

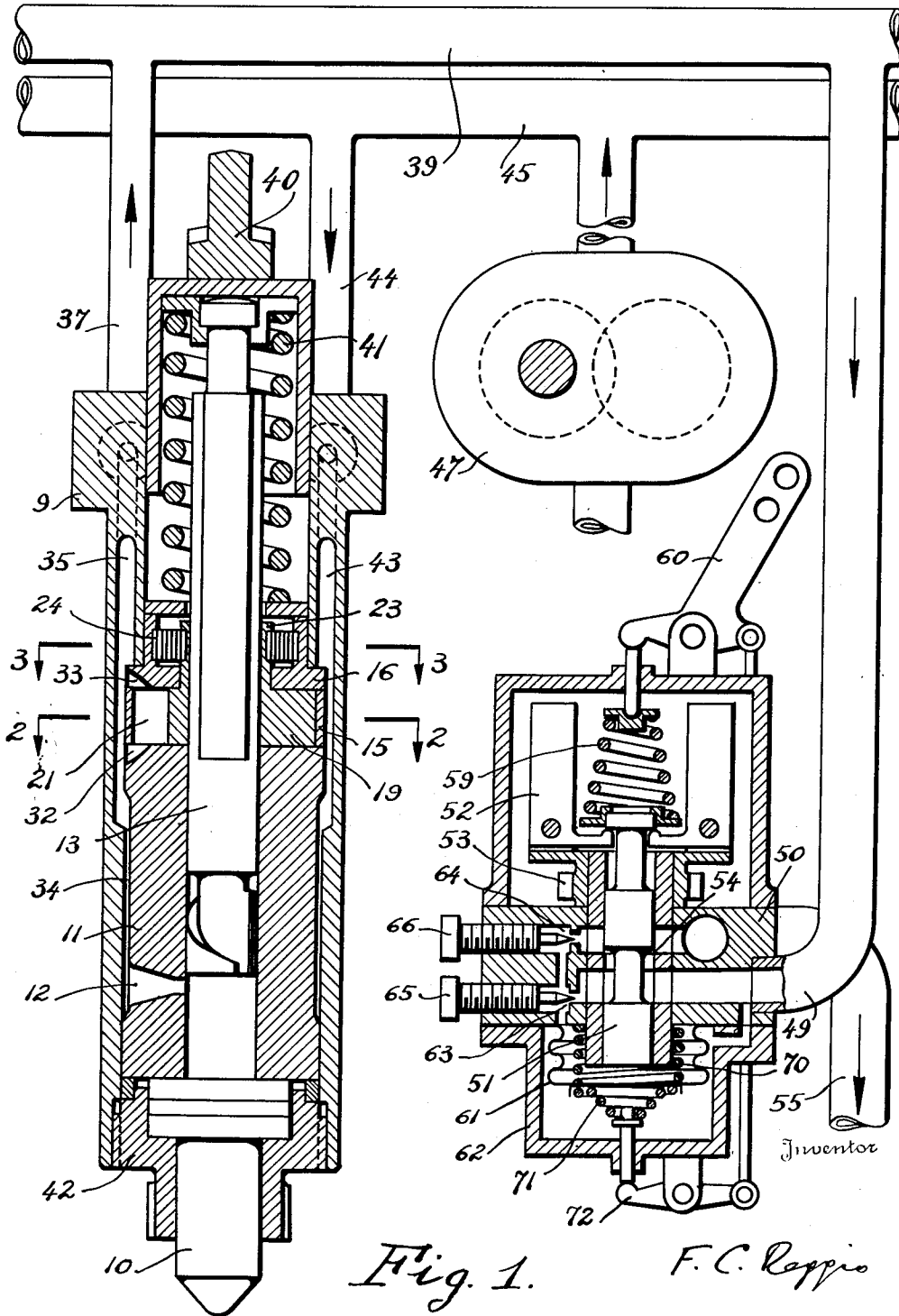
Dec. 11, 1962

F. C. REGGIO
FUEL SUPPLY SYSTEM

3,067,581

Filed Nov. 4, 1943

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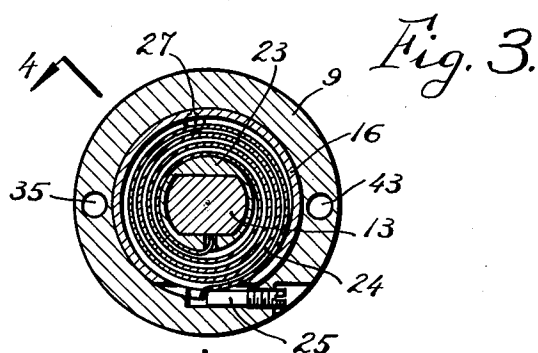
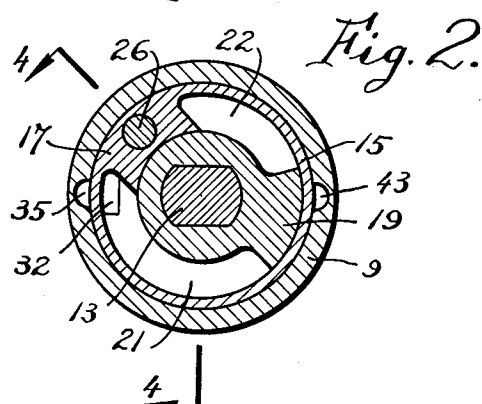
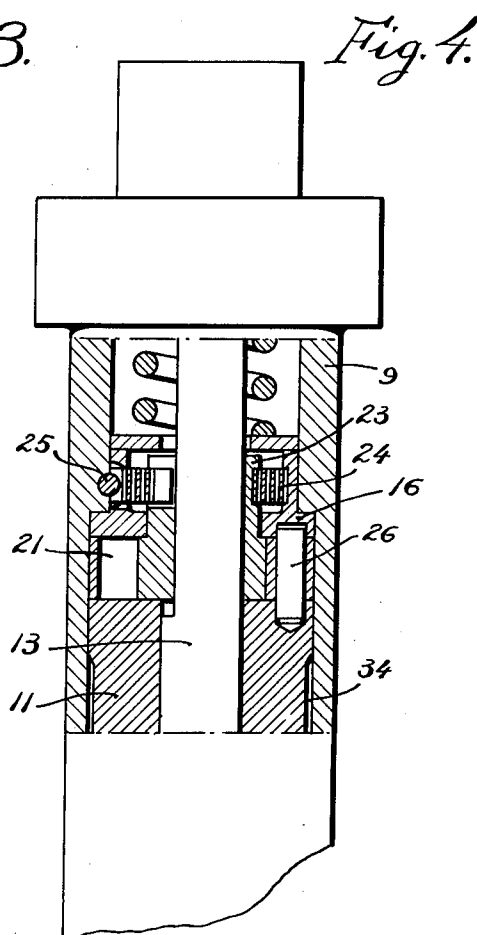
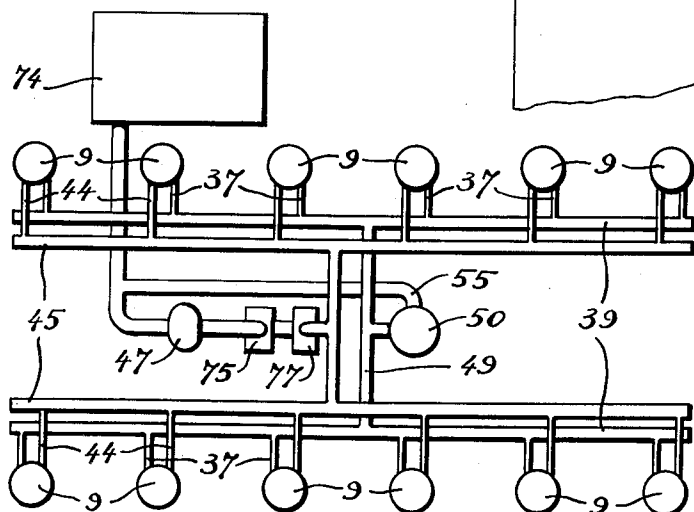
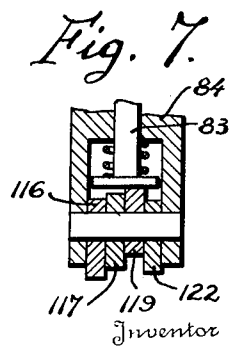
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F. C. REGGIO
FUEL SUPPLY SYSTEM

