

[75] Inventor: **Harold Ernest Jackson**, Plympton St.
Mary, England

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[58] **Field of Search**..... 123/119, 139.17,
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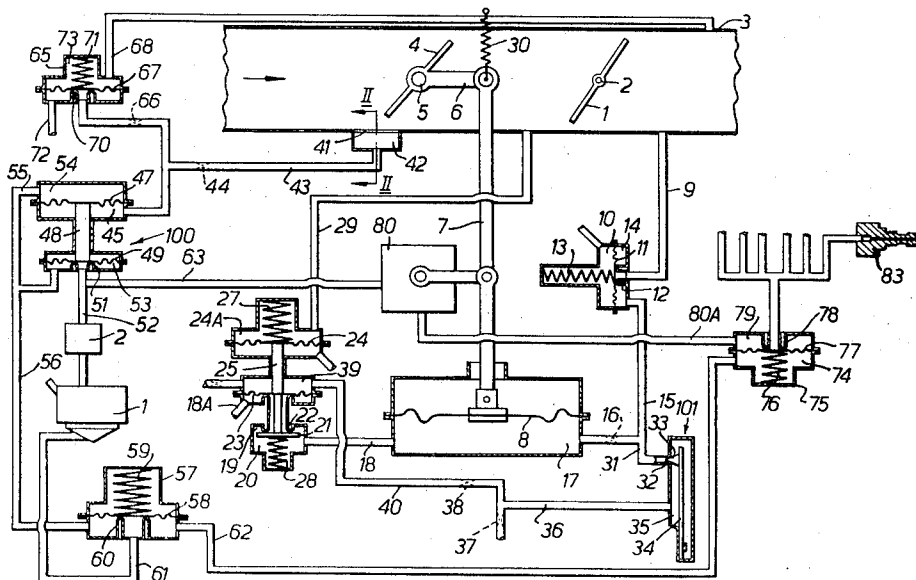
Assistant Examiner—Cort R. Flint

Attorney—Holcombe, Wetherill & Brisebois

[57] **ABSTRACT**

A fuel injection system for an internal combustion engine, including a fuel metering device and/or fuel pressurizing device. The or each device operates in response to adjustment of an air valve located in the engine air intake conduit (for example, upstream of the throttle valve), such adjustment being effected by a control mechanism in the following manner. The air valve produces a control pressure differential in the air intake conduit, which is sensed by the control mechanism. Any change in the pressure differential from a predetermined control valve (caused, for example, by an increase in engine air intake) causes the control mechanism to adjust the air pressure in an air pressure control circuit to which the air valve is connected and thereby adjust the position of the air valve to return the control pressure differential to the predetermined control value. Adjustment of the air valve is accompanied by a change in the fuel flow or pressure of fuel flow to the fuel injector devices.

