Sept. 11, 1956 C. F. WOOD ET AL 2,762,426

GAS TURBINE APPARATUS

Filed May 23, 1951 2 Sheets-Sheet 1

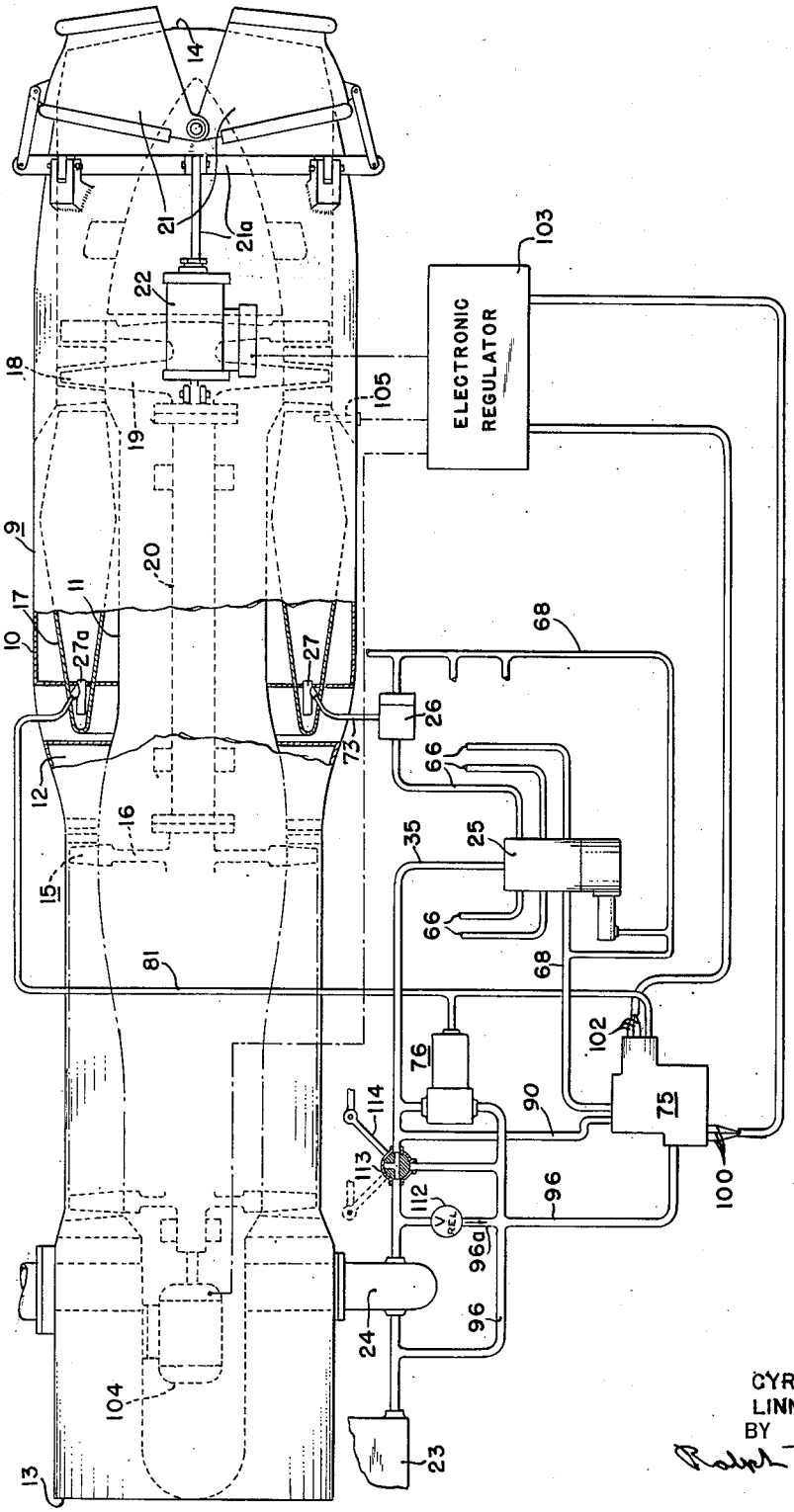


FIG. 1.

