Sept. 9, 1952 F. H. CAREY 2,609,868

FUEL SUPPLY CONTROL FOR GAS TURBINES

Filed Aug. 4, 1947 2 SHEETS—SHEET 1

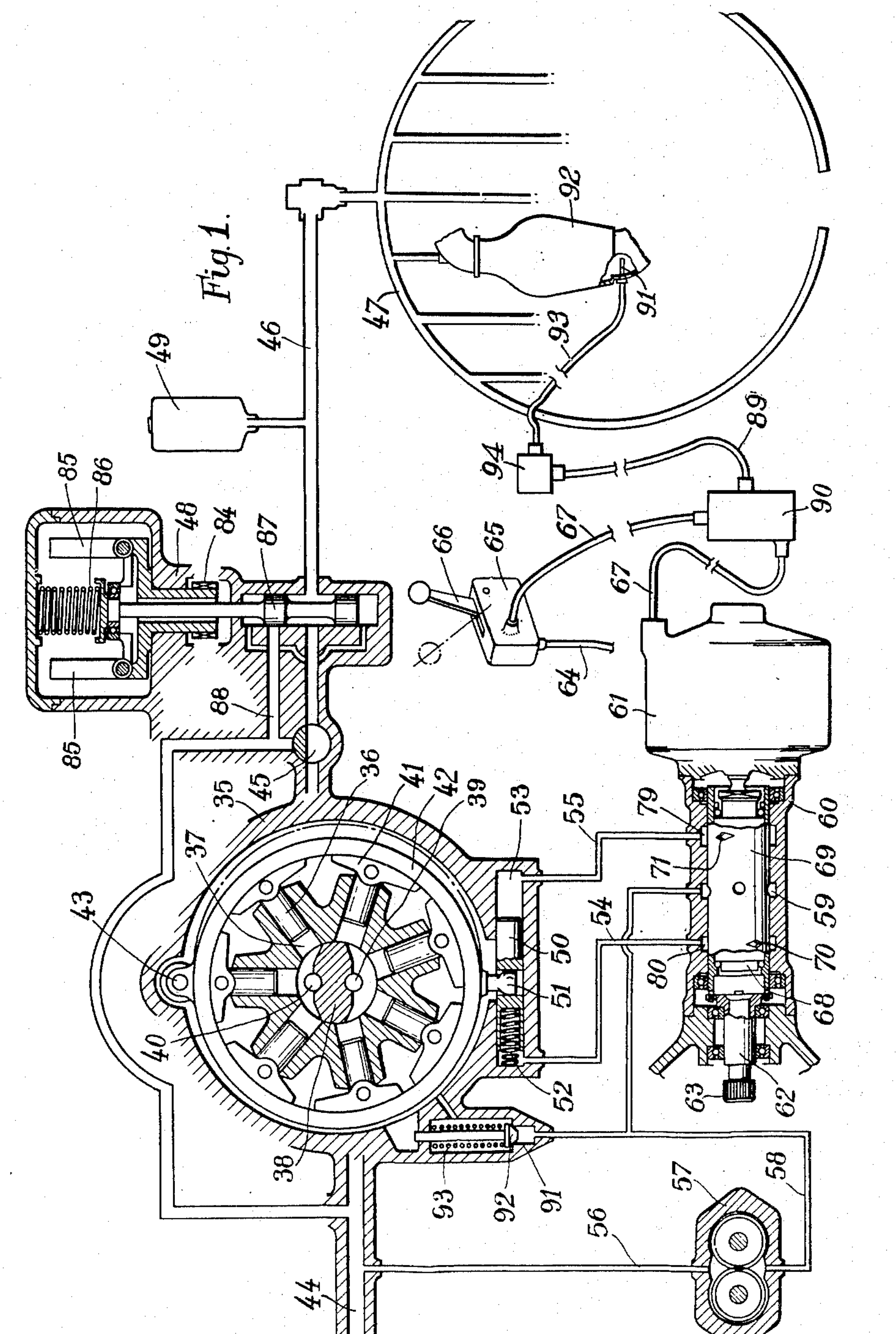

Fig. 1.

