearly by movements proportional to the air flow to the engine to obtain pressure changes in the hydraulic circuit 15 proportional to air flow to the engine.

The advantages and novel results obtained with this system will become more apparent from the accompanying detailed description taken with the accompanying drawings, in which:

Fig. 1 is a schematic representation illustrating the fuel and air circuits with their controls.

Fig. 2 is a schematic representation of a modification of the invention illustrating the fuel and air circuits and their controls.

Fig. 3 is a schematic representation of a second modification of the invention illustrating the fuel and air circuits and their controls.

Fig. 4 is a detailed view illustrating one form of fuel nozzle which is used in the third modification.

Fig. 5 is a schematic representation of a third modification of the system shown in Fig. 1.

Fig. 6 is a cross-sectional view of the nozzle used in Fig. 5.

Fig. 7 is a schematic representation of a fourth modification of the system shown in Fig. 1.

The system about to be described is adapted to be applied to the air induction system of a conventional piston engine. It is well understood in the art that such systems include a single or dual manifold arrangement with one 40 or more throttle controlled intake stacks leading to a manifold with plural outlets connected to the intake ports in the engine. Since the intake system or manifold forms no part of the present invention, the specific features thereof are not shown or described in detail.

In Fig. 1 such an induction system has been shown diagrammatically as comprising an air intake stack 1 which is connected with and forms a portion of an intake manifold 2 having a plurality of outlets 3 and 4 for connection with the several intake ports in the engine. It is also assumed that the engine has a suitable ignition system controlled by a suitable ignition switch of the key type, for example, as illustrated at 6. In addition to controlling the ignition of the engine, the key switch 6 also controls a circuit from the battery B through a solenoid operated valve 7, which is spring closed. The purpose of the valve is to cut off the fuel to the engine when the ignition switch 6 is turned off. The manner in which it operates to perform this function will appear more clearly as this description proceeds.

In the system schematically illustrated in Fig. 1, a pulley 9 on a shaft 10 is arranged to be suitably driven at engine speed by means of a belt between the pulley 9 and a suitable pulley on the engine (not shown). The shaft 10, in turn, powers a plurality of pumps 11, 12 and 13, all of which are connected to be driven from the line shaft 10.

The pump 11 supplies fuel to the engine as regulated by a fuel system hereinafter described, of which it forms a part. Fuel may be supplied to this system from a suitable source, such as a tank, connecting with line 15. The outlet 16 from the pump has a by-pass 17 containing a pressure responsive relief valve 19 operated by a spring

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20, so that the excess delivery from the pump 11 may be by-passed from the outlet to the inlet, and thereby limit the pressure in the supply line 16 extending to the reservoir 22. For example, if the pressure in the supply line 16 is 30 pounds or less gauge, the outlet from the supply line 16 may be easily controlled by a float valve 23 of conventional design operated by a float 24 in a fuel reservoir 22 charged with air at about 25 pounds gauge.

A line 25 extends from the outlet of the fuel bowl 22 to and through the solenoid operated valve 7 to a plurality of branches 26, 27, etc., connecting with fuel nozzles 36, 37, etc., usually arranged to supply fuel adjacent each manifold outlet 3 and 4. Each branch 26, 27, etc., has a restricted metering outlet 46, 47, etc., in the connection to the fuel nozzles 36, 37, etc.

The fuel restrictions 46, 47, etc., above described comprise the main fuel metering restrictions in the fuel system, and, in order to control the amount of fuel delivered through these fuel restrictions or metering orifices, it is necessary to control the pressure drop across each. The system for directly performing this function is pneumatic and comprises an air blower 12 driven from the shaft 10 having an air inlet 50, which may, if desired, be connected with the inlet stack 1 above the throttle. An air discharge line 51 connected with the outlet from the blower 12 has a by-pass line 52 controlled by a suitable spring-pressed relief valve 53. The setting of this valve is such that the discharge air pressure is maintained at approximately 25 pounds pressure gauge. This pressure is supplied to a regulating device (generally designated R) by the line 51, and through line 54 to fuel reservoir 22.

The regulator R has a diaphragm operated inlet valve 55 operated to and from a seat by air pressure acting downstream of the valve 55 on a diaphragm 57 backed by a compression spring 58 acting in a direction to open the valve 55 and increase the pressure acting on the diaphragm 57. A stem 59 integral with the valve 55 is connected by a reverse linkage 60 with a stem 51 secured to a diaphragm 62 exposed to fluid pressure in the line 63. The line 63 is supplied with fluid under pressure from an hydraulic circuit which is regulated by an engine speed responsive and throttle position responsive mechanism to be later described herein, and this pressure acting on the diaphragm 62 is opposed by the force of a spring 64 acting in a balancing direction. The springs 58 and 62 determine the minimum air pressure supplied by regulator R. Diaphragm chamber 56 is connected by a line 65 having a plurality of branches 66, 67, etc., in turn connected to the fuel nozzles 36, 37, etc.

The outlet from each of these nozzles is a metered restriction such as 76, 77, etc., which is so selected as to size that when the pressure drop across each restriction is as much as 15 pounds, the flow through the nozzle will always be at critical speed, and variation in manifold pressure will therefore have no effect upon the pressure inside the nozzle, and consequently no effect upon fuel metering.

In order to vary the pressure in the air line 65, and thus the pressure supplied to each fuel nozzle, a regulating pressure is generated and supplied to the line 63, which regulating pressure varies according to any change in throttle position or engine speed. This circuit includes a fluid pump 13 driven from line shaft 10 and connected to the reservoir 80 by means of a supply line 81. A fluid discharge line 82 connects with the pump 13 and with a variable metering restriction device 83 which has a return line 92 to the reservoir 80. This variable metering device contains an orifice controlled by a tapered needle 84 biased to an open position by a spring 85 acting beneath the head 86. The motor vehicle or engine of the motor vehicle mounts the usual accelerator pedal 87 connected by rod 88 with a pivoted cam 89. Within the air intake to the manifold is a throttle valve 90 positioned by a lever arm connected by a rod 91 with the same cam

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89. The face of the cam 89 rides on the head of the metering stem or rod 84, varying its open position with throttle movement. The pressure generated by the pump 13 is communicated to the regulator R by the line 63, as has been described.

Operation

When the engine is not in operation, the ignition key 6 is turned to the "off" position, and the spring-pressed solenoid operated valve 7 is closed, thereby sealing off the line 25 so as to maintain the fuel supply part of the system under charging pressure. This means that the fuel source 22 remains pressurized at 25 pounds, which is the limited output pressure from the blower 12. A suitable check valve may be provided anywhere in the line 54 for this purpose. Any fuel beyond the valve 7 may leak into the nozzles 36, 37, etc., where it will be trapped. This trapped fuel in the fuel nozzles forms a reservoir of fuel which is useful on engine starting, and eliminates the necessity of an oversized fuel pump for this purpose.