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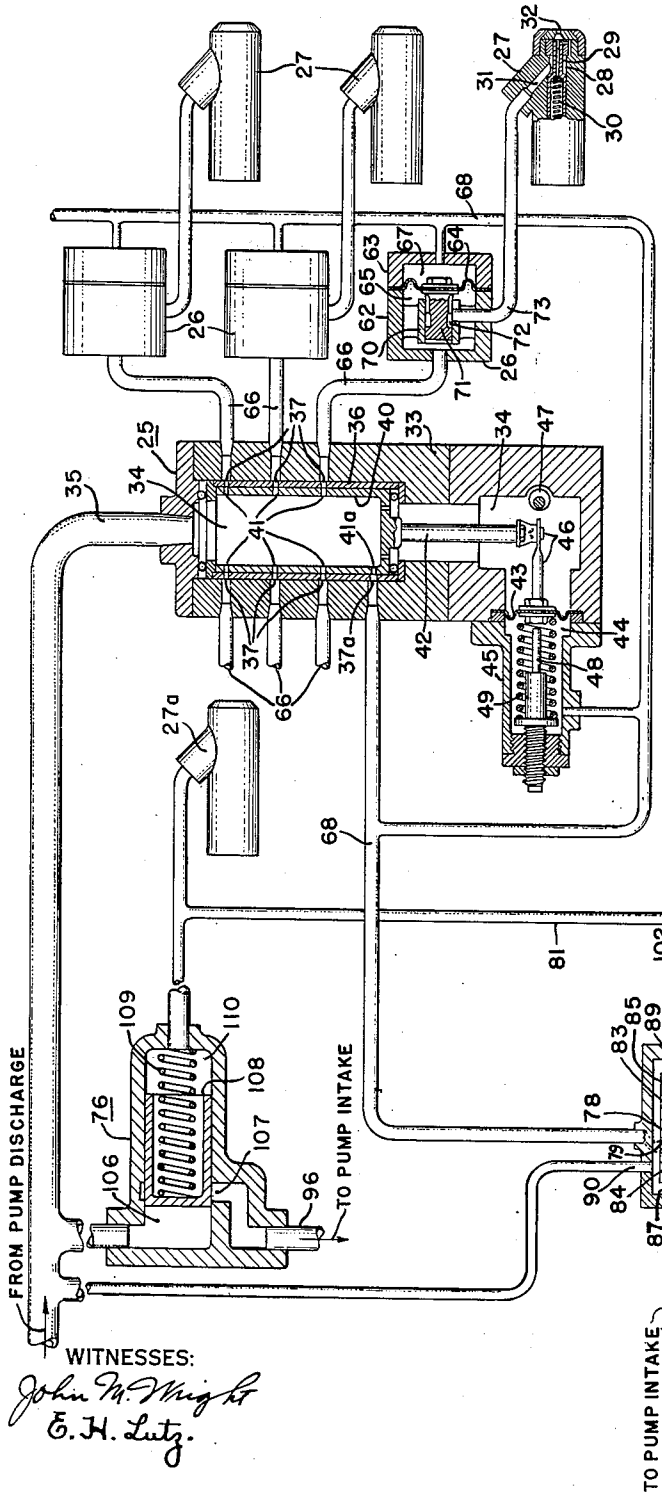


FIG. 2.

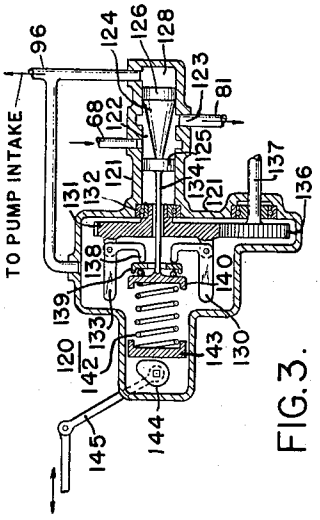


FIG. 3.