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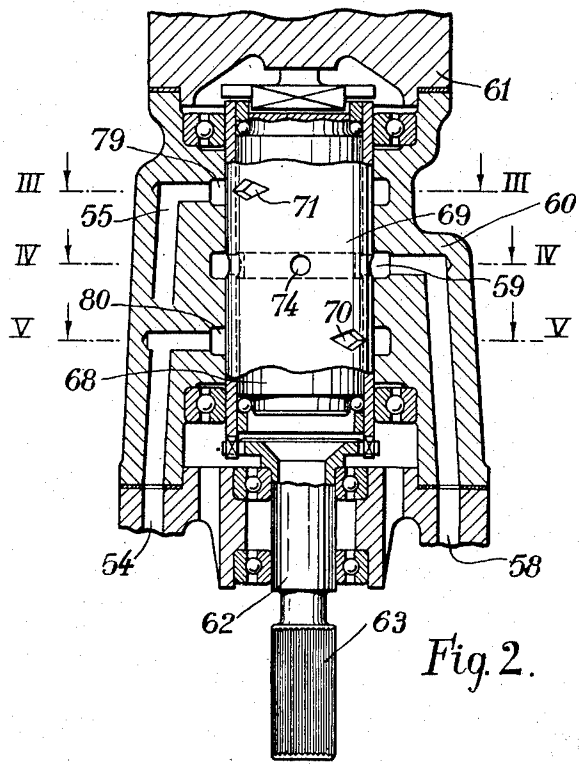

Fig. 2.

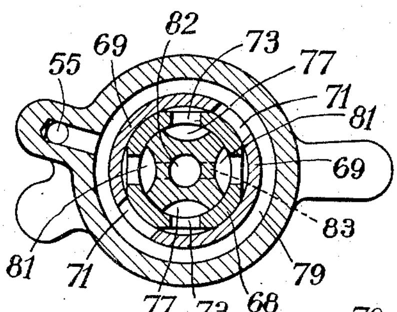

Fig. 3.

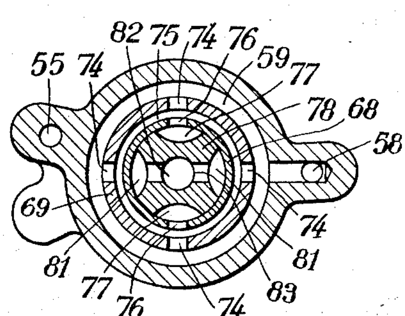

Fig. 4.

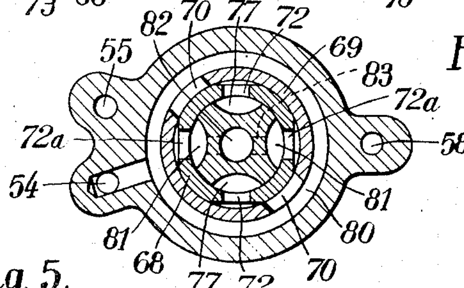

Fig. 5.

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FUEL SUPPLY CONTROL FOR GAS TURBINES

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3 Claims. (Cl. 158—36)

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This invention consists in a fuel supply system for an aircraft internal combustion turbine power unit in which a control member responsive to controllable variable-speed motor means but totally unresponsive to ambient conditions, such as pressure changes due to altitude differences, and a follower member responsive to engine speed are so associated with one another and with means by which fuel is supplied to the engine at a variable rate, that when either of said members tends to lag behind or over-ride the movement of the other, the rate of fuel supply is correspondingly varied to cause the engine to assume a speed dictated by the speed of said motor means.