To start the engine, the ignition switch 6 is turned to the "on" position, energizing the solenoid valve 7 and opening communication through the line 25 from the source of fuel 22 under pressure to the fuel nozzles 36, 37, etc. The engine is then cranked, which rotates the pulley 9 and drives each of the pumps 11, 12 and 13. At cranking speed, the pressure delivered by the pump 13 against the diaphragm 62 will be at a minimum, so that valve 55 will be opened by spring pressure, allowing air under pressure to leave the blower 12 and reach the nozzles 36, 37, etc., by way of the connecting line 65. This air pressure is sufficient to discharge fuel through the metering orifices 76, 77, etc., in the direction of the intake ports of the engine connected with the outlets 3 and 4 of the manifold. Since some fuel will be trapped within the nozzles, and since the pressure on the fuel bowl is high, this mixture will be on the rich side, suitable for starting purposes. If the fuel level within the float bowl 22 drops during the cranking operation or after the engine starts to run, float 24 will open valve 23, permitting fuel to enter from the pump 11 by way of the line 16. When normal fuel level is reached in the bowl 22, float valve 23 is closed so as to hold the proper fuel level. The proper level for the fuel is adjacent to but not above the outlets 76, 77, etc., of the fuel nozzles in the manifold.

After the engine begins to run under its own power, full air pressure will be delivered by the blower 12, and the pump 13 will reach full output. Thereafter, the output from the blower 12 will be limited to approximately 25 pounds by the by-pass control 53, while the output of pump 13 will vary directly as engine speed, since it is a constant displacement pump driven at engine speed through the pulley 9.

The needle 84, at closed throttle, is in a position to form a minimum restriction to flow from pump 13 to reservoir 80. The regulating pressure in line 63 will be relatively low under these conditions with the engine idling. This pressure imposed on diaphragm 62 is not sufficient to overcome spring force alone, and the regulator will move to a position opening valve 55 until fluid pressure on diaphragm 62 and air pressure on diaphragm 57 balance spring forces. When regulator R is properly adjusted, valve 55 will have little throttling effect at engine idling speed—only sufficient to produce a pressure drop of a few inches of water from full blower pressure of 25 pounds gauge. Full blower pressure is always imposed upon the fuel within the float bowl 22. Consequently, with only a few inches of water pressure drop available between the air pressure upstream and downstream of the fuel metering orifices 46, 47, etc., to cause fuel flow, the rate of fuel flow will be relatively low. To obtain the proper rate of fuel flow demanded by the engine at idling speed, either the needle 84 or the spring pressure in the regulator R can be adjusted.

When the throttle 90 is opened by the accelerator

pedal, tapered needle 84 moves into the orifice, causing an immediate pressure rise in the regulating system. This gain in pressure acting on diaphragm 62 unbalances the regulator, moving the valve 55 toward closed position until spring force again balances the fluid pressures on diaphragms 62 and 57. Valve movement will be limited by decreasing air pressure on the diaphragm 57 as a result of the increased throttling by valve 55. As the air pressure is decreased by valve 55, the pressure differential across the metering restrictions 46, 47, etc., increases because the air pressure drops downstream of each metering restriction to cause an increase in fuel flow from each nozzle to enrich the mixture of fuel to air for acceleration.

As engine speed increases, the demand for fuel will increase, requiring increasing rates of fuel flow past the fuel metering restrictions to each nozzle. Since the pump 13 is a constant capacity pump driven at engine speed, then delivery from the pump increases linearly with engine speed. Flow past the needle 84 does not increase linearly, however, but at a rate increasing as the square root of the increase in pressure from the pump. This causes a pressure rise in line 63 proportional to the square of engine speed, and the action of the regulator R in response to this rate of pressure rise will increase the throttling effect of valve 55 to produce a pressure drop in line 65 which is inversely proportional to the rate of pressure rise in line 63, so that the flow of fuel through metering restrictions 46, 47, etc., will increase linearly with engine speed.

Closing the throttle 90 from any open position causes a decrease in regulating pressure from pump 13, and thereby a sudden increase in air pressure, as springs 58 and 64 expand, opening valve 55. A decrease in fuel flow occurs as the pressure differential across the orifice decreases, causing the rate of fuel flow to decrease. Since the mixture ratio of fuel to air varies directly with the rate of fuel flow, the mixture becomes temporarily lean when the throttle is closed at engine speeds above idle. This effect increases with engine speed so that, when the throttle is closed, fuel is substantially cut off.

The use of air pressure to regulate the pressure drop across each fuel metering orifice provides for equal division of the flow to the several nozzles. The air pressure regulation of fuel flow means an equal pressure differential at each metering restriction.

Instead of controlling the regulating pressure to the regulator R by throttle position, it is possible by a simple change to control the position of the needle 84 by manifold pressure. Such a modification of the invention is disclosed in Fig. 2. The same reference characters have been used to indicate the same parts.

The regulating pressure line 82 from the pump 13 connects with the metering device 83 and with the return line 92 to the reservoir 80. The regulating pressure line 63 connects the metering device 83 with the regulator R in the same manner as disclosed in Fig. 1.

In this modification, the cam 89 has a cam face cooperating with the headed end on the metering pin 84, which is biased against the cam by a spring 85, all in the manner described above. The position of the cam, however, is controlled by a suction motor 94 connected through line 95 with the intake stack 1 of the manifold posterior of the throttle 90. Within the suction motor is a diaphragm 96 urged to the right by a spring 97. An operating rod 98 forms a mechanical connection between the cam 89 and the diaphragm 96.

Operation

According to this modification, when the engine is being cranked, there is very little suction in the intake manifold. Diaphragm 96 is not effective, and the spring 97 rotates the cam 89 to a position to hold the metering pin 84 in flow-restricting position to produce substan-

tially its full throttling effect on fluid circulation by pump 13. Even though, during cranking, pump speed is low, nevertheless, the regulating pressure will increase in the line 63. As the regulating pressure increases, spring force in regulator R will be overcome, causing valve 55 to move toward a flow restricting position. Regardless of blower speed, the pressure differential across the fuel metering orifices 46, 47, etc., will remain high, causing a substantial fuel flow as soon as ignition key 6 is turned on and the engine cranked. Under these conditions, the starting mixture will be suitably rich. Some of this fuel will accumulate within the nozzles 36, 37, etc., so as to be always available for enrichment on acceleration, but most of it will be ejected by air pressure in an atomized condition. It is one of the features of this system that, after the engine begins to run under its own power, the air pressure available to atomize the fuel will be at least 15 pounds, even at full throttle. The outlets of the separate nozzles are each chosen as to size to produce an air flow at critical speed on less than a fifteen pound drop or differential, which means that the air flow capacity of the nozzles will be limited to a constant amount unaffected by changes in manifold pressures.

After the engine starts, the air pressure from the blower 12 will increase to normal, say 25 pounds, so as to decrease the pressure drop across the fuel metering restrictions 46, 47, etc. Then the regulator R functions to adjust this pressure drop precisely, so that at closed throttle it will amount to only a few inches of water pressure. The flow of fuel depends upon the air pressure differential, which, in turn, depends upon the action of valve 55. Regulator R is, in turn, responsive to fluid pressure in line 63, which is a function of engine speed and density, as hereinafter described.