3,067,581

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F. C. Reggio

Dec. 11, 1962

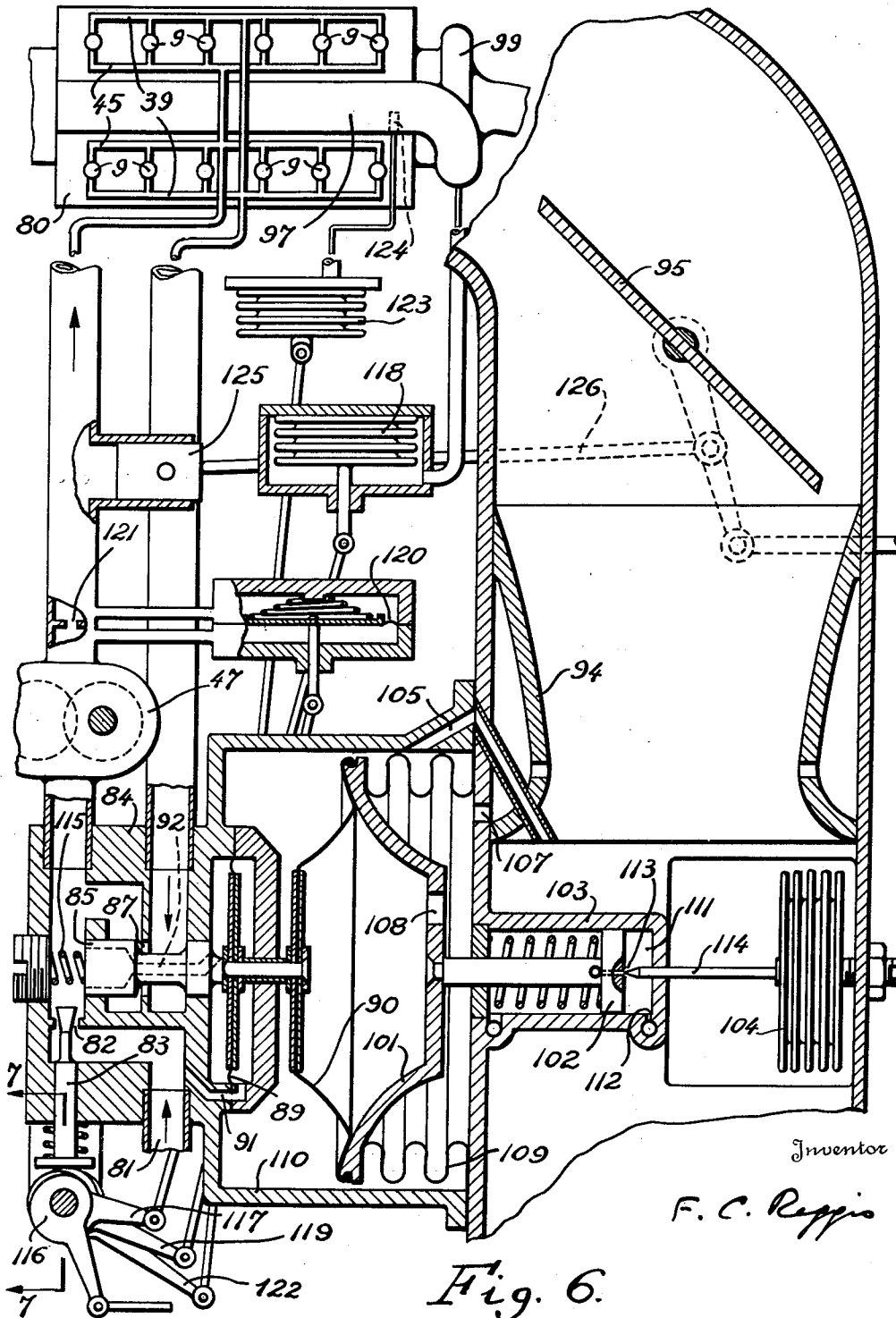
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FUEL SUPPLY SYSTEM