If the operator wishes to speed up the engine he will move his lever or other actuator to selectively increase the speed of the variable-speed motor means. This will cause the control member to tend to over-ride the follower member with the result that the rate of fuel supply will be increased, which will increase the speed of the engine until the follower member is in synchronism with the control member at the selected increased speed. If, on the other hand, the operator wishes to slow down the engine he will slow down the variable-speed motor means which will cause the control member to tend to lag behind the follower member and so bring about a reduction in the rate of fuel supply and hence a corresponding reduction in the engine speed. In other circumstances, assuming the operator wishes the engine to continue to operate at a selected speed, it may be (and is the case in aircraft internal combustion turbine power units) that the engine fuel requirements at the selected speed may vary owing, for example, to variation in altitude or ambient temperature. In such an event the unaltered rate of fuel supply will, with the changing conditions, cause the engine speed to increase or decrease as the case may be. This, according to the present invention, will react through the control and follower members to bring about the appropriate variation in the rate of fuel supply until the engine is running at the selected speed but in the changed conditions. From the above it will be seen that any position of the operator's lever or other actuator will correspond to a definite R. P. M. of the engine irrespective of influences such as changes in altitude or ambient temperature which tend to alter the engine speed.

The control and follower members may directly operate means for metering the fuel flow, whether in a delivery line or in a spill return line, or they may control some intermediate means by which the fuel may be controlled. As an example of

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the latter form of systems, the output of a variable delivery pump, or the setting of a metering orifice, may be controlled by fluid pressure means the sense of operation of which is determined by the relationship of the control and follower members.

In order that it may be clearly understood and readily carried into effect, the invention will now be described with reference to the accompanying diagrammatic drawings, of which:

Figure 1 is a schematic layout diagram of a fuel supply system according to the invention.

Figure 2 is a section through the compensating means embodied in the Figure 1 arrangement, and

Figures 3, 4 and 5 are sections taken respectively on the lines III—III, IV—IV and V—V of Figure 2.

The system now to be described has been developed as an absolute speed control for an internal combustion reaction turbine for aircraft propulsion. In Figure 1, the reference numeral **35** represents a variable delivery pump. In this case, the pump is of the radial cylinder type with plungers **36** operating in the radial bores **37** of the rotor which is driven for rotation by an external drive connection. The cylinder assembly rotates about the stationary spindle **38**, which incorporates the inlet port **39** and the outlet port **40**. Slipper bearing members **41** are mounted on the outer ends of the plungers and abut against the internal periphery of the track ring **42**, the eccentricity of which is variable about the pivot **43** so as to vary the effective stroke of the plungers in rotation. As shown in Figure 1, the track ring is in a minimum eccentricity condition at which the delivery is at its minimum.

The pump takes liquid fuel from the fuel supply tanks along the conduit **44** and fuel feeds into the inlet port **39** and is then pumped via the pistons through the outlet port **40** of the pump for delivery past the emergency fuel control cock **45** along the conduit **46** to the burner ring **47**. The burner ring is provided with a number of burners **92**, at least one for each combustion chamber of the turbine. For details of such burners and the fuel supply system wherein they may be employed, reference is made to my copending application Serial No. 2343, filed January 14, 1948. The fuel delivery conduit **46** runs through a governor controlled valve **48** which provides an overspeed control limiting the maximum speed of the turbine and a starting accumulator **49** also feeds into the fuel delivery conduit **46**.

In the case of the arrangement shown in Figure

1, the eccentricity of the pump track ring 42 is controlled by a fluid actuated piston 50. The piston is provided with a central slot into which the control arm 51 of the track ring projects. The piston is loaded to a maximum eccentricity position for starting purposes by the spring assembly 52 and the piston operates in the cylinder 53 with fluid supply conduits 54 and 55 respectively running to each end of the cylinder. Fluid supplied for track ring eccentricity variation is tapped off the fuel supply conduit 44 running between the tanks and the pump through the actuating system supply conduit 56 leading into the auxiliary pump 57, which in this case is a gear pump. The conduit 58 leads from the pressure outlet of the auxiliary pump 57 into the central annulus 59 of a rotary control valve 60, the details of which will later be described, but, for the time being, it suffices to explain that according to whether the electric motor 61 tends to be driven at a higher or lower speed than the speed of rotation of the engine driven shaft 62, actuating fluid is metered by the valve to flow either along the conduit 54 or along the conduit 55. The arrangement is in fact such that delivery of actuating fluid along the conduit 55 into the cylinder 53, moves the track ring control plunger 50 leftwardly for reduction of eccentricity of the track ring whereby to reduce the quantity of fuel delivered along the fuel delivery conduit 46 to the burner ring. Conversely, actuating fluid supplied at pressure along the conduit 54 increases track ring eccentricity.