Manifold suction during engine operation opens needle valve 84, lowering the pressure in line 63 and on diaphragm 62, tending to close valve 55. The springs 58 and 64 tend to open valve 55 and, because spring forces are the greater, the valve will open or remain open. The degree of opening depends upon the degree of force exerted on the diaphragms 57 and 62 by fluid pressures. At idle, the springs are so calibrated as to produce a few inches of water pressure drop across valve 55. Thus the air pressure to the nozzles is only slightly under 25 pounds gauge. This differential causes a low rate of fuel flow through the metering restrictions 46, 47, etc., which corresponds to the fuel requirements of the engine at dead idle engine speed.

Any time the throttle 90 is opened, however, there will be a change in density (manifold pressure), which change will be reflected by a corresponding change in the position of needle 84, increasing the throttling effect of the metering device 83. The resulting increase in the regulating pressure in line 63 unbalances the forces in regulator R, moving valve 55 toward a closed position until equilibrium is reached between spring force and diaphragm force. Any degree of movement of the valve 55 in a closing direction increases its throttling effect to increase the pressure drop and the pressure differential across the fuel metering orifices 46, 47, etc., to increase the rate of fuel flow. Accordingly, any degree of density change operates directly on fuel flow rate. Opening the throttle effects an enrichment of the mixture and, conversely, closing the throttle acts to lean out the mixture. This latter effect can shut off the fuel entirely if engine speeds are much above idle speed when the throttle is closed.

As the engine speed increases, the engine demand for fuel will increase in a near linear relation. The delivery of the pump 13 will also increase in a near linear relation with increases in engine speed. The flow through the metering device 83 increases as the square root of the pressure output of pump 13, and therefore the pressure in line 63 increases as the square of engine speed. The

response of the regulator R produces a pressure drop across valve 55 inversely proportional to the pressure rise in line 63, so that air pressure downstream of the fuel metering orifices 46, 47, etc., will cause a pressure differential to act on the fuel, which varies directly as the square function of engine speed. Translated into terms of rate of fuel flow through fuel metering restrictions 46, 47, etc., a pressure differential which varies as the square of engine speed causes a varying rate of fuel flow bearing a near linear relation to variations in engine speed.

When the throttle 90 is closed, manifold pressure decreases, moving needle 84 to decrease the throttling effect of metering device 84. A sudden decrease in regulating pressure follows, and regulator R responds, moving valve 55 toward open until a new equilibrium is reached between spring force and fluid force. As valve 55 opens, the air pressure differential decreases because the pressure acting downstream of each fuel metering restriction 46, 47, etc., increases.

Translated into terms of rate of fuel flow, a decrease in air pressure differential means a lower rate of fuel flow. With the speed density system described, the rate of fuel flow varies directly with manifold pressure, and, since the latter is an indication of the rate of air flow through the manifold to the engine, it follows that the rate of fuel flow varies directly with the rate of air flow to the engine.

In the modification shown in Figs. 3 and 4, a system similar to those previously described is illustrated in which the principal difference resides in a novel form of fuel nozzle. According to this modification, the pressure drop across each of the fuel orifices in the respective nozzles increases the size or area of the nozzle discharge orifice.

As in the previous views, the system is schematically illustrated, and the engine is not shown, since it forms no part of the invention. An air induction system suitable for use on an engine having a plurality of inlet ports is schematically illustrated. The elements in Figs. 3 and 4 which correspond with those previously described in Figs. 1 and 2, will be indicated by the same reference characters preceded by 100.

Fig. 3 shows an engine induction system comprising an air intake stack 101 which is connected with and forms a portion of an intake manifold 102 having a plurality of outlets 103 and 104 for connection with the several intake ports of the engine. The engine has a suitable ignition system (not illustrated) controlled by a suitable ignition switch 106 of the key type. In addition to controlling the ignition of the engine, the key switch 106 also controls a circuit from the battery B through a solenoid operated valve 107 which is spring closed.

In Fig. 3 a pulley 109 on a shaft 110 is arranged with respect to the engine to be suitably driven at engine speed by means of a belt between the pulley 109 and a suitable pulley on the engine (not shown). Shaft 110, in turn, powers a plurality of pumps 111, 112, and 113, all of which are connected to be driven directly at engine speed by the pulley 109. The pump 111 supplies fuel to the engine as regulated by a fuel system hereinafter described, of which it forms a part. Fuel may be supplied to this system from a suitable source such as a tank connecting with the line 115. The outlet 116 from the pump has a by-pass 117 containing a pressure responsive relief valve 119 operated by a spring 120, so that the excess delivery from the pump 111 may be by-passed from the outlet to the pump inlet, and thereby limit the pressure in the supply line 116 extending to the reservoir 122. Preferably, the pressure in the supply line 116 is maintained at, say 30 pounds or less, so that the outlet from the supply 116 may be easily controlled by a float valve 123 operated by a float 124 in the reservoir 122 which is under an air pressure of 25 pounds all the time.

A fuel line 125 extends from the outlet of the fuel

bowl 122 to and through the solenoid operated valve 107 to a plurality of branches 126, 127, etc., connected with fuel nozzles 136, 137, etc., arranged to supply fuel adjacent each manifold outlet 103 and 104. Each branch 126, 127, has a restricted metering outlet 146, as shown in Fig. 4.

The fuel restrictions 146 are at the fuel inlet for each of the nozzles 136, 137, etc., and each forms a part of the main fuel metering in the fuel system. In order to control the amount of fuel delivered through each of these fuel restrictions or metering orifices, it is necessary, of course, to control the pressure drop across each. This system includes a pneumatic circuit for this purpose which will be variable according to the engine requirements, and uniform in its effect in each nozzle. The pneumatic circuit performing this function comprises an air blower 112 driven from the shaft 110 having an air inlet 150 which may, if desired, be connected with the inlet stack 101 above the throttle. An air discharge line 151 connected with the outlet from the blower 112 has a by-pass 152 controlled by a suitable spring pressed relief valve 153. The setting of this valve is such that the discharge air pressure is maintained at approximately 25 pounds pressure gauge.

This pressure supply is connected to a regulating device generally designated as 2R, and also to the fuel nozzles and fuel source. As will be noted, a line 154 supplies the fuel bowl 122 with air under full pump pressure. Likewise, a line 168 from blower 112 is connected by branches 169, 170, with each of the nozzles 136, 137, etc. Fig. 4 illustrates the manner of connection of the pressure line 169 with one of the fuel nozzles 136.

The regulator 2R has a diaphragm operated inlet valve 155 operated to and from a suitable seat by the air pressure acting downstream of the valve 155 against a diaphragm 157 in a chamber 156. The diaphragm 157 is, in turn, connected to a second diaphragm 162 by a reverse linkage 159, 160, and 161. Each diaphragm, in turn, is backed up by a compression spring such as 158 and 164.

The diaphragm 162 is exposed to fluid pressure from an hydraulic circuit communicated thereto by the line 163, which, in turn, is a regulated fluid pressure varying in a controlled manner in response to throttle position and engine speed. This pressure acting on the diaphragm 162 is opposed by the force of spring 164 acting in a balancing direction. Diaphragm chamber 156, of course, is exposed to the pressure downstream of the valve 155, which pressure is, in turn, opposed by the spring 158.

An air line 165 is connected with the chamber 156 of the regulator 2R and with each of the nozzles 136, 137, etc., through suitable branches 166, 167, etc. The manner of connection to the nozzle is specifically illustrated in Fig. 4, and the operation and function of each will be later described.