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GAS TURBINE APPARATUS

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Application May 23, 1951, Serial No. 227,894

5 Claims. (Cl. 158—36.4)

This invention relates to liquid fuel systems, and more particularly to fuel control apparatus for controlling the supply of fuel to an aviation gas turbine engine.

It has been proposed to provide fuel control apparatus for an aviation gas turbine which is operative to effect equal division and distribution of fuel supplied at a selected rate through the plurality of nozzles to an annular combustion apparatus, or to an annular group of combustion chambers or cans, so as to facilitate maintenance of uniform heat release and temperature distribution at the turbine inlet. A flow divider apparatus of this type is disclosed in the copending application of Wood and Cummings, Serial No. 98,334, now Patent No. 2,692,797 issued October 26, 1954, filed June 10, 1949, and assigned to the assignee of the present invention. It is an object of the invention to provide improved fuel control apparatus adapted for use in a system of this character.

Another object of the invention is the provision of an improved fuel system for supplying equal quantities of fuel to a plurality of variable orifice nozzles, including a flow divider valve device, balancing or equalizing valves for controlling the rates of flow of fuel therefrom to the several nozzles, respectively, and selectively operable control valve means for metering fuel to a single master nozzle from the flow divider valve device, while also maintaining a control pressure to which each balancing valve is responsive for effecting equal flow of fuel to the other nozzles.

In a previous construction of a fuel system for a jet engine equipped with variable orifice fuel distributing means, the total flow of fuel to the engine was controlled by operation of valve means of relatively large capacity interposed in the fuel line between the usual gear pump and the flow distributing means feeding the several nozzles. It is a further object of the present invention to provide such a fuel system with a pressure-responsive by-pass valve device operative to control the total flow of fuel delivered by a gear pump to the engine by way of the fuel distributing means, and a pilot control valve device metering fuel from the latter to a master nozzle at a pressure which is utilized to actuate the by-pass valve device, thus dispensing with a large capacity valve means between the pump and distributor, other than a simple cut-off valve adapted to be closed when the power plant is shut down.

Still another object is to provide control valve means adapted to meter fuel to a single control nozzle, and means responsive thereto for controlling total flow of fuel supplied to the engine from a fuel system of the above type, the metering of fuel to the control nozzle being utilized to establish a reference pressure for effecting equal fuel flow from each of the other nozzles.

These and other objects are effected by the invention as will be apparent from the following description and claims taken in connection with the accompanying drawings, forming a part of this application, in which:

Fig. 1 is a schematic elevational view, partly in section, of an aviation gas turbine power plant equipped with

fuel supply apparatus constructed in accordance with the invention;

Fig. 2 is a diagrammatic view of the improved fuel distributing apparatus; and

Fig. 3 is a diagrammatic view of a control valve device embodying the invention in a different form and adapted to be substituted for the pilot valve device of Fig. 2.

In Fig. 1 of the drawings, the invention is illustrated in association with the combustion apparatus of a conventional gas turbine engine 9, which in the form shown comprises a cylindrical outer casing structure 10 having mounted therein a sectional core structure 11, which with the casing structure 10 defines an annular flow passageway 12 that extends longitudinally through the apparatus from a frontal air intake opening 13 to a rearwardly disposed discharge nozzle 14. The casing structure 10 is adapted to be mounted in or on the fuselage or wing of an aircraft (not shown), with the intake opening 13 pointed in the direction of flight. The axially aligned operating elements of the engine disposed in the casing structure 10 include an axial-flow compressor 15 having a rotor 16, annular fuel combustion apparatus 17, and a turbine 18, the rotor 19 of which is operatively connected to the compressor rotor 16 through the medium of a hollow shaft 20, which may be suitably journaled in the casing structure. In operation, air drawn into the intake opening 13 is compressed by the compressor 15 and delivered to the combustion apparatus 17, to which fuel is supplied by way of apparatus hereinafter described. The resultant hot motive gas is then supplied from the combustion apparatus to the turbine 18, and is finally discharged through the nozzle 14 in the form of a jet establishing a propulsive thrust. The flow area of the nozzle 14 may be varied by operation of movable closure members 21, which are operatively connected by linkage 21*a* to a suitable motor device 22 carried on casing 10.