28 Claims, 10 Drawing Figures



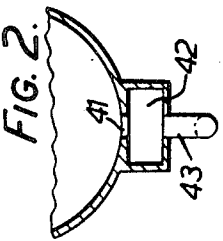
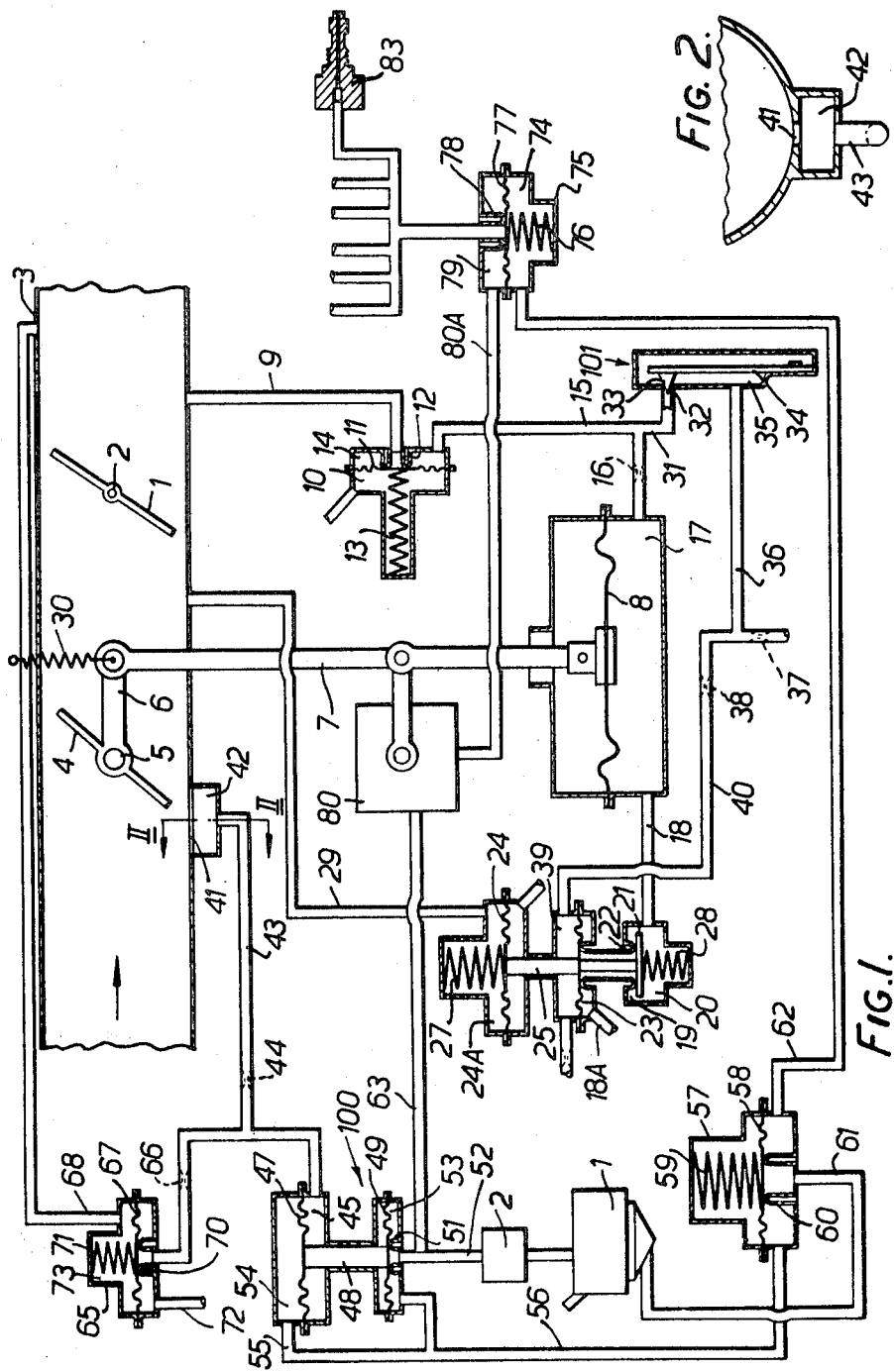
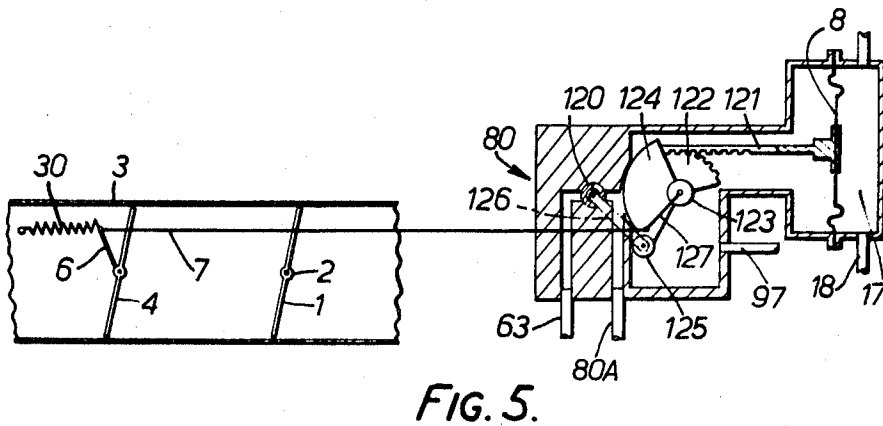
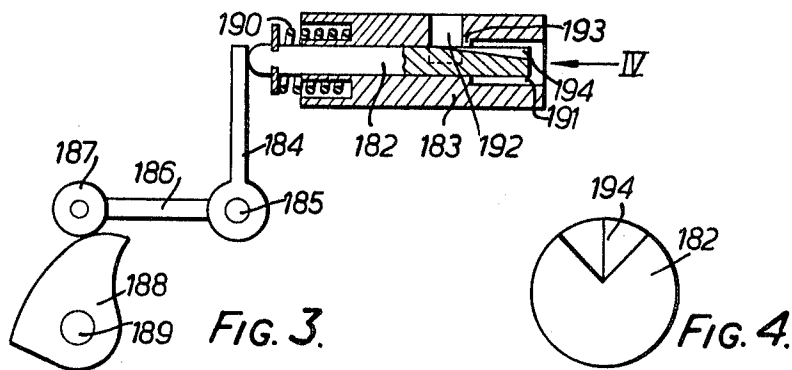
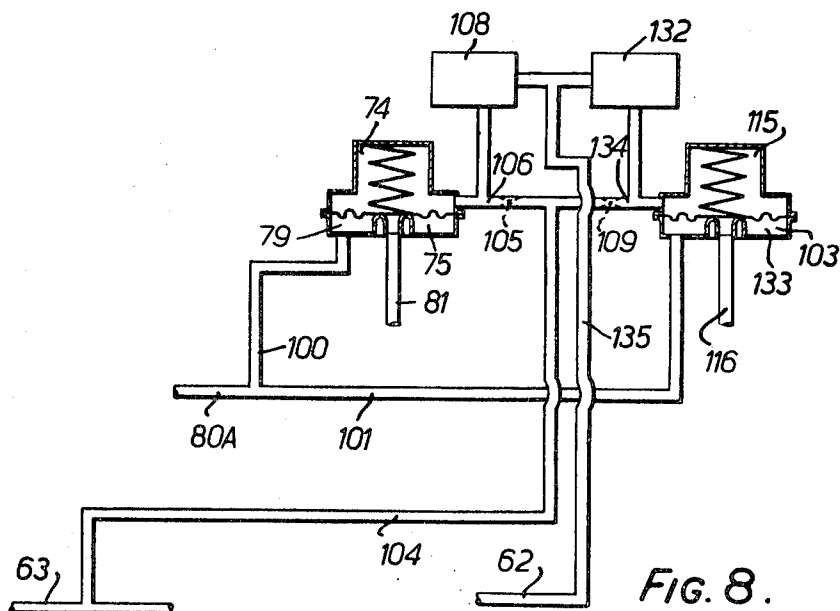
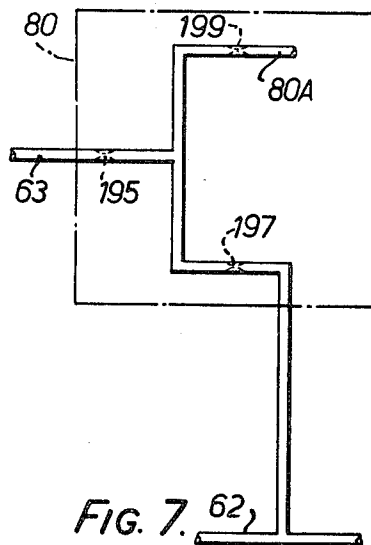
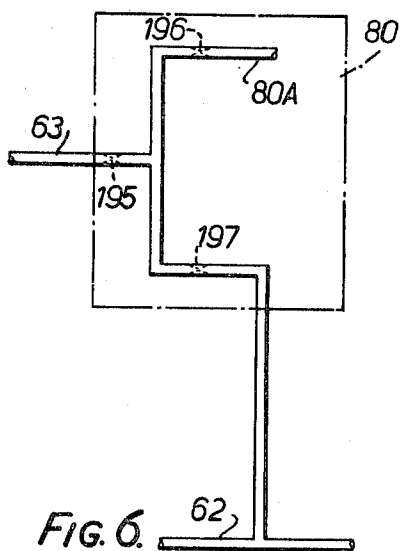
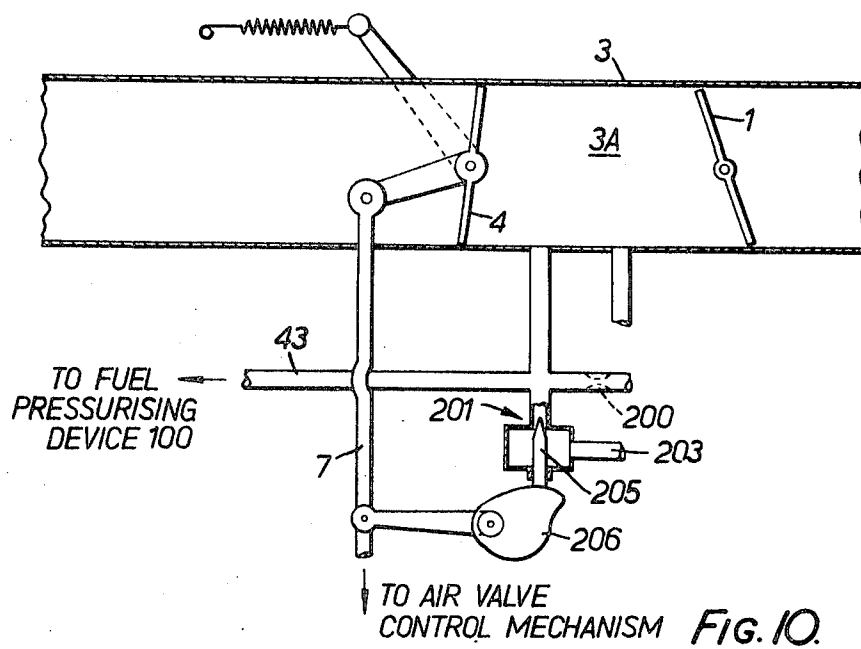
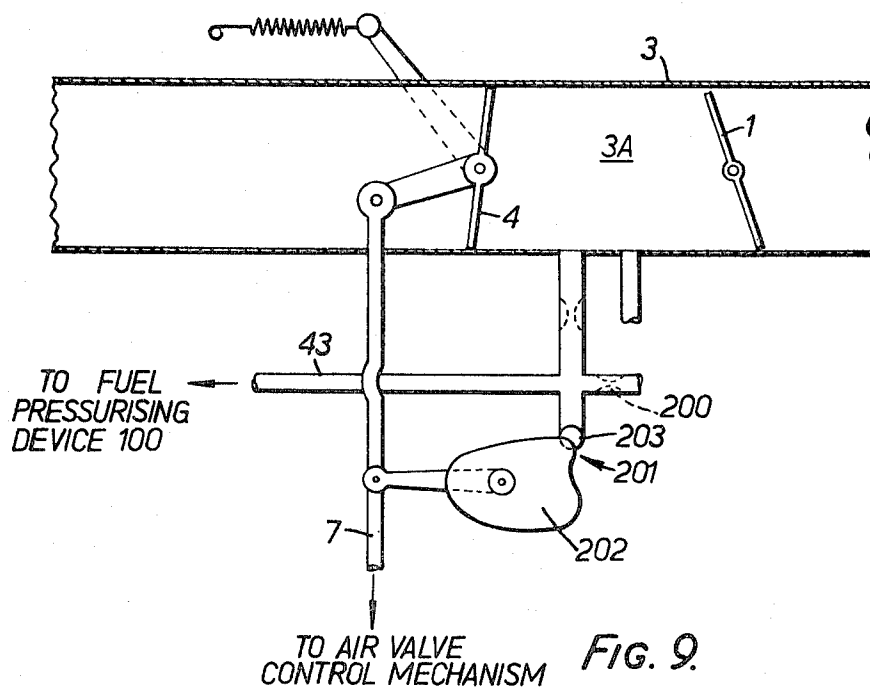