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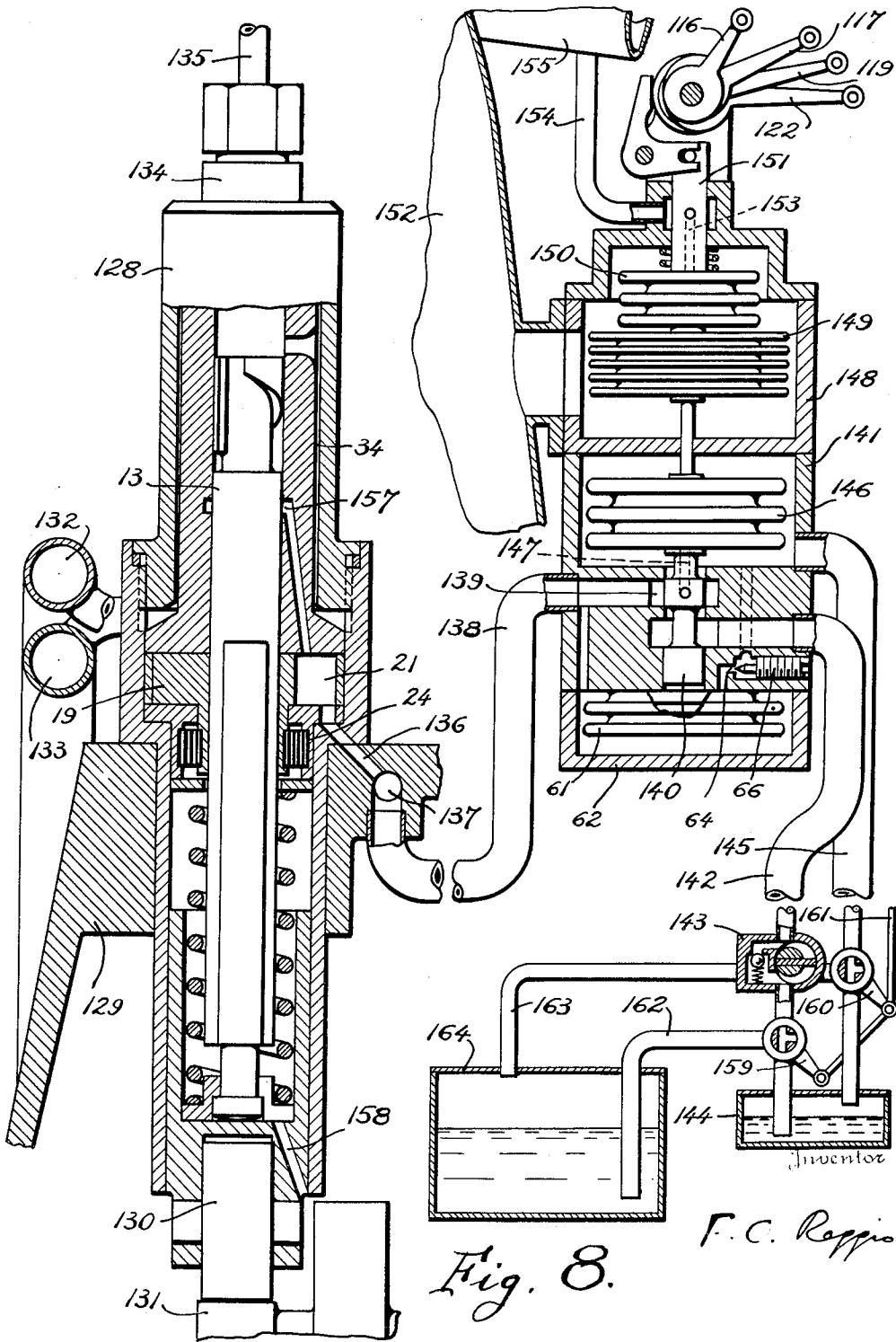
F. C. REGGIO

3,067,581

FUEL SUPPLY SYSTEM

Filed Nov. 4, 1943

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3,067,581
FUEL SUPPLY SYSTEM
Ferdinando Carlo Reggio, Buffalo, N.Y.
(P.O. Box 692, Norwalk, Conn.)
Filed Nov. 4, 1943, Ser. No. 508,897
25 Claims. (Cl. 60—39.28)

This invention relates to fluid supply systems and in particular to devices for supplying fuel in measured quantity to an engine, or devices such as disclosed in my copending applications Serial No. 333,529, filed May 6, 1940, now Patent No. 2,384,340; Serial No. 376,170, filed January 27, 1941, now Patent No. 2,364,817; Serial No. 466,041, filed November 18, 1942, now abandoned; and Serial No. 533,417, filed April 29, 1944, now Patent No. 2,516,828.

One of the objects of the invention is to provide a simple and compact fluid pressure controlled fuel metering unit.

A more specific object is to provide a fluid metering unit including a fluid pressure actuated rotary control device.

Another object resides in the provision of a hydraulically controlled fuel metering unit of substantially cylindrical form devoid of transversely arranged slidable control members.

A further object resides in the provision of an improved fuel supply system including individual fluid pressure controlled metering units and a fluid pressure regulating valve.

Still another object is to provide an improved engine fuel-air ratio regulating device.

Another object resides in the provision of an improved flow metering device for a fluid.

A still further object is to provide a hydraulically controlled fluid supply system in which the hydraulic medium may be changed to meet different operational requirements.

The above and other objects will be apparent as the description proceeds. In the following description and in the claims various details will be identified by specific names for convenience, but they are intended to be as generic in the application as the art will permit.

In the drawings, which show some examples of embodiment of the invention,

FIG. 1 is a sectional elevational view of an injector connected with a governing device, as it may be used in connection with a diesel or compression-ignition engine.

FIGS. 2 and 3 are cross-sectional views taken along the lines 2—2 and 3—3 of FIG. 1, respectively.

FIG. 4 is a fragmentary sectional view taken along the lines 4—4 of FIGS. 2 and 3.

FIG. 5 is a diagrammatic representation of the arrangement of fuel injection system in a multicylinder compression-ignition engine.

FIG. 6 is a sectional elevational view of a fuel-air ratio regulating device and diagrammatically indicates the connections thereof with the engine and the fuel metering units.

FIG. 7 is a fragmentary section taken along the lines 7—7 of FIG. 6.

FIG. 8 is a sectional elevational view of another embodiment of fuel supply system for spark-ignition engine.

Referring in particular to FIGS. 1–5, 9 is a fuel metering unit which includes a nozzle valve 10 and a metering pump having a barrel 11 provided with at least one port 12. A plunger 13 slidable in the barrel has at least one inclined or helical edge controlling the port 12, whereby the fuel delivery of the unit is controlled by rotating the plunger 13 relatively to the barrel.

Conventional fuel injection pumps of this type are provided with a pinion non-rotatably connected with the

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plunger and meshing with a transversely arranged slidable control rack. This crosswise rack renders the unit more complicated, expensive and cumbersome, and in many cases precludes the location of the injector unit directly on the engine cylinder or in the immediate vicinity thereof owing to lack of sufficient available space. To avoid these drawbacks a fluid pressure actuated rotary oscillating vane device is provided to control the angular adjustment of the plunger and in turn the fuel delivery. This vane device includes a housing 15 mounted between the barrel and an annular cover 16 and forming a cylindrical cavity coaxial with the plunger and interrupted by an inwardly extending radial wall 17. A rotary vane 19 having a circular hub portion and a radial wall portion is rotatably mounted with small clearance within said cavity and determines therein two variable volume chambers 21 and 22. A cylindrical portion 23 of the vane hub, formed with smaller outer diameter, axially extends through the central opening of the cover 16. The vane hub is provided with an axial non-circular opening within which the outer portion of the plunger 13 is slidably but non-rotatably mounted, whereby rotation of the vane is transmitted to the plunger.