As will be realized by those skilled in the art, in order to control the amount of fuel delivered through each nozzle, it is necessary to precisely control the pressure drop across the metering restrictions 146, etc., in each nozzle. To do this, it is necessary to control the difference in pressure between the fuel pressure in the bowl 122 (upstream of the fuel metering orifice) and line 166 (downstream of the fuel metering orifice). This is accomplished by variations in a regulating or reference pressure which is generated and supplied to the line 163 from the hydraulic circuit about to be described acting on the regulator 2R. This hydraulic circuit includes the fluid pump 113 driven from line shaft 110 and connected to the reservoir 180 by a supply line 181. A fluid discharge line 182 connects with the pump 113 and with a variable metering restriction device 183 which has a return line 192 to the reservoir 180. This variable metering device 183 contains an orifice controlled by a tapered needle 184 biased to an open position by spring 185 acting beneath the head 186. The motor vehicle or engine of

the motor vehicle mounts the usual accelerator pedal 187 connected by a rod 188 with a pivoted cam 189. Within the air intake stack to the manifold is a throttle valve 190 positioned by a lever arm connected by a rod 191 with the same cam 189. The face of the cam 189 rides on the head of the metering stem or rod 184, varying the open position of the metering rod with throttle movement.

The mechanism so far described in Fig. 3 differs from that in Figs. 1 and 2 only in the addition of the extra air pressure line 168, its branches 169 and 170, and the type of fuel nozzle used; otherwise, the system is the same and operates in the same manner. The nozzle construction is best illustrated in Fig. 4.

According to this figure, nozzle 136 has a barrel containing a cylinder 194 which reciprocally mounts a piston 195 for operating a discharge valve 196. A spring 197 resists valve opening. Within the head of the valve is a passage 198 which extends upwardly into the stem to communicate with inlet ports 199 which are located a substantial distance above the nozzle outlet.

Operation

As stated above, the operation of the system in Fig. 3 is similar to that in Figs. 1 and 2 above explained except for the difference in nozzle construction. In this modification, the upper side of the piston 195 is exposed to constant blower output pressure through the lines 168, 169, 170, etc. The lower side of the piston 195 is exposed to the pressure in lines 165, 166, 167, etc., from the regulator 2R. The spring 197 is suitably calibrated to resist small differences in pressure above and below the piston 195 and retain the valve 196 seated. Accordingly, when valve 196 is seated, all of the fuel entering at 146 will accumulate in a small puddle up to the inlet ports 199. When it reaches this level, it will be swept outwardly through the small passage 198 by the continuous passage of air supplied by the pressure regulator 2R through the lines 165, 166, 167, etc. The ports and passages 198 and 199 are so dimensioned that, at about 15 pounds air pressure, the flow through the passages 198 will be at critical speed, so that changes in pressures downstream or within the manifold have no effect upon the amount of air flowing through the nozzles, and therefore no effect upon the pressure within the nozzle beneath piston 195.

As in the previous modifications described, a check valve may be placed in the line 154 to maintain the fuel bowl 122 under pressure after the engine stops operating.

When the engine is stopped, valve 196 will remain closed in each injector nozzle, due to the fact that the pressure in the lines 165 and 168 will decrease simultaneously. Although the pressure in the fuel bowl 122 is retained, the flow of fuel to the nozzles is cut off by the solenoid valve 107.

To start the engine, the ignition switch 106 is turned on, supplying fuel under pressure to each of the nozzles. As the engine is cranked, this fuel under pressure will be forced out through the ports 199 in the passages 198, in the form of a spray, by the air pressure delivered from the pump 112.

After the engine starts, full blower pressure from the air pump 112 will be available to operate the system, and substantially the same pressure will exist above and below each of the pistons 195 in each of the injector nozzles. Spring 197 holds each of the valves seated, so that the air through the lines 166, 167, etc., forces the fuel out through this restricted passage 198 in the valve of each of the nozzles.

The hydraulic circuit, including the pump 113 and its effects upon the pressure regulator 2R, is the same as that described in the operation of Fig. 1, and a description of it will not be repeated here.

When the throttle 187 is opened, which indirectly causes

an increase in the pressure differential on the fuel upstream and downstream of the metering orifices 146, the same differential will operate on the opposite sides of the piston 195, producing a force, eventually, which is great enough to compress the spring 197 and unseat each of the valves 196 in each of the nozzles. With the valves 196 unseated, the flow capacity of each nozzle is increased a like amount, depending, of course, upon the amount of displacement of the piston 195 against the spring in each nozzle. As each of the valves 196 opens, or as each is forced from its seat, the amount of fuel which has accumulated between the valve seat and the orifices or ports 199 will be discharged so as to enrich the fuel mixture delivered to the engine, and thus smooth out the acceleration in engine speed.

By the use of the nozzle shown in Fig. 4, several distinct advantages are gained. A like amount of fuel will accumulate in each nozzle for uniform charging of each engine intake port. This can be determined by the distance of the inlet port 199 above the outlet of the nozzle. These can be made uniform in each nozzle for uniform metering. In the prior construction, the minimum size of the nozzle outlets 76, 77, etc., would be determined by the maximum amount of fuel supplied to the engine. This size would require a large air pump to supply enough air to the nozzle and still maintain the required pressure in the chamber to control the fuel flow. By using the valve which opens as the fuel flow increases, the amount of air used at low pump speeds and engine speeds is thereby drastically reduced.

In the modification shown in Figs. 5 and 6, a system similar to those previously described is shown in which the principal difference resides in two features. According to this modification, the pressure drop across each of the fuel metering orifices in the respective nozzles is controlled in response to the rate of air flow to the engine measure directly by a flow responsive valve. The second difference resides in the particular fuel nozzles in which the fuel metering orifices are located. In this modification, the rate of air flow to the engine not only controls the pressure drop across the fuel metering orifices in all the nozzles, but also the size or area of these orifices simultaneously producing a like variation in the outlet for each of the nozzles.

As in the previous views, the engine is not shown, since it forms no part of the invention, and the air induction system which is merely schematically illustrated, is one adapted to serve a multiple of cylinders having suitable inlet ports. Elements in Figs. 5 and 6 corresponding with those previously described will be indicated by the same reference characters preceded by 200.

The air induction system has an air intake stack 201 connecting with a manifold 202 having a plurality of outlets 203 and 204, two of which are shown. In the intake stack 201 are two pivoted valves 208 and 290, the latter of which is a manually controlled throttle valve.

In order to retain the fuel end of the system under pressure at all times, even when the engine is inoperative, and at the same time shut off the fuel from the engine, this system is provided with a similar control to those previously described, operated from the ignition switch 206 which connects the battery B with a solenoid operated valve 207 when the ignition is on. When the ignition is off, the solenoid valve 207 is de-energized so that the valve can close, shutting off the fuel from the engine.

The fuel part of the system includes a pulley 209 suitably driven at engine speed on a line shaft 210 which, in turn, drives the fuel pump 211 and the air blower 213. Fuel is supplied to the pump 211 from a suitable source 215, and is delivered by that pump to a line 216. Around the pump 211 is a by-pass 217 containing a pressure limiting valve 219. This by-pass insures a constant supply of fuel under pressure through the line 216 to a float bowl 222. The admission of fuel to the float bowl 222 is under control of float valve 223 operated from the float

224. Fuel is discharged through a line 225 past the sole-noid operated valve 207 to a plurality of fuel nozzles 236, 237, etc., by way of branch lines 226 and 227.