FIG. 1.

INVENTOR
BY *Jackson, Harold E*
ATTORNEY







FUEL INJECTION SYSTEMS

This is a continuation, of application Ser. No. 31,315, filed Apr. 23, 1970, now abandoned.

This invention relates to fuel injection systems for internal combustion engines.

The invention provides a fuel injection system for an internal combustion engine, including a fuel flow path, at least one fuel injector device connected to receive fuel from the flow path, and a fuel metering device connected in the flow path and operable to vary fuel flow to the injector device(s), in response to adjustment of an air valve which is located in the engine air supply path to produce a control pressure differential over a portion of the air supply path, the air valve being adjustable to vary the control pressure differential in response to variation in the air pressure in an air control circuit, the system also including an air valve mechanism operable in response to a value of control pressure differential other than a predetermined value to vary the pressure in the air control circuit and thereby adjust the air valve to maintain the control pressure differential substantially constant at the said predetermined value. The system may also include a fuel pressurizing device connected in the flow path and operable, in response to adjustment of the air valve, to vary the pressure at which fuel flows to the injector device(s).

The invention also provides a fuel injection system for an internal combustion engine, including a fuel flow path, at least one fuel injector device connected to receive fuel from the flow path, and a fuel pressurizing device connected in the flow path and operable to vary the pressure at which fuel flows to the injector device(s), in response to adjustment of an air valve which is located in the engine air supply path to produce a control pressure differential over a portion of the air supply path, the air valve being adjustable to vary the control pressure differential in response to variation in the air pressure in an air control circuit, the system also including an air valve mechanism operable in response to a value of control pressure differential other than a predetermined value to vary the pressure in the air control circuit and thereby adjust the air valve to maintain the control pressure differential substantially constant at the said predetermined value.

The fuel pressurizing device may be a pressure-responsive device exposed to the control pressure differential to an extent which varies with adjustment of the air valve. The pressurizing device may, for example, be operable to by-pass fuel from the flow path in dependence on the adjustment of the air valve, the system including means operable to supply fuel to the flow path in excess of the engine operating requirements.

The air valve may be located in the engine air supply path upstream of the customary throttle valve.

The system may include a mixture valve operable to admit atmospheric air to the control chamber to adjust the air valve independently of the air valve mechanism. The mixture valve operates to vary the fuel/air mixture supplied to the engine and may be responsive to a selected temperature, such as the temperature of the engine to ensure, for example, that the engine receives a richer fuel/air mixture when cold. In an embodiment of the invention described herein, the mixture valve is operable to adjust the air supply to the engine simultaneously with adjustment of the air valve to provide the engine with greater amounts of both fuel and air.

When the system includes a fuel pressurizing device as defined above, it may also include a fuel pressure adjustment mechanism by which the pressurizing device can be operated independently of the air valve. The pressure adjustment mechanism may be responsive to engine air intake, as represented by, for example, air pressure in the engine air supply path downstream of the customary throttle valve. The adjustment mechanism may, for example, be responsive to the engine air intake condition which indicates that the engine is developing maximum power, to cause operation of the pressurizing device to increase fuel pressure.

A system in accordance with the invention may be employed in conjunction with an engine having a dual inlet manifold arrangement. To this end, the system may include at least two fuel injector devices each connected to receive fuel from the fuel flow path, and each having a respective fuel pressure responsive injector control valve exposed to fuel pressure in the flow path and operable to permit fuel flow to the injector device, and a respective control device operable in response to an engine operating parameter to adjust the injector control valve from an inoperative state in which fuel pressure in the flow path is insufficient to operate the injector control valve to an operative state in which fuel pressure in the flow path is sufficient to operate the injector control valve.

When the system includes a fuel metering device, this may include a variable metering orifice which is connected in the fuel flow path to supply fuel to the injector device(s) and the area of which is adjustable in response to adjustment of the air valve. Alternatively the fuel metering device may include a variable metering orifice which is connected in the fuel flow path to by-pass fuel from the injector device(s) and the area of which is adjustable in response to adjustment of the air valve.

The present invention also provides a fluid flow control valve including a valve member located within and axially movable relative to a sleeve member, one of the said members including a groove which extends in the axial direction and the cross-sectional area of which varies in that direction, the groove cooperating with a portion of the other of the said members to define a metering orifice the area of which is variable by relative axial movement between the valve member and the sleeve member. The groove may have a V-shaped cross-section with the depth of the groove varying in the axial direction.