A calibrated spiral spring 24 has its inner coil secured to the extension 23 of the vane 19, while the outer coil thereof is connected with the cover 16. The spring load, which exerts upon the vane a torque tending to turn it in a direction to decrease the volume of the chamber 21, may be adjusted by means of a screw 25 tangentially mounted in the body 9. A dowel 26 keeps in predetermined relative angular adjustment the barrel 11, the housing 15 and the cover 16. The chamber 22 may be vented to the atmosphere by means of a duct 27 formed in the cover 16, or, if desired, may be connected with a suitable fluid leakage return conduit, not shown in the drawings. The chamber 21 communicates through grooves 32 and 33 with an annular cavity 34 comprised between the bore of the unit body 9 and the barrel 11, and by means of a duct 35 and pipe 37 with the excess fuel return line 39.

The plunger 13 may be reciprocated in the usual way from an engine driven cam, for instance by means of a rocker arm 40, the return or suction stroke thereof being determined by a spring 41. The various parts of the injector are assembled through the lower end of the bore formed in the body 9 and are clamped by means of a threaded cap 42. Fuel under pressure is led to the annular space 34, in which the admission port 12 opens, by way of a duct 43 and pipe 44 connected with the fuel supply line 45 receiving fuel under pressure from a pump 47 driven from the engine or other suitable power source and designed to deliver fuel in excess of the engine consumption.

The excess fuel from the line 39 is led through a conduit 49 to a governor device 50 having a slidable pilot valve 51 the upper end of which is connected with flyballs 52 driven from the engine through a gear 53. This valve controls a flow restricting orifice 54 through which the excess fuel must pass before attaining the pipe 55 which leads back to the reservoir 57 or to the intake side of the primary pump 47. The centrifugal force of the flyballs 52 tending to lift the valve 51 is balanced by the load of a spring 59 adjustable by means of the speed control lever 60. The lower end of valve 51 is subject to the pressure of fuel contained within a resilient bellows 61 mounted in a housing 62. The interior of this bellows is connected with lines 49 and 55 by means of small orifices 63 and 64 adjustable by way of needle valves 65 and 66 respectively, while the space comprised between the bellows and the housing 62 is connected with the conduit 49 by means of a duct of comparatively large section.

The movable wall of bellows 61 is subject to oppositely

directed axial loads of two springs 70 and 71, the latter spring being so designed as to have a number of active coils which depends upon its load. The lower end of this spring 71 is connected by means of a linkage 72 with the speed control lever 60 in such manner that clockwise rotation of the latter compresses and stiffens the spring.

An example of arrangement of injection system for a V-12 compression-ignition engine or for two 6-cylinder synchronized engines is diagrammatically shown in FIG. 5. Like reference numeral in the various drawings indicate like parts. Fuel from a tank 74 is delivered by the primary pump 47 through a heat exchanger 75, a filter 77 and the supply lines 45 and 44 to the admission port 12 and vane chamber 21 of each metering unit 9. The excess fuel from each unit 9 is lead through pipes 37, 39 and 49 to the pressure regulating orifice 54 controlled by valve 51 of the governor 50, and thence by way of pipe 55 to the intake side of the pump 47. In the preferred embodiments of the invention which are shown in the drawings, the port-controlling edge of plunger 13 is so designed that the fuel delivery increases as the pressure in chamber 21 increases and causes rotation of the vane 19 against the torque transmitted thereto by the calibrated spiral spring 24. This torque is initially adjusted by means of the screw 25 so that each metering unit under specified conditions of cam speed and pressure in chamber 21 discharges a determined quantity of fuel in a given time, thus rendering these units interchangeable. With engine fuel conduits properly designed to keep the fuel pressure in the chamber 21 of the various units at substantially uniform value, the engine cylinders will receive equal fuel supplies.

The engine fuel supply system operates as follows: assuming the needle valve 65 in the governor 50 to be so adjusted as completely to close the orifice 63, under steady engine operative conditions the pilot valve 51 regulates the effective area of the orifice 54 in such manner as to maintain in the vane chambers 21 of the injection units 9 the pressure corresponding to the necessary engine fuel supply. The fuel pressure at the lower end of the valve 51 is kept at atmospheric value by means of the orifice 64 and pipe 55 connected to the tank 74; and the centrifugal force of the flyballs 52 is balanced by the spring 59.

If the engine load varies, for instance increases, the engine-driven flyballs 52 decelerate, the centrifugal force decreases, and the pilot valve 51 moves downward. As a result, the effective area of the orifice 54 decreases and determines an increase of fuel pressure in the chambers 21 of the metering units which causes rotation of the plungers 13 thereof in a direction to increase the engine fuel supply, thus tending to restore the initial engine speed. As the pressure within the housing 62 increases, the bellows 61 contracts, forcing fuel through the small orifice 64 and bringing about a temporary increase of pressure within the bellows whereby a temporary fuel pressure load is upwardly exerted on the lower end of the pilot valve 51 which tends to restrain the downward motion thereof. Although this restraining load is only a small fraction of the centrifugal force, it is sufficient to prevent overtravel of the valve and avert hunting.

With a bellows 61 having an effective diameter considerably larger than that of the valve 51, for instance three times as large as shown in the drawings, when the end wall of the bellows moves at certain velocity forcing fuel through the orifice 64 it determines a pressure variation within the bellows which is 81 times as large as that produced by a displacement of the valve 51 of same velocity. It will therefore be appreciated that the orifice 64, properly adjusted to cause upon displacement of the bellows a restraining pressure variation of proper magnitude to eliminate hunting, will not determine any material pressure variation upon initial motion of the pilot valve which may delay this motion. Such a delay would be harmful as under sudden changes of engine

load it would cause a serious underspeed or overspeed condition.

It is thus apparent that the governor 50 reacts to a change of engine speed by varying the hydraulic pressure which controls the rotary vane servo motor 19 included in the metering units 9. As the bellows 61 approaches its new position of equilibrium corresponding to the changed surrounding fuel pressure, the restraining pressure load on the pilot valve gradually diminishes and the engine speed resumes the initial value, at which speed the centrifugal force again balances the load of spring 59. This load, and in turn the engine speed, may be varied by changing the adjustment of the speed control lever 60.

As stated above, it has been found that the restraining pressure load which is to be applied to the pilot valve 51 in order to eliminate hunting is a small fraction of the centrifugal force transmitted thereto by the flyballs 52. It further appears desirable that the ratio therebetween be maintained substantially constant regardless of speed changes. To that end when the speed control lever 60 is turned clockwise to decrease the engine speed, the linkage 72 causes compression and stiffening of the spring 71. Thus, under a certain pressure variation within the housing 62, both the displacement and the magnitude of the restraining pressure variation at the lower end of the pilot valve 51 will be smaller.