The fuel enters each of the nozzles 236, etc., through a line 226 as illustrated in Fig. 6, and flows out of the nozzle through a metering restriction 246 into a chamber where it mixes with air supplied to the nozzle through the line 266. Fuel mixed with air is discharged through the metered outlet nozzle 276 adjacent the outlets 203, 204, etc., of the intake manifold and into the engine. The modification in Fig. 6 differs from prior nozzles shown in the other modifications in that the fuel metering orifice 246 and the nozzle area 276 are simultaneously variable in response to variations in air pressure differentials, as will be described hereinafter. Within the body of the nozzle 236 is a double-tapered metering rod 239 actuated by a diaphragm 240 and spring 241. Air pressure from the line 266 is supplied to one side of the diaphragm 240, while fuel pressure from the line 226 is supplied to the opposite side of the diaphragm 240. As in prior devices, the pressure drop across the metering orifice 246 is controlled by the air pressure drop through the pressure regulator 3R connected with each line 266, 267, by the supply line 265.

The air pressure to the nozzles is supplied by a separate circuit including the blower 213 driven by the engine through the pulley 209 taking air in through an inlet 250, which may be connected with the inlet stack 201 posterior of the throttle 290, if desired. The discharge pressure from the blower 213 is regulated by the pressure relief valve 253 in the by-pass line 252, and the air is discharged through the line 251 to the pressure regulator 3R.

In the pressure regulator is a valve 255 controlled by a diaphragm 257 and a balance spring 258 calibrated to give a maximum output pressure only slightly lower than the output pressure from the blower 213. Air passing the valve 255 enters a chamber 256 where it acts in a closing direction against the opposition of the calibrated spring 258. The pressure in the chamber 256 is communicated to the supply line and the nozzles by the branch lines 266, 267, etc., from line 265.

In this modification, the regulating pressure is supplied through a by-pass around the fuel pump controlled by an air flow responsive device in the inlet stack of the manifold. This system includes a line 282 containing a fixed metering orifice 291 communicating fuel pump output pressure to the opposite side of the diaphragm 257. An orifice 283 controlled by the tapered needle 284 throttles the discharge of fuel from this side of the diaphragm 257 to a by-pass relief line 292 leading to the inlet of the fuel pump 211. The position of the tapered needle 284, and therefore the exposed area of the orifice 283 is controlled directly by the rate of air flow through the inlet stack 201 by an unbalanced valve 208 having a counterweight. A link 298 connects needle 284 with arm 289 on the shaft of the unbalanced valve 208. As the regulating fuel pressure increases, it tends to open the valve 255, aiding the action of the spring 258. On the other hand, as the datum fuel pressure decreases, the force tending to open the valve 255 decreases.

The air pressure supplied by the blower 213 is impressed upon the fuel in the fuel bowl 222 by way of a line 254, so that the pressure differential across the fuel metering orifice 246 in the nozzles 236, 237, etc., depends upon the degree of throttling of the valve 255, whose position, in turn, is influenced by the fuel pressure in the hydraulic circuit 282, 283, and 292, from the pump 211, and the pressure of the air acting on the upper side of the diaphragm 257.

Output pressure from the pump 211 is limited by the relief valve 219 in by-pass passage 217 to a maximum slightly greater than the maximum output pressure from blower 213 as limited by relief valve 253 in by-pass line 252. Accordingly, the pressure available in the hydraulic circuit to regulator 3R is always sufficient to

overcome the air pressure acting on the opposite side of the diaphragm tending to close valve 255. In order to regulate the degree of opening of valve 255, line 282 directly from pump 211 has a metering orifice 291, so that, when the open areas of restricting device 283 and 291 are equal, pressure beneath diaphragm 257 remains constant. When the open area of 283 is larger than the open area of 291, the pressure will fall beneath diaphragm 257. When the open area of 283 is less than 291, the pressure beneath diaphragm 257 increases.

Operation

When the engine is not operating, the parts are in the position as shown in Figs. 5 and 6. To start the engine, the ignition switch 206 is turned on, thereby supplying fuel under pressure through the connection 225 to the separate fuel nozzles 236, 237, etc. During cranking of the engine, surplus fuel flow into the nozzles, due to the pressure differential between the fuel bowl and the nozzles, will accumulate above the orifice 276, valve 255 will open wide, and air under pressure will be supplied from the blower 213 to each of the nozzles through the line 265. The accumulation of gasoline in the nozzles will supply a rich mixture—in other words, little air and a great deal of fuel—so as to make starting easy.

After the engine begins to run, both fuel pressure output and air pressure output come up to operating limits, say 30 and 25 pounds, respectively. With valve 208 slightly open to accommodate low air flow rates suitable at engine idling speeds, restricting device 283 will have a minimum open area, causing the pressure in the hydraulic circuit to build up to maximum, opening valve 255 so that it produces only a slight throttling effect on air flow to the nozzles, sufficient to give a slight pressure drop across the fuel metering orifices 246 for low fuel flow. In this phase of the operation, the air pressure on diaphragms 240 will be almost equal to the fuel pressure acting on the diaphragms 240 in each of the nozzles, and springs 241 will move the double tapered needles to their lower position within the orifices 246 and 276 to reduce their open area to minimum. When the amount of opening in the orifices 276 is minimum, a pressure drop of 15 pounds produces a flow at critical speeds. This maintains an air pressure downstream of the fuel metering orifices 246 to the regulated pressure. The fuel pressure upstream of the orifices 246 will be the same as blower discharge pressure, or 25 pounds.

As the throttle 290 is opened manually, valve 208 will respond according to the rate of air flow through the intake stack 201. Needle 284 will then take up a new position, opening orifice 283 to lower the fuel pressure below the diaphragm 257. Regulator 3R is unbalanced by lowering the pressure below diaphragm 257 in a direction tending to close valve 255. As the valve moves toward closed, its throttling action lowers the air pressure on the upper side of diaphragm 257 until air pressure balances spring pressure and the decreased fuel pressure. Since the pressure in chamber 256 of the regulator 3R drops with throttle opening, while the fuel pressure from the source 222 remains constant, diaphragms 240 in each of the nozzles overcomes the force of springs 241 to take up a new position, enlarging the metering orifices 246 for fuel to accommodate increasing fuel flow. Simultaneously, orifice 276 is enlarged to facilitate the delivery of larger quantities of fuel. It will be understood that each change in throttle setting and each change in engine speed will produce a different setting for the air valve 208, and thereby a change in the air pressure in regulator 3R supplying the fuel nozzles 236, 237, etc. Each change in air pressure in turn varies the fuel delivery from the nozzles by changing the pressure drop across the metering orifices 246 and their area in each nozzle. The area adjustment may be effected through either a part of the range of pressure variations or throughout the full range.

When the ignition switch 206 is turned off, the fuel flow to the nozzles is stopped by the closing of the solenoid valve 207.