The fuel supply apparatus may comprise a reservoir 23, engine-driven pump apparatus 24 of the positive displacement or gear type, and a distributing valve system including a flow divider valve device 25, and a plurality of pressure balancing valves or equalizing valve devices 26, each of which is individually operative to supply fuel to one of a number of fuel nozzles 27 associated with the combustion apparatus 17. In a typical turbojet engine, sixteen nozzles, including a master nozzle 27*a* hereinafter referred to, may be provided. These nozzles are preferably of the variable orifice type, and may each have the construction illustrated in Fig. 2, comprising a casing having a bore 28 in which a piston valve 29 is slidably mounted. The piston valve 29 is subject to the opposing pressures of a spring 30 and of fuel admitted to the bore 28 by way of an inlet passage 31, and is operative according to the fuel pressure for effecting discharge of fuel at a variable rate from the bore through an outlet opening 32.

As shown in Fig. 2 of the drawings, the flow divider valve device 25 comprises a casing structure 33 having a chamber 34 which communicates through a conduit 35 with the discharge side of the gear pump device shown in Fig. 1. Mounted in the upper end of the chamber 34 is a cylindrical bushing 36 in which are formed a plurality of outlet ports 37 corresponding in number to the nozzles 27. For varying the flow areas of the ports 37 there is provided a sleeve valve member 40, which is rotatably mounted in the bushing 36 and has a plurality of calibrated orifices 41 adapted to register with the respective ports 37. The sleeve valve member 40 has an axial shaft 42 which extends into the lower end of the chamber 34, where a diaphragm 43 is mounted between that chamber and a chamber 44, formed in a casing section 45. The diaphragm 43 is operative to effect turning of the shaft 42 through the medium of

suitable linkage 46. Movement of the linkage in one direction is limited by an adjustable stop cam 47 carried by the casing structure 33, and in the other direction by an adjustable stop rod 48 disposed in the chamber 44 of the casing section 45. A coil spring 49 is interposed between the diaphragm 43 and a wall of the chamber 44 for biasing the diaphragm toward a normal position, which may be the position in which the flow areas of ports 37 will be a minimum.

Each of the similar equalizing valve devices 26 associated with the individual nozzles 27 comprises casing sections 62 and 63 between which is clamped a diaphragm 64, the casing sections and diaphragm cooperating to provide, at one side of the diaphragm, a valve chamber 65 communicating through a conduit and passage 66 with one of the ports 37 in the ditributing valve device 25, and at the other side a chamber 67 which is connected to a control conduit 68. The control conduit 68 communicates with the chamber 44 of the distributing valve device 25, and is adapted to be supplied with fuel flowing from the chamber 34 by way of an orifice 41*a* in valve member 40 and a registering port 37*a*, the pressure of such fuel being determined in a manner hereinafter explained. Mounted in a guide 70 in each valve chamber 65 is a slide valve 71, which is operatively connected to the diaphragm 64 and has an annular groove 72 for controlling communication between the valve chamber 65 and a port and conduit 73 communicating with the inlet 31 of the associated nozzle 27.

According to the invention in the form illustrated in Fig. 2, one of the nozzles, having the same construction as nozzles 27 but designated 27*a* in Fig. 2, is adapted to be operated as a master nozzle in cooperation with a control or pilot valve device 75 and a differential by-pass valve device 76, for maintaining the desired control pressure in the control conduit 68 as well as for determining the rate of flow of fuel supplied from the pump through pipe 35 to the distributor valve device 25. The control valve device 75 comprises a casing 77 having a valve chamber 78 communicating through an inlet passage 79 with the control conduit 68, and also connected by way of a valve port 80 with a conduit 81 leading to the control nozzle 27*a*. Slidably mounted in the valve chamber 78 is a fluid pressure responsive valve element 83 having a tapered portion cooperative with the port 80 for varying the flow area thereof. The valve element has enlarged opposite ends or piston portions 84 and 85 formed thereon. The piston portion 84 is subject to pressure of fuel in a chamber 86 communicating, by way of a restricted passage 87 and a passage and pipe 90, with the supply pipe 35. It will thus be understood that the pipe 90 is adapted to supply fuel under pressure from the usual pump for operating the valve element 83. The piston portion 85 is subject to the opposing pressure of fuel in a chamber 88, which communicates with passage 90 through a restricted passage 89.