By way of example, fuel injection systems constructed in accordance with the invention will be described with reference to the accompanying drawings, of which:

FIG. 1 is a diagram of a system constructed in accordance with the invention;

FIG. 2 is a view on the line II—II of FIG. 1;

FIG. 3 is a diagrammatic illustration of a control valve suitable for use in the system shown in FIG. 1;

FIG. 4 is a view, on an enlarged scale, of part of FIG. 3 in the direction of the arrow IV;

FIG. 5 illustrates a suitable arrangement of certain of the components of the system shown in FIG. 3, and

FIGS. 6 to 10 illustrate modifications of the system shown in FIG. 1.

In the system shown in FIG. 1, fuel is drawn from a tank 1 and supplied by any suitable form of pump 2 to a supply conduit 52. Fuel passes from the conduit 52

to a further supply conduit 63 at a pressure determined by a control valve mechanism 100, excess fuel being returned, via a chamber 53 in the mechanism 100, a conduit 56, a relief valve 57 and a conduit 61 to the tank. The supply conduit 63 leads to a metering valve 80 which supplies fuel, via a conduit 80A to a distributor unit 75 from which the fuel injector nozzles 83 are fed.

As mentioned above, the valve 100 controls the pressure at which fuel is supplied to the metering valve 80, this control being effected, as will be described below, in dependence on the engine air intake. The metering valve 80 controls the amount of fuel supplied to the injector nozzles, this control also being effected, as will be described below, on the engine air intake.

The system shown in FIG. 1 also includes an ambient temperature responsive valve 101 operable to provide an enriched fuel/air ratio when the engine is cold; and a full power enrichment valve 65 operable, at any speed, to provide an enriched fuel/air ratio when the engine is developing maximum power. These components will also be described below.

The control mechanism of the metering valve 80 will first be described. Control of the valve 80 is effected by a servomechanism in dependence, as mentioned above, on engine air intake: more particularly control is effected by a servomechanism which operates to maintain a constant pressure difference across a variable restrictor located in the engine air intake path.

In FIG. 1, the engine air intake conduit is indicated by the reference numeral 3 and feeds air to the engine in the direction left to right as seen in the drawing. The conduit 3 includes the customary throttle valve 1 which is mounted on a spindle 2 extending across the conduit 3 and which is manually operated in a conventional manner. The conduit 3 also includes, upstream of the throttle valve 1, an air valve 4 which is mounted on a spindle 5 and which is biased towards a closed position by a spring 30. The air valve 4 is operated through a lever 6 and a control lever 7 which is coupled to a vacuum motor diaphragm 8. The control lever 7 is also coupled to the metering valve 80.

The vacuum motor diaphragm 8 forms one wall of a chamber 17 which is connected by a conduit 18 to a signal valve 19 which controls communication between the chamber 17 and atmosphere. The chamber 17 is also connected to the engine side of the throttle valve 1 via a conduit 9, a constant vacuum valve 10, and a conduit 15 including a restrictor 16.

The signal valve 19 includes a plate valve member 21 which is biased by a spring 28 towards a position in which the valve member 21 co-acts with a seat 22 to close the chamber 20 and cut-off communication between the vacuum motor chamber 17 and atmosphere via a conduit 18A in the signal valve. The valve member 21 is coupled, through a rod 25 to a diaphragm 24 which is biased by a spring 27. The spring 27 acts in opposition to, and is stronger than, the spring 28, and is located in a chamber 24A which is defined by the diaphragm 24 and which is connected, by a conduit 29, to the engine air intake conduit 3 at a point intermediate the air valve 4 and the throttle valve 1.

The signal valve also includes a further chamber 39 including a diaphragm 23 connected between the plate valve member 21 and the diaphragm 24. The purpose of this further chamber 39 and diaphragm 23 will be described below.

The constant vacuum valve 10 includes a diaphragm 11 defining a chamber 14 which is connected to the vacuum motor chamber 17 through the conduit 15 and restrictor 16. The diaphragm 11 has a seating 12, but is urged away from the seating by a spring 13, to allow air to pass through the conduit 15 and chamber 14 to the engine air intake conduit 3 via the vacuum motor chamber 17 or (as will be described below) the ambient temperature responsive valve 101. The passage of air through chamber 14 creates a depression in chamber 14 but, if the depression exceeds a value determined by the spring (say, 1 inch of mercury) the diaphragm 11 approaches the seating 12 and limits the amount of air passing through the unit. Thus a substantially constant vacuum is maintained in the chamber 14 of valve 10.

Operation of the metering valve control mechanism is as follows:

When the throttle valve 1 is opened (the air valve 4 being in the closed position) there is created a depression in the conduit 3 between the valves 4 and 1, and hence in the conduit 29, which draws up the diaphragm 24 and seats the valve member 21. This in turn creates a depression in vacuum motor chamber 17 via conduit 9, valve 10 and conduit 15, which draws down the vacuum motor diaphragm 8 and so opens air valve 4. The opening of air valve 4 reduces the depression in conduit 3 and hence in conduit 29 and allows the diaphragms 24 to descend slightly and so to unseat valve member 21 and allow air to leak from atmosphere via conduit 18A chamber 20 and conduit 18 into chamber 17 and reduce the effective force which was opening air valve 4. In this manner, air valve 4 takes up a position where the depression in the portion of conduit 3 between the air valve 4 and the throttle valve 1 is a substantially constant value determined by the setting of signal valve 19. Any alteration in the engine air intake will be accompanied by an adjustment in the position of the air valve 4 and hence in the setting of the metering valve 80 to which the air valve is coupled through control lever 7. The metering valve will be described in greater detail below, and for the present it is sufficient to state that, as the air valve 4 opens, more fuel is fed, by the metering valve to the injector devices 83. It is to be noted that friction and other causes of stiffness in the connections between diaphragm 8 and air valve 4 including the stiffness of the diaphragm 8 are in no way effective in altering by any substantial amount the constant depression in conduit 3.

It will be appreciated from the above that the diaphragm 23 in the signal valve 19 is not an essential component in control of the metering valve 80 in dependence on engine air intake, and could be omitted. The diaphragm 23 is however part of the means for supplying a richer fuel/air mixture when the engine is cold, as will now be described. A conduit 31 extending from conduit 15 passes to an orifice 32 in ambient temperature responsive valve 101, which forms a seating for a shaped pin 33 mounted on a strip of material 34 which bends when warmed to cause the pin 33 to close orifice 32. Orifice 32 communicates with a chamber 35 in the ambient temperature responsive valve, from which a conduit 36 leads via a restrictor 38 and conduit 40 to the chamber 39 containing diaphragm 23 in the signal valve 19. Conduit 36 also has a branch which is open to atmosphere via a restrictor 37. When the engine is cold, strip 34 in ambient temperature responsive

valve 101 is bent in a clockwise direction taking pin 33 partly or wholly out of orifice 32. The controlled depression from chamber 14 of the constant vacuum valve 10 draws air through the orifice 32 from the atmosphere via restrictor 37, and also via chamber 39 which is open to atmosphere via a restrictor. There will now be a depression in chamber 39 which, acting on diaphragm 23, will assist diaphragm 24 of the signal valve 19 in lifting under the influence of the depression in chamber 24A. As a result, the air valve 4 is constrained, by the vacuum motor diaphragm 8, to open until a new equilibrium position is reached and, as a result of the further opening of air valve 4, the fuel metering unit 80 allows more fuel to be delivered to the engine.