Fig. 7 shows a modification in which the regulating pressure supplied to the regulator R is controlled by engine speed, throttle position, and manifold pressure. When all three are combined as illustrated, the regulating pressure includes a compensation for change in altitude or density.

As in the previous views described, this system is schematically illustrated, and the engine is not shown, since it forms no part of the invention. The elements shown in Fig. 7 which correspond with those previously described in Figs. 1 and 2 will be indicated by the same reference characters preceded by 300.

This description will be limited to the differences over those previously described in Figs. 1 and 2.

In this embodiment, the variable regulating or reference pressure is generated by a pump 313 driven at engine speed and supplied by a line 363 from an hydraulic circuit about to be described.

The output of pump 313 connects by way of a line 382 and 382' with two metering devices 383 and 383'. Within these metering devices are variable metering rods 384 and 384' which control the flow of fuel through each metering device into a return line 392' and 392 leading back to a sump 380. The hydraulic fluid in the sump 380 feeds to the pump 313 through an input line 381.

Within the metering device 383 is an orifice controlled by a movable tapered needle 384 positioned by a spring 385 acting under a fixed head 386 on the needle 384. The position of the needle 384 in the orifice is controlled through a cam 389 connected by a link 388 with the accelerator pedal 387 of the motor vehicle. A link 391 connects with the throttle valve 390 within the intake stack 301 which supplies the air to the intake manifold of the engine.

Within the metering device 383' is an orifice controlled by a tapered needle 384', in turn positioned by a spring 385' acting beneath the head 386' of the needle. A cam 389' engages the head 386' and limits the outward movement of the needle from the orifice. The cam is, in turn, positioned by a link 398 connected with the diaphragm 396 of the suction motor 394. A pipe 395 connects the suction motor 394 to the intake stack of the manifold 301 posterior of the throttle 390. Suction beneath the throttle valve 390 acts on the diaphragm 396 in a direction to compress the spring 397, and the diaphragm is moved to the left by the pressure differential existing between atmosphere and the pressure posterior to the throttle 390, which will be greatest when throttle 390 is in closed position. Spring 397 is suitably calibrated to move the link 398 to the right as the pressure differential on the diaphragm 396 decreases.

The regulating pressure in the line 363 will therefore be a function of engine speed, throttle opening, and manifold pressure, so that, with this system, decreases in atmospheric pressure operate on the mixture control.

In all other respects, this system is identical with that shown in Fig. 1, and a further description of the construction and operation is deemed unnecessary in view of the preceding description.

A structure has been described which will fulfill all the objects of this invention, but it is contemplated that other modifications will occur to those skilled in the art which come within the scope of the appended claims.

We claim:

1. A fuel injection system for an internal combustion engine having an air passage for supplying air to the engine comprising, in combination, a source of fuel, a fuel passage connecting said source and said engine, a fuel metering restriction in said passage, pump means for supplying a fluid under positive pressure to said source, separate passages connecting said pump means

with said fuel passage at spaced locations upstream and downstream of said fuel metering restriction, means acting to control the fluid pressure in said separate passages to control the pressure differential across said fuel metering restriction and thereby the rate of fuel flow to said engine, means responsive to changes in the rate of air flow to said engine for regulating the action of said control means, and means for injecting the fuel passing said fuel metering restriction into said engine.

2. A fuel injection system for an internal combustion engine having an air passage for supplying air to the engine comprising, in combination, a source of air under pressure, a source of fuel, a fuel passage connecting said source of fuel and said engine, a fuel metering restriction in said passage, air passages connecting said source of air under pressure with said fuel passage at spaced locations upstream and downstream of said fuel metering restriction, respectively, means acting to control the air pressure in said air passages to control the pressure differential across said fuel metering restriction and thereby the rate of fuel flow to the engine, means responsive to changes in throttle position and engine speed for regulating the action of said control means, and means for injecting the fuel passing said fuel metering restriction into said engine.

3. A fuel injection system for an internal combustion engine having an air passage for supplying air to the engine comprising, in combination, a source of fuel, a fuel passage connecting said source and said engine, a fuel metering restriction in said passage, an air pump, separate air passages connecting said air pump with said fuel passage at spaced locations respectively upstream and downstream of said fuel metering restriction, means acting to control the air pressure in said separate passages to control the pressure differential across said fuel metering restriction and thereby the rate of fuel flow to said engine, means responsive to air pressure in said engine induction air passage and engine speed for regulating the action of said control means, and means for injecting the fuel passing said fuel metering restriction into said engine.

4. A fuel injection system for an internal combustion engine having an air passage for supplying air to the engine comprising, in combination, a source of fuel, a fuel passage connecting said source and said engine, a fuel metering restriction in said passage, a source of air under positive pressure, separate air passages connecting said source of air under pressure with said fuel passage at spaced locations respectively upstream and downstream of said fuel metering restriction, means acting to control the air pressure in said separate passages to control the pressure differential across said fuel metering restriction and thereby the rate of fuel flow to said engine, means responsive to changes in throttle position and engine speed for regulating the action of said control means, and a fuel nozzle having an outlet in said air passage for supplying air to the engine, forming a part of said fuel passage between said source and said engine and a part of one of said separate air passages between said source of air under pressure and said fuel passage downstream of said fuel metering restriction.

5. A fuel injection system for an internal combustion engine having an air passage for supplying air to the engine comprising, in combination, a source of fuel, a fuel passage connecting said source and the engine, a fuel metering restriction in said passage, a source of air under pressure, separate air passages connecting said source of air under pressure with said fuel passage at spaced locations respectively upstream and downstream of said fuel metering restriction, means to control the air pressure in said separate passages to control the pressure differential across said fuel metering restriction and thereby the rate of fuel flow to said engine, means responsive to changes in throttle position and engine speed for regulating said control means, and means for in-

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jecting the fuel into said engine, including a fuel nozzle having an outlet of variable area opening into said air passage for supplying air to the engine and forming a portion of said fuel passage between said source of fuel and said engine and a part of one of said separate air passages connecting said source of air under pressure with said fuel passage downstream of said fuel metering restriction, a valve for varying the outlet from said nozzle having a metered opening constantly in communication with said engine, and means for varying the area of said outlet by valve movement including means for operating said valve in an opening direction in response to the differential in pressure between said separate air passages.

6. A fuel injection system for an internal combustion engine having an air passage for supplying air to the engine comprising, in combination, a source of fuel supply for the engine, a fuel passage between said source and the engine, a fuel metering restriction in said passage, a source of air under pressure, separate air passages connecting said source of air under pressure with said fuel passage at separate locations respectively upstream and downstream of said fuel metering restriction, means to control the air pressure in said separate passages to control the pressure differential across said fuel metering restriction and thereby the rate of fuel flow to said engine, means responsive to changes in throttle position and engine speed for regulating the action of said control means, and means for injecting the fuel metered into said engine, including a fuel nozzle opening into said air passage for supplying air to the engine and forming a part of one of said separate air passages connecting said source of air under pressure with said fuel passage downstream of said fuel metering restriction and a part of said fuel passage including said fuel metering restriction, means responsive to fuel pressure upstream of said fuel metering restriction and said air pressure downstream of said fuel metering restriction for varying the area of said fuel metering restriction and the outlet from said nozzle.