For selectively varying the fuel pressures in the chambers 86 and 88, an electro-responsive teeter valve mechanism 91 may be provided, comprising a pair of teeter valves 92 and 93 which are pivotally connected to a yoke 94 having a stationary fulcrum pin 95. The teeter valve 92 is adapted to control discharge of fuel under pressure from the chamber 86 to a return conduit 96 leading to the intake communication of the pump 24 shown in Fig. 1. Similarly, the teeter valve 93 controls communication between the chamber 88 and the return conduit 96. It will be apparent that if the valve 92 is moved toward open position and the valve 93 toward closed position, the pressure of fuel flowing through chamber 86 will fall below that in chamber 88, so that the valve element 83 will be shifted to the left. A reverse movement of the valve element is effected upon opening of the valve 93 and closure of valve 92.

The teeter valve mechanism 91 may be controlled in any suitable manner, and is preferably actuated in accordance with differential energization of a pair of magnet coils 97 and 98, under control of a suitable electric circuit, indicated at 100. The position of the valve element 83 may also be indicated by suitable electrical means, including a feedback potentiometer 101 interposed in a circuit 102. These circuits, as shown in Fig. 1, may constitute elements of an electronic power regulator, not shown in detail but indicated generally at 103 in Fig. 1, which is adapted to coordinate control of the fuel control valve device 75 and of the variable area nozzle motor 22 in accordance with engine speed, which may be communicated to the regulator 103 from an engine-driven generator 104, and temperature, which may be measured and communicated to the regulator by means of a thermo-responsive element 105. Such an electronic control equipment is disclosed and described in detail in the copending application of Cyrus F. Wood, Serial No. 121,171, filed October 13, 1949, now Patent 2,734,340 and assigned to the assignee of the present invention. It will be understood that the electronic regulator apparatus 103 includes suitable electrical means and circuits adapted to be manually set to effect suitable energization of the circuit 100, when it is desired to vary the fuel input to the power plant.

The differential by-pass valve device 76 is adapted to respond to variations in the pressure of fuel metered by the control valve device 75 through conduit 81 to the control nozzle 27*a*, for regulating the by-passing of fuel under pressure from the supply pipe 35 to the intake of the fuel pump 24. The by-pass valve device 76 comprises a suitable casing having a valve chamber 106 which communicates with the supply pipe 35 and with a port 107 connected to the return pipe 96. Mounted in the valve chamber 106 is a piston valve element 108 that is biased by a spring 109 toward a position in which the port 107 is closed, as shown in Fig. 2. The spring 109 is contained in a chamber 110 communicating with the conduit 81, so that pressure of fuel supplied to the control nozzle 27*a* augments that of the spring on piston valve 108 in opposition to the fuel at pump discharge pressure in the valve chamber 106. It will be understood that the normal pump discharge pressure in chamber 106 will be sufficient to overcome the force of the biasing spring 109 unless a predetermined control nozzle pressure is maintained in 110.

As shown in Fig. 1, an excess pressure operable relief valve device 112 of conventional construction may be interposed in a branch conduit 96*a* connecting the supply pipe 35 to the return conduit 96. A suitable normally open cut-out valve device 113 may also be interposed in the supply pipe 35, and is adapted for operation by suitable means such as a linkage 114 to ensure complete cutoff of fuel flow to the system, by connection of the discharge outlet of pump 24 to the return pipe 96, as when the power plant is to be shut down.