A drive to the engine speed responsive shaft 62 is picked up through the pinion 63 and the electric motor 61 is supplied from a conveniently available source of electric power through the power cable 64 which leads up to a variable resistance housed in the control box 65. The current passed to the motor from the control box can be varied by manipulation of the engine speed control lever 66 which operates directly upon the variable resistance, current flowing from the resistance to the motor through the current lead 67. The speed of rotation of the motor which is designed so as to be capable of exceeding the intended maximum speed of rotation of the engine speed responsive shaft 62 can thus be varied by manipulation of the engine sped control lever 66. The purpose of the resistance box 90 will presently appear, and can be disregarded at this stage.

Dealing now with the detail construction of the rotary valve, the details are best seen with reference to Figures 2, 3, 4 and 5, through the main parts are shown in the schematic layout of Figure 1. The basic elements of the valve are two-ported rotary sleeves, the inner sleeve 68 of which is revealed in Figure 1 by breaking away of the ends of the outer sleeve 69. Both sleeves have co-operating ports, of which the ports 70 and 71 of the outer sleeve are visible in Figure 1, whereas the ports of the inner sleeve which co-operate with the ports 70 and 71 are seen respectively in Figures 4 and 6. It is convenient to refer to the ports which operate for metering the flow, as control ports. Thus the ports 70 and 71 of the outer sleeve are the control ports of the outer sleeve and, correspondingly, the control ports of the inner sleeve which co-operate with the control ports 70 of the outer sleeve are designated by the reference numeral 72. Likewise, the control ports 73 of the inner sleeve co-operate with the control ports 71 of the outer sleeve. The orifice area which is variable for

flow metering purposes is thus controlled by relative rotary displacement of the inner and outer sleeves, which can rotate relatively to a limited extent. Fluid flows to the interior of the control valve through the auxiliary pressure supply conduit 58 into the annulus 59 and therefrom through the centre ports 74 of the outer sleeve into an annulus 75 between the inner and outer sleeves and from the annulus 75 through the centre ports 76 of the inner sleeve to pressurize the spaces 77 defined between the inner sleeve and a centre piece 78 fixed therein to extend throughout the length of the inner sleeve 68. It thus follows that the spaces 77 are pressurized to the pressure at the output of the auxiliary pump 57 at all times when the system is working.

At this point in the description, it is believed that it will facilitate matters if the auxiliary system flow be traced through the valve, having particular reference to the sectional Figures 3, 4 and 5. In that respect, Figure 4 is basic in that it deals with the pressurization of the spaces 77, from which it follows, if reference be directed to Figure 3, that, if the inner sleeve 68 be rotated clockwise, as viewed on the section, relative to outer sleeve 69, flow will be permitted from the port 77 through the control port 73 of the inner sleeve and out through the control port 71 of the outer sleeve into the annulus 79 from which actuating fluid can flow along the conduit 55 to the cylinder 53 to operate the plunger 50 to reduce track ring eccentricity, and therefore to reduce the amount of fuel supplied. The inner sleeve 68 is rotated by the electric motor 61, and such a movement corresponds to a decrease of the speed of the electric motor in relation to the engine speed responsive shaft 62 from which the outer sleeve is driven. Movement of the stroke control plunger 50 displaces liquid from the other end of the cylinder 53 along the conduit 54 into the annulus 80 (see Figure 5) and the corresponding relative clockwise movement of the inner sleeve 68, which brings the control ports 71 and 73 of Figure 3 into register, also brings the ports 70 of the outer sleeve into register with the ports 72a of the inner sleeve which lead into the exhaust spaces 81 which, like the pressure spaces 77, extend throughout the length of the inner sleeve. The exhaust spaces 81 are in communication with the central exhaust duct 82 through the transverse port 83 seen in Figure 4 and, in dotted lines, in Figures 3 and 5, and the exhaust from the central exhaust duct 82 is piped away back into the fuel supply reservoir.