With the orifice 63 closed, the pressure variations within bellows 61 which follow changes of load are only temporary, whereupon as the pressure therein returns to the atmospheric value the engine resumes the initial speed regardless of engine load, the operation of the governor being isochronous. However, where the orifice 63 is open, the pressure within the bellows 61 under steady operating conditions is proportional to the pressure in the chambers 21 of the metering units, the ratio therebetween being dependent upon the ratio of the effective areas of the orifices 63 and 64. The upward pressure load applied to the pilot valve 51 is greater under full load than under no engine load, and the centrifugal force required to keep the valve 51 in balance, being equal to the spring load minus the upward fuel pressure load applied thereto, will decrease with an increase of engine load. The engine speed will accordingly be lower under full engine load than under no load; and the difference between these speeds may be increased or decreased by augmenting or reducing the open area of orifice 63.

While the above described injection system is suitable for compression-ignition engines, a device intended for spark-ignition engines is illustrated in FIGS. 6 and 7, in which at 80 there is diagrammatically indicated an engine having fuel metering injection units 9 as above described in detail. An engine driven primary fuel pump 47 is supplied with fuel at atmospheric or other suitably low pressure from a conduit 81 through an orifice 82 whose effective area is controlled by a needle valve 83, and delivers a quantity of fuel exceeding the engine consumption through the supply lines 45 to the units 9. The excess fuel is led therefrom through the lines 39 to a pressure regulating device 84 having a slidable valve 85 which controls a flow restricting orifice 87 through which the excess fuel is forced before being led back to the intake side of the pump 47, downstream with respect to the orifice 82. The fuel flow through the latter orifice is thus equal to the engine fuel supply.

The valve 85 is actuated by two pressure responsive diaphragms 89 and 90. By means of conduits 91 and 92 the fuel pressure upstream and downstream of the orifice 82 is brought to bear on opposite sides of the former diaphragm, thus applying to the valve 85 an axial load, which increases with the engine fuel supply, in a direction to increase the effective area of the orifice 87.

The engine 80 is provided with an air induction system including orifice or venturi means 94, a throttle valve 95 and a manifold or reservoir 97 connected with the cylin-

der inlet ports. A supercharger 99 may also be provided in connection with the air induction system. The flexible diaphragm 90, connected at its center with the valve 85, has a cup-shaped outer portion whose periphery is secured to a cooperating cup-shaped member 101 connected with the resiliently loaded piston 102 of a hydraulic servomotor 103 controlled by a venturi air density responsive bellows 104. By means of a conduit 105 and passages 107 and 108 the venturi differential pressure is brought to bear on opposite sides of the diaphragm 90, thus transmitting to the valve 85 a load which increases with the venturi air flow and tends to shift the valve in a direction to decrease the open area of the pressure regulating orifice 87. A bellows 109 connected with the cup member 101 serves to define higher and lower air pressure chambers within the diaphragm housing. The cup-member 101 and the diaphragm 90 are so designed that as the former slides toward the latter an increasing annular outer portion of the diaphragm is caused by the air pressure differential to come into contact with the member 101, thereby decreasing the diaphragm area which is effective as pressure responsive means for the actuation of the valve 90. The effective diaphragm area is thus dependent upon the position of the piston 102.

Fluid under pressure, for example lubricating oil from the engine, continuously flows into the cylinder chamber 111 through a small flow restricting orifice 112. This oil leaves the cylinder chamber through another orifice 113 formed in the piston 102 and controlled by a needle valve 114 connected to the bellows 104. Thus the piston constantly follows the needle 114 at definite distance therefrom without exerting any reaction on the bellows 104: when the latter contracts, the open area of orifice 113 increases, the oil pressure in chamber 111 drops, and the piston spring plus the differential air pressure on member 101 move the piston 102 toward the bellows. Conversely, when the latter expands, the effective area of orifice 113 decreases, and the increasing oil pressure in chamber 111 moves the piston away from the bellows.

The bellows 104 contains a definite mass of air or gas, and the walls thereof are so highly flexible as to expand or contract within the designed limits under negligible load. This bellows is surrounded by induction air in the immediate vicinity of the venturi, the air within the bellows thus being at the same pressure and temperature as the air flowing through the venturi, and therefore having the same density. As a result, the volume and in turn the length of the bellows are inversely proportional to the venturi air density.

The mass air flow per second W through the venturi may be calculated by the following formula

$$W = K\sqrt{\delta I}$$

where δ is the venturi air density and I is the venturi pressure differential. In the above formula and in the following ones K represents various constants dependent upon the geometrical unchanging dimensions of the metering devices and, in some of the formulae, also upon the fuel density.

The load P applied to the valve 85 by the diaphragm 90 is

$$P = KD^2I = KD^2 \frac{W^2}{\delta}$$

wherein D is the effective diameter of the diaphragm, that is the diameter of that portion thereof which is not in contact with the cup member 101.

On the other hand the fuel flow per second w through the orifice 82 is

$$w = Ks\sqrt{i}$$

where s is the variable effective area of the orifice 82, and i is the fuel pressure drop through the orifice. The

load transmitted to the valve 85 by the diaphragm 89 is

$$p = Ki = K \frac{w^2}{s^2}$$

The valve 85 is subject to the light load of an idling spring 115 adjustable by means of a threaded cap. However when the engine operates at normal speed this spring load is negligible with respect to the loads p and P . Furthermore, under the oppositely directed loads p and P the valve is in equilibrium. Substituting the relation $p = P$ in the above equations we obtain the following expression for the engine fuel-air ratio

$$\frac{w}{W} = Ks \frac{D}{\sqrt{\delta}}$$

The diaphragm 90 and the cup member 101 are so designed that as the venturi air density varies and the bellows 104 expands or contracts and shifts the cup member, the effective diameter of the diaphragm varies proportionally to the square root of the air density, thus rendering the fraction $D/\sqrt{\delta}$ constant. This fuel-air ratio then becomes $w/W = Ks$, in other words this ratio is determined by the adjustment of the needle valve 83 exclusively, regardless of changes of altitude within the designed limits.

The profile of the cup member 101 and diaphragm 90 may readily be designed to satisfy the above requirement. If the axial length of the bellows 104 when subject to standard sea level air density is L , and the corresponding predetermined effective diameter of the diaphragm is d , at high altitude where the venturi air density is one-half of the standard sea level value the length of the bellows is $2L$, and owing to the changed position of the cup member relative to the diaphragm, the effective diameter of the latter will be $0.707d$. At higher altitude where the venturi air density is one-fourth of the standard sea level value, the length of the bellows is $4L$, and the effective diameter of the diaphragm will be $0.5d$.