The apparatus shown in Fig. 2 operates as follows: Fuel under pressure delivered by the gear pump equipment 24 is supplied by way of the conduit 35 to the chamber 34 of the distributing valve device 25, and thence flows through the registering orifices and ports 41 and 37 and related conduits 66 to the valve chambers 65 of the several equalizing valve devices 26. Fuel under pressure also flows from chamber 34 through orifice 41*a* and port 37*a* to the control conduit 68. With the valve element 83 of the control or pilot valve device 75 meanwhile positioned in accordance with response of the teeter valve mechanism 91 to the selected energization of the magnet coils 97 and 98 to meter fuel through conduit 81 to the control nozzle 27*a*, the back pressure of fuel in control conduit 68 constitutes a control pressure which is communicated to the diaphragm chamber 67 of each equalizing valve device 26, and also to the chamber 44 of the distributing valve device 25. The diaphragms 64 of all equalizing valve devices 26, and

diaphragm 43 in chamber 44 of the distributing valve device 25, are thus subjected to the same control pressure for rendering uniform the rate of flow of fuel by way of the associated slide valves 71 to the connected nozzles 27.

Since the adjustment of the rotary sleeve valve 40 of the distributing valve device 25 is effected by operation of the diaphragm 43 and linkage 46 in accordance with the differential between the control pressure in chamber 44 and the pressure of fuel supplied to the chamber 34, the flow areas of all the registering ports 37 and 41, and ports 37*a* and 41*a*, will be equal and will correspond to fuel demand. When the pressure of fuel supplied to the chamber 34 is greater than the pressure of the spring 49 and of fuel at the control pressure in chamber 44, the diaphragm will be forced outwardly against the latter pressures, thereby turning the shaft 42 and sleeve valve 40 to provide large flow areas for all of the ports 37—41 and ports 37*a* and 41*a*, simultaneously. Upon a reduction in fuel pressure in chamber 34 below the pressure of the spring 49 and the control fuel pressure in chamber 44, the sleeve valve 40 will be operated to reduce the flow areas of the said ports controlling flow of fuel to the equalizing valve devices 26, nozzles 27, and nozzle 27*a* via fuel valve device 75. All of the equalizing valve devices 26 will consequently be operative to ensure adequate and uniform supply of fuel at the selected rate to the associated nozzles.

In accordance with the invention, when it is desired to effect a reduction in the rate at which fuel is supplied through the pipe 35 to the chamber 34 of the distributing valve device, the teeter valve mechanism 91 is actuated to effect movement of the valve element 83 to the left, as viewed in Fig. 2 of the drawings, for reducing the flow of fuel through conduit 81 to the control or master nozzle 27*a*. The flow distributing valve system is constructed and arranged to respond to the flow of fuel to the master nozzle to effect the same rate of flow of fuel to each of the other fuel nozzles. Thus, when added pressure drop is effected between the control conduit 68 and conduit 81, the diaphragm 43 and related elements of flow divider valve device 25 become operative to restrict flow of fuel to all the nozzles. The reduction in fuel pressure in chamber 110 of the differential by-pass valve device 76 at the same time permits movement of the piston valve element 108 by the pressure of fuel in the chamber 106, to cause more fuel to be by-passed from the supply pipe 35 to the return pipe 96, so that the amount of fuel delivered to all nozzles of the engine, by way of the flow distributor valve device 25, will be accordingly reduced.

If it is desired to effect an increase in the rate of supply of fuel to the nozzles of the engine, the teeter valve mechanism 91 is actuated to cause the valve element to increase the flow area of the port 80, thus increasing the fuel pressure in the conduit 81 of the control nozzle 27*a*. Resultant movement of the valve element 108 is effected to reduce the by-pass flow of fuel from the supply pipe 35, while the flow divider valve device 25 becomes operative to widen the flow areas of the feed ports therein, so that more fuel is rendered available for flow through the respective nozzles.