If, on the other hand, it is required to increase the speed of the turbine, the speed of the electric motor is correspondingly increased to bring about counter-clockwise movement of the inner sleeve 68 with respect to the outer sleeve 69 and the valve operates exactly as before except with flow reversed, so that auxiliary fluid passes along the conduit 54 to the cylinder 53 with return flow along the conduit 55, and the stroke of the pump and the volume of fuel supply is correspondingly increased.

In operation of the system, starting up from cold, the valve 45 is first operated to open the pump delivery output into the fuel delivery conduit 46 and the engine is run up on the starter. The track ring 42 of the fuel pump is loaded by the spring assembly 52 to a maximum eccentricity position which ensures an adequate supply of fuel for starting. Fuel is piped along the conduit 46 through the governor controlled valve which, be it remembered, operates only as a maximum speed governor. As is usual in gas turbines used for aircraft propulsion, the burners incorporate relief valves which open only when a predetermined pressure has been reached in a fuel supply system. Such an expedient is to ensure a predetermined and adequate delivery of fuel and to prevent burner trouble which might otherwise result in unsatisfactory combustion. By reason of the fact that the valves are operating in the initial stages of running up the engine, fuel is delivered into the small starting accumulator 49 in which compression pressure is built up against resilience in some form until the starting pressure is reached and, at that stage, the relief valves on the burners are opened and a steady delivery of fuel ensues at the burners. The fuel is quickly ignited by the usual electrical igniting means and then very quickly burns continuously. For starting purposes, of course, the engine speed control lever 66 will have been set to the required starting speed which thus limits the driven speed of the electric motor 61 and the result is that, once having started, the engine quickly begins to race so that the inner sleeve 68, driven as it is by the electric motor, immediately tends to lag with respect to the engine speed responsive outer sleeve and fuel is delivered through the conduit 55 to the cylinder 53 to operate the stroke control plunger 50 for reduction of track ring eccentricity against the spring loading 52. Thus, idling speed is achieved almost instantaneously on starting up.

Once having started, any increase dictated by the engine speed control lever 66, speeds up the electric motor until the inner sleeve 68 driven thereby is rotating at such a speed that the engine speed responsive sleeve 69 is the laggard and actuating fluid is delivered to the other end of the cylinder 53 to operate the stroke control plunger 50 for increase of eccentricity of the track ring.

When operating under ideal conditions at a steady setting of the engine speed control lever, the speed of rotation of the sleeves 68 and 69 is identical and once the sleeves 68 and 69 have settled down after the last previous adjustment of the engine speed control lever they will theoretically blank off the pipe lines 54 and 55, though in actual practice it is believed that such an ideal theoretical set up will rarely prevail. The fact that the sleeves 68 and 69 rarely stabilize so precisely does not introduce "hunting" of the speed of the turbine because the response to speed changes is practically instantaneous.

It must be appreciated that the relative movement provided for between the inner and outer sleeves 68 and 69 respectively must be limited to such an extent that at one limit the cooperating ports 70, 72 and 71, 73 are fully in register, whereas in the other limits they are blanked off. To provide such limited relative movement, it suffices to provide co-operating dog and slot projections between the two drives, the one respectively operating between the electric motor driven shaft and the inner sleeve 68 and the other between the engine speed responsive shaft 62 and the outer sleeve 69.

The governor controlled valve 48 has governor weights 85 which are driven for rotation from a suitably arranged auxiliary drive shaft through the pinion 84. Increasing engine speed swings the governor weights 85 out against the loading exerted by the compression spring 86 and, if a predetermined maximum speed is achieved, the upper land 87 of the governor controlled valve 48 opens pump delivery into the relief passage 88. The fuel flowing to the burner ring is thus cut down to effectually limit the maximum speed, excess fuel being returned back to the inlet of the pump 35.