The depression in chamber 35 also as mentioned above, causes air to be drawn from the atmosphere through restrictor 37 so that the engine is drawing, in total, extra fuel and air. The components of the system are so chosen that proportionally more extra fuel than extra air is provided so that when the engine is cold it is fed with a richer mixture. When the engine becomes warm, the strip 34 of valve 101 bends to close orifice 32 and cut-off air flow through the conduit 31.

It will be appreciated that the fuel enrichment valve 101, and diaphragm 23 are not essential to the functioning of the metering valve control mechanism and could be omitted.

The fuel pressure control mechanism 100 will now be described, the effect of this mechanism being to increase the pressure of fuel supplied to the metering valve 80 as the air flow through conduit 3 increases. To this end there is provided in the conduit 3 a closed end slot 41 which communicates with a chamber 42 from which a conduit 43 extends (see also FIG. 2). Conduit 43 leads via a restrictor 44 to chamber 45 in the control mechanism 100. A diaphragm 47 bounding chamber 45 is coupled by a pin 48 to a diaphragm 49 which on its underside co-acts with a valve seat 51 to control fuel flow from the supply conduit 52 into the chamber 53 of the pressure control mechanism 100. Chamber 53 is connected, as mentioned above, to the fuel supply tank 1, via conduit 56 and relief valve 57, and is also connected to a chamber 54 (on the opposite side of diaphragm 47 to the chamber 45) by a conduit 55. Relief valve 57 includes a diaphragm 58 loaded by spring 59 against a valve seat 60 which communicates to the conduit 61 which leads excess fuel back to the fuel tank 1 as mentioned above. The action of the relief valve 57 is to maintain a substantially constant pressure in conduit 56 and, therefore, in chambers 53 and 54 of the pressure control mechanism 100.

When the engine is not running, atmospheric pressure exists throughout the engine air intake conduit 3 and hence in chamber 45 of the pressure control mechanism 100. There is then no force urging the diaphragm 49 towards the seat 51, and the fuel pressure in supply conduits 52 and 63 to the metering valve 80 is the same as fuel pressure in the chamber 53 of the pressure control mechanism 100. When the engine is running with its air consumption at a minimum (which is in the idling mode of operation) the position of the air valve 4 is such that the right hand end of slot 41 lies just on the right hand side of air valve 4 (this position being shown in FIG. 1). As a result a small proportion of the constant depression developed in conduit 3 between the air valve 4 and the throttle valve 1 is applied to conduit 43.

Vacuum valve 65 (which will be described below) is normally open and, for the present, it is sufficient to state that, under these circumstances, atmospheric air can pass through the valve 65 and into the conduit 43 so weakening the depression signal applied to the diaphragm 47 of pressure control mechanism 100. The weakened depression signal on diaphragm 47, acting through rod 48, urges diaphragm 49 towards the valve seat 51. As a result the pressure in conduits 52 and 63 rises until equilibrium is restored. As the air consumption of the engine increases, air valve 4 opens further and, in doing so, exposes more of the length of the slot 41 to the constant depression between valves 4 and 1 and so increases the fuel pressure in conduit 63. During acceleration, that is to say when throttle valve 1 is suddenly opened, the depression between the air valve 4 and the throttle valve 1 rises suddenly. This increased depression is effective immediately, through diaphragm 47, to raise the fuel pressure in conduit 63.

It will be appreciated that use of this fuel pressurizing arrangement 100 is not restricted to system in which fuel metering is also controlled by the maintenance of a constant pressure drop in the air intake (i.e., the fuel pressurizing arrangement is not restricted to systems in which fuel metering is also controlled by the air valve 4). Similarly, use of the fuel metering control arrangement 8, 19 is also not restricted to systems in which fuel pressurization is controlled in the manner described above.

It has been stated above that vacuum valve 65 is normally open. The purpose and operation of this valve will now be described.

When the engine is running under part throttle conditions the fuel/air mixture has to be weak in order to operate with optimum fuel consumption and particularly in order to minimize the production of noxious gases in the form of carbon monoxide, oxides of nitrogen, and unburned hydrocarbons. On the other hand, when the engine is operated to produce its maximum power at any speed the fuel/air mixture must be considerably richer. It is not feasible to use the position of the air valve 4 to control the full power enrichment of the fuel air mixture because the position of the air valve at full power and low speed is identical with its position at part throttle at some higher speeds. However, the depression in conduit 3 on the engine side of the throttle valve 1 is an indication of the proportion of full power at which the engine is operating.

The vacuum valve 65 embodies a diaphragm 67 which is urged towards a valve seat 70 by a spring 71. When the diaphragm 67 is unseated, atmospheric air can pass, from a conduit 72 through the valve 65 and a restrictor 66 into the conduit 43 as mentioned above. A chamber 73 above the diaphragm is exposed through a conduit 68 to the vacuum in conduit 3 on the engine side of throttle valve 1. The relative area of diaphragm 67 and strength of spring 71 are so selected that when a certain vacuum (say 1 inch of mercury) exists in chamber 73, the diaphragm 67 closes with seat 70. As soon as the diaphragm closes on the seat leakage of atmospheric air from conduit 72, through the valve 65 and into conduit 43 ceases and the vacuum in conduit 43 is accordingly increased. The increased vacuum in conduit 43 acts on diaphragm 47 of the fuel pressure control mechanism 100 and, as a result, the fuel pressure in supply conduit 63 rises. It will be appreciated however, that the vacuum valve 65 is not essential to

the pressurization of fuel in conduit 63 and could be omitted.

In order to ensure that the fuel in the system remains liquid at all times even when the fuel temperature rises considerably above normal ambient temperatures it is desirable to maintain it at a pressure higher than atmospheric. It is for this reason that the relief valve 57 is introduced. It should be noted that, since chamber 53 of fuel pressure control mechanism 100 is connected to chamber 54 of the mechanism, the pressure raised by relief valve 57 has no effect on the operation of the control mechanism.