The principal features of the invention may, if preferred, be embodied in somewhat different form in fuel control apparatus of the type including a mechanically operated speed-responsive governor or pilot control valve device 120, shown in Fig. 3, which is adapted to be substituted for the control valve device 75 with gas turbine equipment such as that shown in Figs. 1 and 2. The control valve device 120 comprises casing structure 121 having formed therein a valve chamber 122, which communicates with the control conduit 68 leading from the distributor valve device 25, shown in Fig. 2, and through a valve port 123 with the pipe 81 connected to the master nozzle 27*a*. A tapered slide valve element 124

is mounted in the valve chamber 122 for varying the flow area of the valve port 123. The valve element 124 has enlarged balancing portions or lands 125 and 126 subject to fluid pressure in chambers 127 and 128, respectively, both of which chambers communicate with the pump intake pipe 96. It will be understood that the valve element 124, shown in Fig. 3, is operative for controlling the metering of fuel under pressure from the distributing valve device 25 to the control nozzle 27*a* and chamber 110 of the by-pass valve device 76 to achieve the same results already explained with respect to valve element 83 of the control valve device 75 shown in Fig. 2.

For actuating the valve element 124 there is provided an engine speed-responsive mechanism, generally indicated at 130, comprising a gear element 131 that is journaled on a bearing 132 mounted in the casing structure 121, and a pair of fly-weights 133 pivotally mounted on the gear element for shifting the valve element 24 through the medium of a stem 134. The gear element is adapted to be rotated at a speed indicating rotor speed of the power plant 9 shown in Fig. 1, and may readily be connected thereto through the medium of suitable gearing, including a driving pinion 136 meshing with the gear element 131 and having a shaft 137 journaled in the casing structure 121. Each of the pivoted fly-weights 133 carries an inwardly extending arm 138, which engages an annular thrust plate 139, which in turn rotatably bears through a bearing against a head portion 140 of the valve stem 134. An adjustable speeder spring 142 is provided for opposing movement of the valve element 124 by the centrifugal force of the fly-weights 133, this spring being interposed between the head portion 140 and a follower plate 143, which may be operatively engaged by a cam 144 adapted to be actuated through the medium of suitable throttle linkage 145.

It will be apparent that, in operation, with the speeder spring 142 adjusted by means of the linkage 145 to regulate operation of the power plant at the speed desired, the speed-responsive mechanism 130 will be correspondingly operative to position the control valve element 124 for effecting the metering of fuel through conduit 81 to the control or master nozzle 27*a* at a suitable rate, thus ensuring control of the total flow of fuel to the engine in the manner hereinbefore described with relation to the apparatus shown in Fig. 2. Thus, if the engine speed should tend to increase beyond the speed setting, the fly-weights will be moved farther outwardly, thereby shifting the valve element 124 against the force of the speeder spring 142, to reduce the flow area of the fuel valve port 123. A reduction in speed will produce an opposite result, the spring 142 then becoming effective to cause the valve element 124 to increase the flow area of the valve port 123. Operation of the pressure-responsive by-pass valve device 76, shown in Fig. 2, will of course correspond to the operation of the valve element 124, as already explained.

To summarize, it will be seen from the foregoing that the invention constitutes an improved fuel control apparatus having favorable weight and reliability characteristics, with the alternative forms of the pilot or control valve means constructed and arranged to afford complete control of the fuel flow to all nozzles of the engine in accordance with variations in pressure effected in the line connected to the master nozzle 27*a*. According to the invention, the pilot or control valve means is required to handle only the fuel delivered to a single nozzle, while the other fuel nozzles are operated in "slave" relation thereto and are adapted to be supplied with equal volumes of fuel, thus ensuring maintenance of flow balance and consistency of distribution of fuel in the engine, without requirement of bulky valve arrangements of large capacity between the usual pump and the flow distributor.

While the invention has been shown in several forms,

it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various other changes and modifications without departing from the spirit thereof.