7. A fuel injection system for an internal combustion engine having an air passage for supplying air to the engine, comprising, in combination, a source of fuel supply for the engine, a fuel passage between said source and said engine, a fuel metering restriction in said fuel passage, a source of air under pressure, separate air passages connecting said source of air under pressure with said fuel passage at separate locations upstream and downstream, respectively, of said fuel metering restriction, means to control the air pressure in said separate passages to control the pressure differential across said fuel metering restriction and thereby the rate of fuel flow to said engine including a valve in one of said separate air passages connecting said source of air under pressure with said fuel passage downstream of said fuel metering restriction, means responsive to air pressure downstream of said valve for urging said valve toward a closed position, a hydraulic circuit having an output pressure variable in response to changes in throttle position and engine speed, and means responsive to changes in hydraulic pressure in said hydraulic circuit for urging said valve toward a closed position.

8. The combination of an engine, an air induction system for said engine, and a fuel injection system for supplying fuel to a plurality of nozzles located in said induction system adjacent the air intake ports of the engine, comprising, a source of fuel for supplying said engine, branched fuel passage means connecting said source and each of said nozzles, a fuel metering restriction in each of the branches of said passage means to said nozzles, an air pump for supplying air under positive pressure, separate passages connecting said air pump with said fuel passage means at spaced points located respectively upstream and downstream of each of said fuel metering restrictions, means to control the fluid pressure in said separate air passages to uniformly control the pressure differential across each of said fuel metering restrictions

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and thereby the total rate of fuel flow to said engine from said source of fuel and maintain equal rates of flow past each of said fuel metering restrictions, means responsive to changes in the rate of air flow to said engine through said induction system for regulating the action of said control means, and means in said nozzles for injecting the fuel passing said fuel metering restrictions into said engine.

9. In combination, an engine, an air induction system for said engine, and a fuel injection system for supplying fuel to a plurality of nozzles located in said air induction system adjacent the air intake ports of said engine, comprising a source of fuel supply for said engine, a fuel passage between said source and each of said nozzles, a fuel metering restriction in each of said fuel passages, an air pump, separate air passages connecting said air pump with said fuel passages at spaced locations respectively upstream and downstream of each of said fuel metering restrictions, means to uniformly control the air pressure in said separate air passages to control the pressure differential across each of said fuel metering restrictions and thereby the total rate of fuel flow to said engine from said source of fuel and maintain equal rates of flow past each of said fuel metering restrictions, means responsive to changes in throttle position and engine speed for regulating the action of said control means, and means in said nozzles for injecting the fuel passing said fuel metering restrictions into said engine.

10. In combination, an engine, an air induction system for said engine, and a fuel injection system for supplying fuel to a plurality of nozzles located in said air induction system adjacent the air intake ports of the engine, comprising a source of fuel supply for the engine, a fuel passage between said source and each of said fuel nozzles, a fuel metering restriction in each of said fuel passages, an air pump driven from said engine, pairs of separate air passages each connecting said air pump respectively with one of said fuel passages upstream of the fuel metering restriction therein and the corresponding fuel nozzle downstream of said fuel metering restriction, means to uniformly control the air pressure in said separate passages to control the pressure differential across said fuel metering restrictions and thereby the total rate of fuel flow to said engine from said source of fuel and maintain equal rates of flow past each of said fuel metering restrictions, means responsive to air pressure in said engine induction air passage and engine speed for regulating the action of said control means, and means connected with said nozzles for injecting the fuel passing said fuel metering restrictions into said engine.

11. In combination, an engine, an air induction system for said engine, and a fuel injection system for supplying fuel to a plurality of nozzles located in said induction system adjacent the air intake ports of the engine, comprising a source of fuel supply for said engine, a fuel passage between said source of fuel supply and said engine and each of said nozzles, a fuel metering restriction in each of said fuel passages, a source of air under positive pressure, pairs of air passages each connecting said source of air under pressure with one of said fuel passages at spaced locations respectively upstream and downstream of the fuel metering restriction therein, means to uniformly control the air pressure in the groups of separate air passages at points connecting with said fuel passages respectively upstream and downstream of said fuel metering restrictions to control the pressure differential across each of said fuel metering restrictions and thereby the total rate of fuel flow to said engine from said source of fuel and maintain equal rates of flow past each of said fuel metering restrictions, means responsive to changes in throttle position and engine speed for regulating the action of said control means, and an outlet for each of said nozzles opening into said air induction manifold for said engine selected to produce air flow at critical speeds from the nozzle to eliminate the effects of pressure varia-

tion in said air induction system on the fuel metering function.

12. In combination, an engine, an air induction system for said engine, and a fuel injection system for supplying fuel to a plurality of nozzles located in said induction system adjacent the air intake ports of said engine, comprising a source of fuel supply for the engine, a fuel passage between said source of fuel supply and said fuel nozzles, a fuel metering restriction in said fuel passage upstream of each of said nozzles, a source of air under pressure, separate air passages connecting said source of air under pressure with said fuel passage at separate locations upstream and downstream, respectively, of each of said fuel metering restrictions, means to uniformly control the air pressure in said separate air passages leading upstream and downstream of said fuel restrictions to control the pressure differential across said fuel metering restrictions, and thereby the total rate of fuel flow to said engine from said source of fuel and maintain equal rates of fuel flow past each of said fuel metering restrictions, means responsive to changes in throttle position and engine speed for regulating said control means, outlet means in said fuel nozzles opening into said air induction system for said engine and forming a portion of said fuel passage between said source of fuel and said engine and also forming a portion of said separate air passages connecting said source of air under pressure with said fuel passage downstream of each of said fuel metering restrictions, a valve for varying said outlet means from each of said fuel nozzles having metered openings constantly in communication with said engine, and means for varying the area of said outlet means by valve movement including means for operating said valves in an opening direction in response to the differential in pressure between said separate air passages.

13. In combination, an engine, an air induction system for said engine and a fuel injection system for supplying fuel to a plurality of nozzles located in said air induction system adjacent the air intake ports of the engine, comprising a source of fuel supply for the engine, a fuel passage between said source of fuel supply and each of said nozzles, a plurality of fuel metering restrictions in said passage, each between said source of fuel supply and one of said nozzles, a source of air under pressure, separate air passages connecting said source of air under pressure with said fuel passage at separate locations respectively upstream and downstream of each of said fuel metering restrictions, means to uniformly control the air pressure in said separate passages leading downstream of said fuel metering restrictions to control the pressure differential across each of said fuel metering restrictions and thereby the total rate of fuel flow to said engine from said source of fuel supply and maintain equal rates of flow past each of said fuel metering restrictions, means responsive to changes in throttle position and engine speed for regulating the action of said control means, means forming an outlet in each of said fuel nozzles for receiving air from said separate air passages connecting with said source of air under pressure and fuel from said fuel metering restrictions, and means in each of said nozzles responsive to fuel pressure upstream of said fuel metering restrictions and air pressure downstream of each of said fuel metering restrictions for varying the area of said fuel metering restrictions and the outlet from each of said nozzles.