Manual as well as automatic control of the valve 83 may be provided to regulate the engine fuel-air ratio. Four cams are shown in FIGS. 6 and 7 for actuating this valve. The cam 116 is manually controlled by means of suitable linkage means. Cam 117 is connected to a manifold air pressure responsive bellows 118. Cam 119 is actuated in dependence upon the engine speed by a resiliently loaded diaphragm 120 responsive to the fuel pressure drop determined by an orifice 121 provided on the discharge side of the volumetric engine-driven pump 47; and cam 122 is actuated by a bellows 123 connected with an element 124 responsive to the manifold air temperature and preferably also responsive in predetermined degree to the engine cylinder temperature. The number, character and arrangement of the automatic devices connected with the mixture control valve 83 may of course be varied to suit specific characteristics of various types of engines.

Fuel displacing plunger 125 connected by means of a rod 126 with the throttle valve 95 and hydraulically connected with the vane servo-motors of the metering units 9 serves to increase temporarily the delivery of the latter when the throttle valve is being opened.

In FIG. 8 there is shown a modified form of fuel metering pump 128 which is radially mounted in the housing 129 of a radial aircraft engine. The pump plunger 13 is reciprocated by means of a roller 130 from a cam 131 which may be the same cam from which the engine intake or exhaust valves are actuated. A fuel supply line 132 and an excess fuel return line 133 are connected with the annular fuel reservoir 34. The metered fuel is led through a check valve 134 and a pipe 135 to the injection nozzle, not shown, mounted preferably on the cylinder head.

In the fuel metering unit 128 the fluid pressure chamber 21 of the rotary vane servomotor is not connected with the fuel system. It is instead connected by means of conduits 136, 137 and 138 to a port 139 controlled by a

slidable valve 140 of a regulating device 141. The valve 140 as shown in the drawing is in neutral position and closes the port 139. Upward displacement of this valve connects the chamber 21 with a conduit 142 which is supplied by means of a pump 143 with lubricating oil under pressure from the engine sump or other suitable reservoir 144. Downward motion of the valve 140 connects the chamber 21 with a return pipe 145 which leads the oil back to the reservoir 144.

The valve 140 is attached to the lower wall of a coaxial resilient bellows 146 which is surrounded by atmospheric or engine sump pressure. The pressure within the bellows is kept by means of a duct 147 at the same value as in the chamber 21. The upper wall of this bellows is connected by way of a rod slidable through the wall of a housing 148 with two more bellows 149 and 150. The latter is carried by a rod 151 whose axial adjustment is controlled by cams 116, 117, 119 and 122 as already described in connection with FIG. 6. The housing 148 is filled with air having substantially the same pressure and temperature as in the engine induction manifold 152, while the interior of bellows 150 is connected by means of conduits 153, 154 with the engine exhaust pipe 155. At the lower end of valve 140 there is provided an anti-hunting device including a bellows 61 contained in a housing 62, and a small orifice 64 controlled by valve 66 between the interior of the bellows and the low pressure fluid system, the function and manner of operation of which device are similar to those which have already been set forth in detail in connection with the governor 50.

The bellows 149, like bellows 104 of FIG. 6, has highly flexible walls, contains dry air, and therefore is a highly sensitive manifold air density responsive device. It is apparent that the axial adjustment of the valve 140 is dependent upon the angular adjustment of the cams 116, 117, 119 and 122, upon the difference between exhaust and manifold air pressures, the manifold air density, and the pressure within the chamber 21 of the vane servomotor. During steady engine operation the valve 140 is in neutral position. If the manifold air density varies, for instance increases, the bellows 149 contracts and lifts the valve, determining admission of pressure oil to the chamber 21, rotation of the control vane 19 against increasing torque of spring 24, and increase of engine fuel supply. Rotation of the vane stops as the increasing pressure within the bellows 146 so expands the latter as to bring the valve 140 back to neutral position. A decrease of exhaust pressure also brings forth an increase of fuel supply. This supply is further altered when the axial adjustment of the rod 151 is changed by means of the cams connected therewith.

The space between housing 62 and bellows 61 is connected with the port 139 by means of a passage of sufficiently large section as to maintain the pressure of the fluid within said housing at the same value as in the vane chambers 21 and within bellows 146. The space within bellows 61, on the other hand, is connected with the fluid return pipe 145 through the small orifice 64 adjustable by means of the needle valve 66. It follows that during steady operation the pressure within bellows 61 is the same as in the return pipe 145. The bellows is in equilibrium, so contracted as to set up a resilient reaction which balances the difference between the external and internal pressures applied to the movable wall thereof. If now one of the bellows 146, 149, 150 expands or contracts, or one of the cams 116, 117, 119, 122 is rotated, the valve 140 is shifted so as to connect the vane chambers 21 with either the high pressure line 142 or the low pressure line 145 and cause a variation of engine fuel supply. The motion of this valve 140 displaces a certain volume of fluid contained within the bellows 61 and determines a flow of fluid at comparatively low velocity through the orifice 64, whereby the fluid pressure variation at the lower end of the valve is negligible. Thus the initial motion of the valve 140 is not damped by the fluid

within bellows 61. However, as the pressure in the vane chambers 21 and in the housing 62 varies as a result of the movement of the valve 140, the bellows 61 contracts or expands, determining in either case through the orifice 64 a flow of fluid at much greater velocity, and causing a correspondingly important variation in the pressure at the lower end of the valve 140 in a direction to restrain the motion thereof, so as to prevent overtravel of the valve and avert hunting, as already stated in connection with FIGURE 1.

Oil lubrication of the plunger 13 is provided by means of a groove 157 connected with the chamber 21. This arrangement has been found particularly advantageous, as the pressure of the lubricant in the groove is comparatively small when the engine is idling, and increases with the engine load. Oil leakage from the chamber 21 is returned to the engine sump through a duct 158. In a multicylinder radial engine the metering pumps 128 are preferably radially arranged, symmetrically with respect to the engine crankshaft, and are connected with the corresponding cylinders by means of short fuel pipes 135 of equal length. The fuel supply and return lines 132 and 133 may have substantially annular form, with the metering pumps connected thereto in parallel, each pump 128 being also connected with the oil line 137.

On the suction side of pump 143 and in the return pipe 145 there are provided two three-way cocks 159, 160 actuated by a common link 161. In normal operation these cocks connect the regulator 141 with the lubricating oil sump or reservoir 144, as already stated. When these cocks are turned anticlockwise, however, they connect the regulator, through alternate supply and return pipes 162 and 163, with a tank or reservoir 164 containing engine fuel or other liquid having sufficiently low freezing temperature. This arrangement is particularly suitable for engines operating in cold weather: a few seconds before stopping the engine, the cocks are turned counterclockwise so as to fill the regulator and the conduits up to the chambers 21 of the metering pumps with fuel. When the cold engine is started the fuel control system will operate promptly and correctly; and as soon as the lubricating oil is sufficiently warm the cocks may be turned clockwise again to connect the regulator 141 with the lubricating oil reservoir.