It will appreciated that numerous modifications may be incorporated without departing from the nature of the invention; thus the motor 61, which is the actual speed controlling means, might conceivably be a hydraulic motor or air driven motor, but, in that respect, it should be stated that an electric motor presents many points of advantage. One such advantage has in fact been subject to consideration in the present system where specifically adapted for supplying fuel to a gas turbine for aircraft propulsion on the jet reaction principle. In such installations, burner failures have introduced difficulties because of disproportioned metering of the fuel to the remaining burners should one or more burners fail. To avoid overheating of the remaining burners, a thermo-couple is fitted to each burner, viz. the thermo-couple 91 fitted to the burner 92 in Figure 1. The thermo-couple 91 is connected by a current lead 93 to an amplifying stage 94 which is in turn connected by the current lead 89 to the resistance box 90. If the burner 92 fails, the thermo-couple 91 acts through the amplifying stage 94 upon tappings in the resistance box 90 to increase the resistance in the motor current lead 67. The speed of the electric motor 61 is thereby reduced, and consequently the total fuel supply to the remaining burners is proportionately cut down.

It is an important feature of the present invention that speed compensation throughout the whole speed range can be achieved without the necessity for an over-ride barometric control such as has hitherto been regarded as necessary in aircraft which may be called to operate at any altitude from sea level to 40,000 or 50,000 feet, at the present stage of development.

The fuel control cock 45 serves a dual purpose. On the one hand it operates as a shut-off cock when the system is not operating, in which event the delivery is opened back into the relief port 88 so that the pumps or the system will not be injured should the starter be operated with the fuel delivery conduit 46 shut off, whereas, on the other hand, it can be used in emergency should the automatic compensating side of the system fail, in which event the pilot can still land in emergency by manual manipulation of the control cock 45.

It is believed that the only other item which is seen in the drawings and which has not so far been referred to is the relief valve 91 which operates to relieve any excessive pressure which may be developed in the auxiliary system. To that end, the spring loaded relief valve 92 can be blown open against the loading exerted by the compression spring 93 to give relief into the pump casing and therefrom into the inlet side of the pump.

It will be appreciated that the rotary form of control valve of Figure 1 might be employed equally well as a variable restriction directly metering the fuel supply, or the spill return line from the burners, in which event the pump 35 could be replaced by a constant delivery pump.

I claim:

1. A control valve for use in a fuel system for an aircraft internal combustion turbine engine, in which fuel system a pressure-fluid operable shifter is operatively connected to decrease or increase the effective fuel supply, said valve com-

prising two concentric, rotative sleeves, one of said sleeves constituting a follower sleeve arranged for connection to and for rotation at a speed corresponding to the speed of the engine, and the other of said sleeves constituting a control sleeve and being arranged for rotation at a speed which is variable at will, but constant at any selected speed, means so to rotate said control sleeve at any selected speed within a range embracing the operative speeds of the follower sleeve, a fixed central core, affording supply and drainage connections, respectively, each of limited angular extent, within the inner sleeve, and a casing surrounding the outer sleeve and defining axially spaced annuli pressure connected to the shifter to effect, respectively, opposite movement thereof according to which annulus is pressurized, the two sleeves being complementally ported, in registry with each annulus, and each port registering, as it rotates, alternately with the pressure supply and the drainage connections, the ports for registry with one annulus being angularly spaced relative to those for registry with the other annulus, whereby to determine the connection of one or the other annulus to the pressure connection, and the other to the drain connection, in accordance with which of said two concentric sleeves tends to overrun or to lag behind the other.

2. A control valve as in claim 1, wherein the shifter constitutes the track ring of a variable-delivery pump which by its shifting effects decrease or increase in effective fuel supply to the fuel system, and a plunger operatively connected to shift said track ring, and itself pressure-connected to the valve's annuli for actuation automatically under control of said valve.

3. A control valve as in claim 1, including a variable-speed electric motor operatively connected to rotate the control sleeve at any one of a plurality of constant speeds, and means manually operable to alter the speed of said electric motor.

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