What is claimed is:

1. Liquid fuel control apparatus comprising a pressure-responsive variable orifice master nozzle; a flow divider device having an inlet and a plurality of feed ports; a control conduit connected to one of said feed ports; another communication connecting said control conduit to said master nozzle; a selectively operable control valve element interposed in the last-named communication between said control conduit and said master nozzle; and means for selectively actuating said control valve element, the back pressure in the control conduit upstream of said control valve element constituting a control pressure for regulating the operation of said flow divider device; said flow divider device further including a movable valve member having orifices registering with the respective feed ports for varying the flow areas thereof, a spring, and a movable abutment operatively connected to said movable valve member and subject on one side to the pressure of fuel entering the inlet of the flow divider device and on the other side to the pressure of fuel in said control conduit and the force of said spring; a positive displacement pump; and means for varying the fuel flow from said pump to the inlet of the flow divider device, including a spring, and a movable abutment subject on one side to the pressure of fuel from the pump and on the other side to the pressure of said spring and of fuel in the communication connected to the master nozzle.

2. Liquid fuel control apparatus comprising a pressure-responsive variable orifice master nozzle; a flow divider device having an inlet and a plurality of feed ports; a control conduit connected to one of said feed ports; another communication connecting said control conduit to said master nozzle; a selectively operable control valve element interposed in the last-named communication between said control conduit and said master nozzle; and means for selectively actuating said control valve element, the back pressure in the control conduit upstream of said control valve element constituting a control pressure for regulating the operation of said flow divider device; said flow divider device further including a movable valve member having orifices registering with the respective feed ports for varying the flow areas thereof, a spring, and a movable abutment operatively connected to said movable valve member and subject on one side to the pressure of fuel entering the inlet of the flow divider device and on the other side to the pressure of fuel in said control conduit and the force of said spring; a fixed displacement pump having an outlet connected to the inlet of the flow divider device; and a fluid pressure actuated by-pass valve device adapted to connect said outlet of said pump to the inlet thereof, including spring-biased valve means adapted to maintain the pressure at the pump outlet a predetermined amount above the pressure of fuel in said communication connected to said master nozzle.

3. In a fuel system, comprising a flow distributing valve mechanism having an inlet and having a plurality of variable orifice feed communications, a plurality of fuel nozzles and a plurality of separate passages connecting said fuel nozzles to said feed communications; the combination of a selectively operable control valve means interposed in one of said feed communications for metering fuel therethrough at a predetermined rate, and pressure-responsive valve means responsive to variations in pressure of fuel metered by operation of said control valve means for controlling the supply of fuel at the inlet of said flow distributing valve mechanism.

4. In gas turbine power plant control apparatus comprising a fixed displacement fuel pump having an intake and an outlet, a fuel distributing valve mechanism connected to the outlet of said fuel pump and having a plurality of variable orifice feed outlets for effecting equal distribution of fuel to a plurality of fuel nozzles; the combination of a control pressure conduit connected to one of said variable orifice outlets, by-pass valve means connected to the outlet of said pump and operative to divert to said intake some of the fuel flowing from said pump outlet, said by-pass valve means including a fluid pressure-responsive operating element subject to the pressure of fuel supplied from said control pressure conduit, a fuel control valve device interposed in the control pressure conduit for controlling the flow of fuel from said distributing valve, electro-responsive means connected in operative relation with said fuel control valve device, and engine power regulator means for controlling energization of said electro-responsive means.

5. In a gas turbine power plant control system having a fixed displacement fuel pump provided with an intake and an outlet, and a fuel distributing valve mechanism connected to said fuel pump and having a plurality of variable fuel outlets individually connected to a plurality of fuel nozzles; the combination of a control conduit having a communication with one of said fuel outlets, by-pass valve means connected to the outlet of said pump and operative to divert to said intake some of the fuel flowing from said pump outlet, said by-pass valve means including a fluid pressure-responsive operating element subject to the pressure of fuel supplied from said control pressure conduit, a fuel control valve device interposed in the communication connecting said distributing valve to the control conduit for controlling the flow of fuel from said distributing valve, and engine-driven speed-responsive governor means for actuating said fuel control valve device.

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