In the embodiment of the invention disclosed in connection with FIGURE 8 the fuel control 148 includes a first bellows 149 responsive to engine induction air pressure and temperature. In the preferred embodiment this bellows 149 so actuates the valve 140 as to vary the engine fuel supply proportionally to the engine air supply regardless of changes of air pressure and temperature in the induction manifold 152. That is to say, for a given adjustment of the rod 151, the bellows 149 operates to maintain the fuel/air ratio of the engine combustible mixture constant. The ratio between fuel and air supplies may however be altered by shifting the rod 151. This is obtained by rotating the cams 116, 117, 119 and 122. The first cam is controlled manually, while the remaining ones are adjusted automatically by means of the air pressure responsive bellows 118, speed responsive diaphragm 120 and temperature responsive element 123—124 shown in FIGURE 6. It will be appreciated that the profile of the various cams can be so designed as to satisfy any specific engine operating characteristic. For example, the cam 122 where intended for use with an air-cooled reciprocating engine may be so designed as to increase the fuel/air ratio as the temperature of element 124 approaches a predetermined maximum operating value. On the other hand, where the cam 122 is intended for use with an internal combustion turbine, it will preferably be so designed as to decrease the fuel/air ratio as high operating temperatures are attained. Similar remarks apply to the cams 117, 119, which may be variously designed to meet different operating requirements as to relation be-

tween fuel/air ratio and engine speed or air induction pressure, respectively.

These embodiments of the invention have been shown merely for purpose of illustration and not as a limitation of the scope of the invention. It is therefore to be expressly understood that the invention is not limited to the specific embodiments shown, but may be used in various other ways, in connection with other mechanisms and regulators, that various modifications may be made to suit different requirements, and that other changes, substitutions, additions and omissions may be made in the construction, arrangement and manner of operation of the parts without departing from the limits or scope of the invention as defined in the following claims.

Certain features disclosed herein are claimed in my co-pending application Serial No. 533,417, filed April 29, 1944, which issued July 25, 1950, as Patent No. 2,516,828.

In interpreting the claims, where they are directed to less than all of the elements of the complete systems disclosed, they are intended to cover possible uses of the recited elements in installations which may lack the non-recited elements.

What I claim is:

1. Engine injection system including a servomotor for regulating the engine fuel supply; a servomotor control member; an expansible device responsive to changes of manifold and exhaust pressures and connected on one side with said member; a plurality of cams each capable of overriding the other cams and singly altering the adjustment of the opposite side of said expansible device; and remote control means and engine speed and operative pressure and temperature responsive means to actuate said cams.

2. Supercharged engine liquid fuel supply system including a fuel control element; coaxial bellows connected end to end and responsive to changes of pressure in the induction manifold between supercharger and engine cylinders and in the engine exhaust conduit; an operative connection between said element and one of the free ends of said bellows; and a plurality of engine operative condition responsive means each capable singly and independently of the others to operate upon the opposite free end of said bellows to alter the adjustment thereof.

3. For use with an engine having an induction system, engine driven fuel injection units, pressure actuated servomotor means in each of said units to control the fuel delivery thereof, fluid conduit means interconnecting said servomotor means, means including induction pressure and temperature responsive means to regulate the actuating pressure in said conduit means to maintain the engine fuel supply proportional to the engine air supply for different values of the latter, manually operated control means for altering said actuating pressure to vary the fuel to air ratio, and engine manifold air pressure responsive means, manifold air temperature responsive means and engine speed responsive means each capable of overriding said manually operated control means and take over exclusive control of said actuating pressure under predetermined conditions of manifold air pressure, or manifold air temperature, or engine speed, respectively.

4. For a combustion engine having an air intake passage leading to the engine combustion chambers, a fuel supply and control system including: a fuel pump; reciprocable plunger means in said pump; means for reciprocating the plunger means from the engine; a chamber for lubricating oil under variable pressure in said pump for hydraulic control and lubrication of the pump; a member in said pump hydraulically actuated upon changes of lubricating oil pressure in said chamber for varying the effective fuel displacement of said plunger means to alter the engine fuel flow; and fuel regulating means including a speed responsive device having means driven from the engine, pressure responsive means connected with

said air intake passage, and a thermal unit responsive to an engine operating temperature and becoming operative at preselected temperature for varying the lubricating oil pressure in said chamber automatically.

5. For use with an engine having an air intake system and venturi means in said system, a fuel supply device including: fuel flow regulating means; a housing; diaphragm means in said housing defining separate pressure chambers therein; a connection between the diaphragm means and the fuel flow regulating means for actuation of the latter; conduit means connecting said pressure chambers with spaced points of said intake system to subject the diaphragm means to a differential pressure set up by air flow past said venturi means; air density responsive means adapted to sense variations in the density of the air in a portion of said intake system; and means under the control of said air density responsive means for varying the effective area of said diaphragm means.

6. A device for sensing variations in the mass of a variable-density fluid flowing through a passage provided with venturi means, said device including: a housing; a flexible diaphragm in said housing defining separate pressure chambers therein; conduit means for connecting said chambers with spaced points of said passage to subject said diaphragm to a differential pressure resulting from flow of said fluid past the venturi means; fluid density sensing means adapted to respond to variations in the density of said fluid in a portion of said passage; and means actuated by said density sensing means for increasing or decreasing the effective area of said diaphragm upon increase or decrease of said density, respectively.

7. A pressure responsive device including: a cup-shaped member; a diaphragm having an outer portion secured to said member; a stiffening plate secured to a central portion of the diaphragm; the intervening portion of the diaphragm being flexible so as to permit relative motion between said member and said plate, and being further adapted to contact said member on an area varying with changes in the relative position of said member and said plate so as to cause variations in the effective pressure responsive area of the diaphragm; and conduit means for subjecting the diaphragm to a controlling pressure.

8. A pressure responsive device including fluid containing means; a flexible membrane defining in part said fluid containing means; conduit means connected with said containing means to subject said membrane to variable pressure; a first member connected with said membrane and actuated thereby upon pressure variations in said fluid containing means; a second member adapted to contact a variable portion of said membrane for variably adjusting the effective pressure-responsive area thereof; and regulating means operating on said second member to alter said effective area of the membrane.

9. In a control valve, a valve member movable to control fluid flow through said valve; and means for controlling the actuation of the valve member including a casing, a flexible diaphragm mounted in said casing and responsive to pressure changes in said casing, conduit means connected with said casing for subjecting the diaphragm to controlling pressure; a second member movable independently of said valve member and adapted to contact a variable portion of said diaphragm so as to alter the effective pressure-responsive area of said diaphragm; and regulating means operatively connected with said second member for actuating the same to variably adjust said effective diaphragm area.