14. In combination, an engine, an air induction system for said engine and a fuel injection system for supplying fuel to a plurality of nozzles located in said induction system adjacent the air intake ports of said engine comprising a source of fuel supply for said engine, a fuel passage between said source of fuel supply and each of said nozzles, a fuel metering restriction in said fuel passage between said source of fuel supply and each of said nozzles, a source of air under pressure, separate air passages connecting said source of air under pressure

with said fuel passage at separate locations respectively upstream and downstream of each of said fuel metering restrictions, means to uniformly control the air pressure in said separate air passages to control the pressure differential across each of said fuel metering restrictions and thereby the total rate of fuel flow to said engine from said source of fuel and maintain equal rates of flow past each of said fuel metering restrictions including a valve in each of said separate air passages downstream of each of said fuel metering restrictions, means responsive to air pressure downstream of each of said valves for urging said valves toward a closed position, an hydraulic circuit having an output pressure variable in response to changes in throttle position and engine speed, and means responsive to changes in hydraulic pressure in said hydraulic circuit for operating said valves.

15. A system for maintaining a proportional flow of air and fuel suitable for combustion comprising an air flow passage with means for varying the air flow through said passage, a hydraulic circuit, means in said circuit for generating an output pressure, means in said circuit movable with changes in air flow through said air passage for varying the output pressure in said circuit, a fuel passage including a supply of fuel and a fuel outlet opening into said air flow passage, and a pneumatic circuit including a source of air under pressure, an air pressure regulator controlled by the output pressure of said hydraulic circuit, and passages connecting said pneumatic circuit upstream and downstream of said regulator with said fuel passage for varying the fuel pressure head on the fuel in said fuel passage.

16. A system for maintaining a proportional flow of air and fuel suitable for combustion comprising an air flow passage with means for varying the air flow through said passage including a valve, a hydraulic circuit, means in said circuit for generating an output pressure, means in said circuit connected with said valve for varying the output pressure in said hydraulic circuit, a fuel passage including a supply of fuel and a fuel outlet opening into said air flow passage, and a pneumatic circuit including a source of air under pressure, an air pressure regulator controlled by the output pressure of said hydraulic circuit, and passages connecting said pneumatic circuit upstream and downstream of said regulator with said fuel passage for varying the fuel pressure head on the fuel in said fuel passage.

17. A system for maintaining a proportional flow of air and fuel suitable for combustion comprising an air passage with means for varying the air flow through said passage including a valve, pressure indicating means connected with said air passage, a hydraulic circuit, means in said circuit for generating an output pressure, means in said circuit connected with said pressure indicating means for varying the output pressure in said hydraulic circuit, a fuel passage, a supply of fuel connected with said fuel passage, a fuel outlet for said fuel passage opening into said air passage, a pneumatic circuit including a source of air under pressure, an air pressure regulator controlled by the output pressure of said hydraulic circuit, and passages connecting said pneumatic circuit upstream and downstream of said air pressure regulator with said fuel passage for varying the fuel pressure head on the fuel in said fuel passage.

18. In combination, an engine, an air induction system for said engine having a throttle, and a fuel injection system for supplying fuel to a plurality of nozzles located in said air induction system, comprising a source of fuel under pressure, fuel passages between said source of fuel under pressure and each of said fuel nozzles, a fuel metering restriction having the same fuel flow characteristics in each of said fuel passages, a source of air under positive pump pressure, air passages connecting said source of air under pressure with said nozzles downstream of said fuel metering restriction, means to uniformly control the air pressure in said air passages to

control the pressure differential across said fuel metering restrictions and thereby the total rate of fuel flow to said engine from said source of fuel under pressure and maintain equal rates of flow past each of said fuel metering restrictions, and means responsive to throttle opening and engine speed for regulating the action of said control means.

19. In a fuel metering device for an internal combustion engine having a throttle controlled air intake with branches extending to the engine combustion chambers, the combination of a system for maintaining the flow of fuel to the engine combustion chambers proportional to the flow of air to the engine comprising a source of fuel under a constant charging pressure, a plurality of passages connecting said source with said engine combustion chambers, a fixed metering orifice in each of said fuel passages all having substantially identical flow characteristics, a variable regulating pressure system including a source of air under pump pressure, means to vary the regulating pressure in said system in response to changes in the rate of air flow to the engine, and means for controlling the pressure downstream of each of said metering orifices connected to said regulating pressure system.

20. In an engine charge forming device having a throttle controlled air intake with branches leading to the combustion chambers of the engine, the combination of a source of fuel under charging pressure, a plurality of fuel passages connecting said source with the combustion chambers of the engine, a variable area fuel metering orifice in each of said fuel passages, a regulating pressure system, means for generating a regulating pressure in said system which varies in response to changes in the rate of air flow to the engine through said air intake, and a motor means to vary each of said variable fuel metering orifices operated in response to the difference between said charging pressure and said regulating pressure.

21. In an engine charge forming device for an internal combustion engine having a throttle controlled air intake with branches extending to the separate combustion chambers of the engine, the combination of a source of fuel under charging pressure, a fuel nozzle discharging into each of the combustion chambers of the engine, separate fuel passages connecting said source of fuel under pressure and each of said fuel nozzles, a variable metering restriction between the source of fuel under pressure and each of said nozzles, a motor means for operating each of said variable metering restrictions, a source of air under pressure connected to each of said fuel passages downstream of the metering restriction therein, means for varying the air pressure from said source in response to changes in the rate of air flow to the engine, and means for operating said motor means

for varying the area of each fuel metering restriction in response to change in the differential between fuel charging pressure and air pressure.

22. In a fuel metering device for an internal combustion engine having a throttle controlled air intake with branches extending to the combustion chambers of the engine, the combination of a fuel pump, a fuel bowl supplied from said pump, a float valve for controlling the fuel level in said bowl, a plurality of fuel nozzles located in said branches, fuel passage means connecting said bowl and said nozzles, a fuel metering device for controlling the fuel discharged from each nozzle, means for charging said fuel bowl with air under positive pressure, air passage means connected with each of said fuel passage means downstream of each of said fuel metering devices, and means responsive to variations in the rate of air flow to the engine past said throttle for controlling the differential between air pressure in said fuel bowl and in said air passage means.

23. In an engine charge forming device, the combination comprising an intake manifold having branches connected with the combustion chambers of the engine, a throttle valve in said manifold, a regulating fluid pressure system, means for controlling the pressure in said regulating pressure system, means responsive to variations in engine speed and throttle opening for operating said control means in said system, a source of fuel, a fuel pump supplied from said source, a plurality of fuel nozzles located in said branches, branch fuel passages extending between said pump and said nozzles, fuel metering devices for restricting the rate of fuel flow through each of said branches, means for varying the fuel pressure downstream of said metering devices, and a connection between said means for varying the fuel pressure and said regulating system.

24. In an engine charge forming device, the combination comprising an intake manifold having branches connected with the combustion chambers of the engine, a throttle valve in said manifold, a regulating fluid pressure system, means for generating a pressure in said regulating pressure system, means responsive to variations in engine speed and throttle opening for controlling the pressure in said regulating pressure system, a source of fuel, a fuel pump supplied from said source, open fuel nozzles in said branches, branch fuel passages between said pump and said nozzles, a plurality of fuel metering devices in said fuel passages, means for varying the opening in said open fuel nozzles, and separate connections from said regulating system and said fuel pump to operate said means to vary the fuel nozzle opening.

No references cited.