The excess fuel return conduit 56 from the pressure control mechanism 100 to the relief valve 57 also communicates with a conduit 62 which leads to a chamber 74 on one side of a diaphragm 77 in the distributor unit 75. Fuel from the metering unit 80 is supplied via the conduit 80A to a chamber 79 on the other side of the diaphragm 77 and a spring 76 in chamber 74 urges the diaphragm towards a seat 78 to cut-off communication between the chamber 79 and the injector devices 83. The pressure in chamber 74 is a constant being equal to the pressure raised by relief valve 57 plus a constant pressure due to the spring 76. Thus the fuel flow to the engine (which is through chamber 79) is unaffected by the pressure imposed on the fuel in conduit 63 by the relief valve 57. The distributor unit 75, as mentioned above, leads fuel to the injector nozzles 83 which introduce the fuel into the engine mixture induction system. After passing across the valve seat 78, the fuel is at low pressure, particularly under engine idling and low power conditions. In view of this, and to avoid fuel vaporization all conduits downstream of the distributor unit 75 are of small cross-section.

The above arrangement is advantageous in that it provides an enriched fuel/air mixture for the engine during sudden acceleration, as may be seen from the following example:

Suppose that the normal depression between valves 1 and 4 in conduit 3 is 1 inch Hg; that the resultant fuel pressure in supply conduit 63 is 10 p.s.i., that the substantially constant minimum pressure imposed by relief valve 57 is 15 p.s.i. and that the spring 76 imposes a substantially constant load equivalent to 2 p.s.i. Under steady conditions the fuel metering pressure is $10 + 15 - (15 + 2) = 8$ p.s.i.

On sudden acceleration, before the position of the air valve 4 has been adjusted, the depression between valves 1 and 4 may rise momentarily to 2 inches Hg. This in turn raises the fuel pressure in conduits 63 to 20 p.s.i. The metering pressure is now $20 + 15 - (15 + 2) = 18$ p.s.i. Thus, while the depression has changed in the ratio 2/1 the fuel metering pressure has changed in the ratio 2.25/1, providing enrichment during acceleration. When the air valve 4 has opened to restore the 1 inch Hg depression between valves 1 and 4, the fuel metering pressure reverts to its original value but the new position of the air valve 4 is accompanied by readjustment of the metering valve 80.

The spring in the fuel distributor also performs the secondary, but important, function of preventing fuel from being delivered to the injectors when the engine is not turning.

The fuel metering valve 80, which has not been described in detail may be of the type described in U.S. Pat. No. 3342449 in which a tubular valve member mounted in a close fitting sleeve can rotate relative to

the sleeve, the tubular member having in its round surface an elongated transversely extending V-slot which can register with an aperture in the sleeve to define a metering orifice, the area of which can be varied by relative rotation between the valve member and the sleeve. The tubular member, which may be closed at one end, can be connected to supply fluid to be metered to the orifice, or to receive metered fluid from the orifice. Alternatively, the V-slot may be formed in the sleeve and registrable with an aperture in the tubular member. The tubular member, which may be closed at one end, can be connected to supply fluid to be metered to the orifice or to receive metered fluid from the orifice. Alternatively, the metering valve may be of the type shown in FIGS. 3 and 4 of the accompanying drawings.

The metering valve shown in FIGS. 3 and 4 includes a pin-shaped valve member 182 located within a tubular sleeve 183. The valve member 182 is engaged at one end by a lever 184 which is rotatable with a spindle 185, and a further lever 186 which is also secured to the spindle 185 carries a roller 187 which cooperates with a cam 188 mounted on a spindle 189. The valve member 182 urged towards engagement with the lever 184 by a spring 190. At the other end of the valve member 182, a tapered slot 194 is formed which may have a V-shaped section as shown in FIG. 6, and the bore 191 of the tubular sleeve 183 surrounding this end of the valve member is enlarged. An aperture 192 is formed in the tubular sleeve 183 to define a projection 193 between the aperture 192 and the enlarged bore portion 191. The projection 193 cooperates with the tapered slot 194 in the valve member 182 to define a metering orifice the area of which varies according to the axial position of the valve member 182 relative to the sleeve 183. Suitable means (not shown) are provided to ensure that the valve member 182 cannot rotate relative to the sleeve 183.

When the metering valve shown in FIGS. 3 and 4 is employed in a system of the type shown in FIG. 1, the cam spindle 189 is coupled to the lever 7 of the control mechanism in such a manner that a change in the position of the air valve 4 is accompanied by rotation of the cam spindle 189 and hence by axial movement of the metering valve member 182. The metering orifice defined by the tapered slot 194 in the valve member 182, and the projection 193 in the sleeve 183 is connected between the fuel supply lines 63, 80A (see FIG. 1) so that fuel flow to the injector devices 83 is adjusted as the position of the air valve 4 varies.

It will be appreciated, however, that use of the metering valve shown in FIGS. 3 and 4 is not restricted to fuel injection systems of the type shown in FIG. 1, or even to fuel injection systems in general.

One suitable arrangement by which the metering valve 80 and the vacuum motor diaphragm 8 of the system shown in FIG. 1 can be coupled to the control lever 7 is illustrated in FIG. 5. This arrangement is shown as applied to a metering valve 80 of the type described in U.S. Pat. No. 3,342,449 but could readily be modified for application to, for example, a metering valve of the type shown in FIGS. 3 and 4. In the arrangement shown in FIG. 5, the vacuum motor diaphragm 8 carries a rack 121 which engages a pinion 122 mounted on a shaft 123. The shaft 123 also carries a cam 124 which bears upon a roller 125 coupled through an arm 126 to the valve member 120 of the metering valve 80. The valve

member 120 is a tubular member in which is defined a V-slot registrable with an aperture in a surrounding sleeve (not shown) to define a metering orifice the area of which can be varied by relative rotation between the valve member 120 and the surrounding sleeve. Also mounted on the shaft 123, but outside the metering valve unit 80 is a lever 127 coupled to the control lever 7. Movement of the diaphragm 8 causes rotation of the shaft 123 and hence adjustment of the air valve 4 through the levers 127 and 7, and also rotation of the valve member 120 through the cam 124 and roller 125. No precision is required in the rack and pinion arrangement 121, 122 since it is loaded in one direction by the spring 30 of the air valve 4.

The injector nozzles 83 of the system shown in FIG. 1, which are not shown in detail in the drawings, may be of a conventional open, air-bled type in which air is drawn into the nozzle through suitable apertures to effect atomization of fuel passing through the nozzle. Preferably, each nozzle includes a flow equalizing restrictor, for example a small diameter stainless steel tube through which the fuel passes, the purpose of these restrictors being to ensure equal fuel distribution between the nozzles.

The system shown in FIG. 1 is a continuous injection system. Continuous injection of fuel is, however, not an essential feature of systems in accordance with the invention: for example, a system incorporating a fuel pressure control mechanism of the type shown at 100 in FIG. 1 could employ intermittent fuel injection in the manner disclosed in my copending U.S. Pat. application No. 46,201 filed June 15, 1970.