10. A fluid pressure device including a valve; a valve member movable to control fluid flow through said valve; a flexible diaphragm; a connection between said diaphragm and valve member for actuation of the latter by the former; a second member movable independently of said valve member and adapted to contact a variable-area portion of said diaphragm so as to alter the effective pressure-responsive area thereof; and automatic

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means operating on the second member variably to adjust said diaphragm effective area.

11. A regulating device including a valve member; first and second pressure responsive diaphragms exerting opposite loads on said valve member; said first diaphragm having variable effective area; area-varying means for the first diaphragm; and regulating means operatively connected with said area-varying means for variably adjusting said effective area of the first diaphragm.

12. For use with an engine having an air intake system and a fuel supply system provided with fuel control means, a control device including: two pressure-responsive diaphragms acting against each other and operatively connected with said fuel control means to actuate the same; conduit means for connecting one of said diaphragms to said air intake system to subject said diaphragm to a pressure which varies with changes of air flow therein; additional conduit means for connecting the other diaphragm to said fuel supply system to subject said diaphragm to a pressure which varies with changes of engine fuel flow; one of said diaphragms having a variable effective area; area-varying means for said diaphragm; and regulating means actuating said area-varying means.

13. In combination, an engine having an air induction system; a fuel supply system; fuel control means; a control device having a housing; first and second pressure-responsive diaphragms in said housing; said two diaphragms being connected with said fuel control means to actuate the same; first conduit means connecting the first diaphragm with said air induction system to actuate the diaphragm upon variations of air flow therein; second conduit means connecting the second diaphragm with said fuel supply system to actuate the second diaphragm upon changes of engine fuel supply; said first diaphragm having a variable effective area; area-varying means for the first diaphragm; and regulating means actuating said area-varying means automatically.

14. As an article of manufacture, a variable-area pressure-responsive device including: a first member having a hollow portion defined internally by a substantially conical surface; a pressure-responsive diaphragm having an outer rim attached to said member, a central portion provided with a stiffening plate and a flexible intermediate portion permitting relative motion between said outer rim and central portion; a second member connected with the central portion of the diaphragm to move therewith; said flexible portion of the diaphragm being adapted to come into contact with said conical surface of the first member, the extent of the contact area therebetween being variable and dependent upon the relative position of said first and second members, whereby the effective pressure-responsive area of the diaphragm varies upon changes in the relative position of said two members.

15. For use with a combustion engine having an exhaust system, a control mechanism including, an element adjustable to regulate an engine operating condition; a casing having a chamber; first conduit means for subjecting the chamber to a pressure varying with the engine air supply; first and second coaxial bellows in said chamber surrounded by said pressure; one of said bellows being sealed; second conduit means for connecting the space within the other bellows with the engine exhaust system; one end of the first bellows and one end of the second bellows being interconnected to move together; means operatively connected to the other end of said first bellows for controlling said element; and means for positioning the other end of the second bellows.

16. For a combustion engine having a combustion space, a first passage system leading combustion air to said space and a second passage system discharging combustion products therefrom, a control mechanism including a casing having a chamber, first conduit means connecting said chamber to one of said passage systems, first and second bellows coaxially arranged in said chamber and subject to the same pressure as in said first

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conduit means, one of said bellows being sealed, second conduit means connecting the space within the other bellows to the other passage system, one end of the first bellows and one end of the second bellows being interconnected to move together, a control member operatively connected to the other end of said first bellows, and means for positioning the other end of said second bellows.

17. A regulator including, in combination, a casing; first, second and third bellows connected in series and arranged co-axially within said casing; first conduit means for connecting the interior of the first bellows with a first source of variable pressure; the second bellows being sealed and interposed between said first and third bellows; second conduit means for connecting the interior of the third bellows with another source of varying pressure; control means operated by said third bellows; and means for positioning said first bellows with respect to the casing.

18. A control mechanism including: a casing; first, second and third bellows connected in series within said casing; first conduit means for connecting the interior of the first bellows to a first source of variable pressure; the second bellows being sealed and interposed between said first and third bellows; second conduit means for connecting the interior of the third bellows to a second source of variable pressure; control means connected to the third bellows and actuated upon motion of said third bellows; and adjustable means mounted in said casing for varying the position of said first bellows relative to the casing.

19. In a regulator, in combination, a control device; pressure responsive means actuating said control device; conduit means for subjecting said pressure responsive means to control pressure; datum-varying means for said pressure responsive means; a cam mechanism including cam follower means for actuating said datum-varying means, a plurality of coaxial rotatable cams operating on said cam follower means and each adapted to provide exclusive control of said datum-varying means; and control means for rotating said cams.

20. In a control system for an engine having fuel control means, fluid pressure operated means connected to actuate said fuel control means, a movable fluid control valve responsive to predetermined operative conditions for controlling said fluid pressure operated means, and means becoming transiently effective upon actuation of said fluid pressure operated means for transiently opposing movement of said control valve.

21. In a regulating apparatus for a prime mover having fuel control means, a fluid pressure motor connected to actuate said fuel control means, a movable fluid control valve responsive to the speed of said prime mover for controlling said fluid motor, and means transiently operated upon actuation of said fluid motor for transiently opposing movement of said control valve.

22. In a regulating apparatus for a prime mover having fuel control means, a fluid pressure motor connected to actuate said fuel control means, a movable fluid control valve responsive to the speed of said prime mover and effecting operation of said fluid motor at a speed substantially proportional to the deviation of the prime mover actual speed from the appointed value, and means responsive to the speed at which said fluid motor is actuated for transiently and proportionally opposing controlling movement of said control valve.

23. In a control apparatus for an engine having fuel control means, a fluid pressure motor connected to actuate said fuel control means, a movable control valve responsive to an engine operative condition for controlling said fluid motor, and means responsive to the speed of said fluid motor for transiently opposing movement of said control valve to prevent excessive rates of variation in the engine fuel flow.

24. In a regulating apparatus for a prime mover hav-

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ing a control member, a fluid pressure motor connected to actuate said control member, a movable control valve responsive to an operating condition of said prime mover for controlling said fluid motor, and means transiently responsive to movement of said fluid motor for transiently opposing movement of said control valve. 5

25. A regulator including, in combination, first, second and third coaxial bellows connected in series; the first bellows being responsive to a first condition, the second bellows being sealed and interposed between first and third bellows, and the third bellows being responsive to a second condition; control means connected with one at least of said bellows to be actuated thereby upon variations in both said first and second conditions; and adjusting means operatively connected with one at least of said bellows to vary the datum thereof. 15

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