Modifications of the system described above are illustrated in FIGS. 6 to 10. In the modification shown in FIG. 6, the fuel metering valve 80 includes two variable fuel metering orifices 196, 197 rather than only one metering orifice as in the metering valves described above. The valve also includes a fixed restrictor 195 through which fuel is fed from the fuel supply conduit 63 to the metering orifices 196, 197. The orifice 196 controls the passage of fuel from the conduit 63 to the conduit 80A and hence to the distributor unit 75 and injector nozzles 83, and the orifice 197 connects the supply conduit 63 to the conduit 62 which contains fuel at the substantially constant pressure determined by the relief valve 57. Both variable orifices 196, 197 are coupled to the control lever 7 of the air valve 4, the arrangement being such that as the air valve opens, so the orifice 196 is enlarged while the orifice 197 is reduced. The remainder of the system may be as shown in FIG. 1.

In the modification shown in FIG. 7, the metering valve 80 includes a fixed restrictor 195 and a variable orifice 197 as in the arrangement shown in FIG. 6, but the variable orifice 196 of FIG. 6 is replaced by a fixed orifice 199. The variable orifice 197 is coupled to the control lever 7 of the air valve 4 so that, as the air valve opens, the orifice 197 is reduced and less fuel is bypassed to the conduit 62 with the result that more fuel passes through the fixed orifice 199 to the distributor unit 75 and injector nozzles 83.

The modification shown in FIG. 8 illustrates the use of a system as shown in FIG. 1 in conjunction with a dual induction manifold arrangement of the type including a plurality of intake tubes connected to the engine inlet ports, a plurality of injector nozzles for introducing fuel into the intake tubes, a further intake tube

which is also connected to the engine inlet ports and an injection nozzle for introducing fuel into the further intake tube.

In the modification shown in FIG. 8, metered fuel from the conduit 80A (which corresponds to the conduit 80A in FIG. 1) is fed through conduit 100 to the chamber 79 of the distributor unit 75 from which, as in FIG. 1, fuel may pass to a set of injector devices (not shown) via a conduit 81. In this modification, fuel from conduit 80A is also fed through conduit 101 to a chamber 133 of a second similar distributor unit 103 from which fuel may pass, to a further injector device or set of injector devices (not shown) via a conduit 116. Fuel at the pressure in conduit 63 (see FIG. 1) is applied to chamber 74 of distributor unit 75 via conduits 104, 106 and restrictor 105 and is also applied to the corresponding chamber 115 of the second distributor unit 103 via conduits 104, 134 and restrictor 109. The conduits 106, 134 are connected to solenoid valves 108 and 132 respectively and the solenoid valves which are closed when not energized are connected, via a conduit 135 to the conduit 62 which contains fuel at the substantially constant pressure determined by the relief valve 57 (see FIG. 1).

When the valves 108, 132 are closed, the pressures on both sides of the diaphragms in the distributor units 75, 103 are equal, so that the diaphragms remain seated and no fuel passes to the engine via conduits 81 and 116. Suitable control means (not shown) cause energization of the solenoid valves 108, 132, independently, in dependence on a suitable engine operating parameter for example the position of the throttle valve 1 (see FIG. 1) or the vacuum in the air intake conduit 3 downstream of the throttle valve. When the solenoid valve 108 is energized, the pressure in chamber 74 of distributor unit 75 drops to the constant pressure in conduit 62. This constant pressure is lower than the pressure in conduit 80A so that the diaphragm of distributor unit 75 lifts and fuel is fed to the engine via conduit 81. Similarly, when the solenoid valve 132 is energized, fuel is fed to the engine via conduit 81.

The modifications shown in FIGS. 9 and 10 relate to the slot arrangement 41 shown in FIG. 1, through which the control depression between valves 1 and 4 in the air intake conduit 3 is applied, to a variable extent to the fuel pressurizing device 100. In the arrangement shown in FIG. 9, the reference numerals 1, 3, 4 and 7 indicate (as in FIG. 1) the throttle valve, the air intake conduit, the air valve and the air valve control lever respectively. The slot 41 shown in FIG. 1 is, however, omitted and the conduit 43 which leads to the fuel pressurizing device 100 (not shown) communicates with the air intake conduit 3 at a point between the valves 1 and 4.

The conduit 43 is vented to atmosphere through a fixed restrictor 200, and a variable restrictor 201 formed by a cam plate 202 cooperating with a vent 203 in the conduit. The cam plate 202 is coupled to the linkage 7 and is moveable by the linkage to vary the restrictor 201.

The pressure communicated to the fuel pressurizing device 100 through conduit 43 (and hence the pressure to which the engine fuel supply is raised) is determined by the degree of communication between the conduit 43 and atmosphere through the restrictor 201. Adjustment of the restrictor 201 accompanies adjustment of the position of the air valve 4 and this, in turn, depends

on engine air intake. The fuel supply is thus pressurized in dependence on engine air intake.

In the alternative arrangement shown in FIG. 10, the variable restrictor 201 is formed by a needle valve, movement of the needle valve member 205 to vary the restrictor 201 being controlled by a cam 206 coupled to the linkage 7. This arrangement functions in a similar manner to that shown in FIG. 9.

I claim:

1. A fuel injection system for an internal combustion engine, including

- a. a fuel flow path (1, 2, 63, 80A, 62, 61),
- b. at least one fuel injector device (83) connected to receive fuel from the flow path,
- c. a fuel metering device (80) connected in the flow path and operable to vary fuel flow to said one injector device,
- d. an air valve (4) located in the engine air supply path (3) to produce a control pressure differential over a portion of the air supply path, and
- e. a servomechanism operable to adjust the air valve to maintain said control pressure differential substantially constant at a single predetermined value under all engine operating conditions, said servomechanism comprising
 - i. an air pressure control circuit (18A, 18, 17, 15),
 - ii. air pressure responsive means (8) exposed to the pressure in the control circuit and connected to the air valve to adjust the air valve in response to variation in the air pressure in the control circuit, and
 - iii. a signal valve mechanism (24, 25, 21) including signal valve means (21) connected in the control circuit,

the signal valve mechanism being exposed to the control pressure differential in the said portion of the air supply path and connected to operate said signal valve means (21) in response to any variation in said control pressure differential from a predetermined value to produce a variation in the air pressure in the control circuit (17) and thereby adjust the air valve to return said control pressure differential to the said predetermined value under all engine operating conditions, the fuel metering device (80) being coupled to the air valve for adjustment in response to adjustment of the air valve.

2. A system as claimed in claim 1, including a fuel pressurizing device connected in the flow path and operable, in response to adjustment of the air valve, to vary the pressure at which fuel flows to said at least one injector device.

3. A system as claimed in claim 1, in which the air valve is located in the engine air supply path upstream of the throttle valve to produce the control pressure differential between the air valve and the throttle valve.

4. A system as claimed in claim 1, in which the air pressure-responsive means is exposed to the pressure in a control chamber in the air control circuit, the control chamber being coupled to a source which provides a constant vacuum throughout the engine operating range, and the signal valve means being operable to admit atmospheric air to the control circuit to produce a variation in the air pressure in the control chamber to adjust the air valve.

5. A system as claimed in claim 4, including a mixture valve operable to admit atmospheric air to the control

chamber to adjust the air valve independently of the signal valve mechanism.

6. A system as claimed in claim 5, in which the mixture valve is operable to adjust the air supply to the engine simultaneously with adjustment of the air valve.

7. A system as claimed in claim 5, in which the mixture valve is responsive to a selected temperature.

8. A system as claimed in claim 1, including at least two fuel injector devices each connected to receive fuel from the fuel flow path, and having respective fuel pressure responsive injector control valves each exposed to fuel pressure in the flow path and operable to permit fuel flow to the associated injector device, and respective control devices operable independently of each other in response to an engine operating parameter to adjust the associated injector control valve from an inoperative state in which a predetermined fuel pressure in the flow path is insufficient to operate the injector control valve to an operative state in which the said predetermined fuel pressure in the flow path is sufficient to operate the injector control valve.

9. A system as claimed in claim 1, in which the fuel metering device includes a variable metering orifice which is connected in the fuel flow path to supply fuel to said at least one injector device and the area of which is adjustable in response to adjustment of the air valve.

10. A system as claimed in claim 1, in which the fuel metering device includes a variable metering orifice which is connected in the fuel flow path to by-pass fuel from said at least one injector device and the area of which is adjustable in response to adjustment of the air valve.

11. A system as claimed in claim 1, in which the fuel metering device includes an elongated valve member located within and axially movable relative to a sleeve member, one of the said members including a groove which extends in the axial direction and the cross-sectional area of which varies in that direction, the groove cooperating with a portion of the other of the said members to define a metering orifice the area of which is variable by relative axial movement between the valve member and the sleeve member.

12. A system as claimed in claim 1, which is operable to discharge fuel continuously from said at least one injector device.

13. A fuel injection system for an internal combustion engine, including

- f. a fuel flow path (1, 2, 63, 80A, 62, 61),
- g. at least one fuel injector device (83) connected to receive fuel from the flow path,
- h. a fuel pressurizing device (100) connected in the flow path and operable to vary the pressure at which fuel flows to said at least one injector device,
- j. an air valve (4) located in the engine air supply path (3) to produce a control pressure differential over a portion of the air supply path, and
- k. a servomechanism operable to adjust the air valve to maintain said control pressure differential substantially constant at a single predetermined value under all engine operating conditions, said servomechanism comprising
 - iv. an air pressure control circuit (18A, 18, 17, 15),
 - v. air pressure responsive means (8) exposed to the pressure in the control circuit and connected to the air valve to adjust the air valve in response to

variation in the air pressure in the control circuit, and

vi. a signal valve mechanism (24, 25, 21) including signal valve means (21) connected in the control circuit,

the signal valve mechanism being exposed to the control pressure differential in the said portion of the air supply path and connected to operate said signal valve means (21) in response to any variation in the control pressure differential from a predetermined value to produce a variation in the air pressure in the control circuit (17) and thereby adjust the air valve to return said control pressure differential to the said predetermined value under all engine operating conditions, the fuel pressurizing device (100) being responsive to a pressure which varies with the position of the air valve whereby the pressurizing device operates in response to adjustment of the air valve.

14. A system as claimed in claim 13, including means operable to supply fuel to the fuel flow path in excess of the engine operating requirements, the pressurizing device being operable to by-pass fuel from the flow path in dependence on the adjustment of the air valve.

15. A system as claimed in claim 13, in which the air valve is located in the engine air supply path upstream of the throttle valve to produce the control pressure differential between the air valve and the throttle valve.

16. A system as claimed in claim 13, in which the fuel pressurizing device communicates through a conduit with a slot which extends along the engine air supply path in the region of the control pressure differential and adjacent the air valve whereby the length of the slot exposed to the control pressure differential is dependent on the adjustment of the air valve.

17. A system as claimed in claim 13, in which the fuel pressurizing device communicates with the control pressure differential region of the engine air supply path through a conduit which is vented to atmosphere through a variable restrictor which is adjustable by operation of the signal valve mechanism.

18. A system as claimed in claim 14, including means operable to maintain a substantially constant pressure in the fuel by-pass path of the pressurizing device throughout the engine operating range, which substantially constant pressure is sufficient to prevent fuel vaporization.

19. A system as claimed in claim 18, in which the fuel flow path is connected to said at least one injector device through a distributor unit including a pressure-responsive member biased, by a resilient member and fuel at the said substantially constant pressure, to a closed position to prevent fuel flow to said at least one injector device and movable against the bias to an open

position by fuel pressure in the fuel flow path.

20. A system as claimed in claim 16, including a fuel pressure adjustment mechanism operable to admit atmospheric air to the conduit connecting the fuel pressurizing device to the control pressure differential region to operate the pressurizing device independently of the air valve.

21. A system as claimed in claim 20, in which the fuel pressure adjustment mechanism is responsive to engine air intake and operable in response to an engine air intake of a predetermined value.

22. A system as claimed in claim 21, in which the fuel pressure adjustment mechanism communicates with the engine air supply path downstream of the throttle valve.

23. A system as claimed in claim 13 including at least two fuel injector devices each connected to receive fuel from the fuel flow path, and having respective fuel pressure responsive injector control valves each exposed to fuel pressure in the flow path and operable to permit fuel flow to the associated injector device, and respective control devices operable independently of each other in response to an engine operating parameter to adjust the associated injector control valve from an inoperative state in which a predetermined fuel pressure in the flow path is insufficient to operate the injector control valve to an operative state in which the said predetermined fuel pressure in the flow path is sufficient to operate the injector control valve.

24. A system as claimed in claim 13, which is operable to discharge fuel continuously from said at least one injector device.

25. A valve as claimed in claim 1, in which the groove has a V-shaped cross-section, the depth of the groove varying in the axial direction.

26. A valve as claimed in claim 25, in which the groove is formed in the valve member.

27. A valve as claimed in claim 25, in which the sleeve member is an open-ended tubular member and the metering orifice is defined in a fluid flow path between the open end of the tubular member and an aperture in the wall of the tubular member.

28. A system as claimed in claim 13, in which the air pressure-responsive means is exposed to the pressure in a control chamber in the air control circuit, the control chamber being coupled to a source which provides a constant vacuum throughout the engine operating range, and the signal valve means being operable to admit atmospheric air to the control circuit to produce a variation in the air pressure in the control chamber to adjust the air valve.

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