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SYSTEM FOR REGULATING THE SUPPLY OF LIQUID FUEL TO A GAS TURBINE

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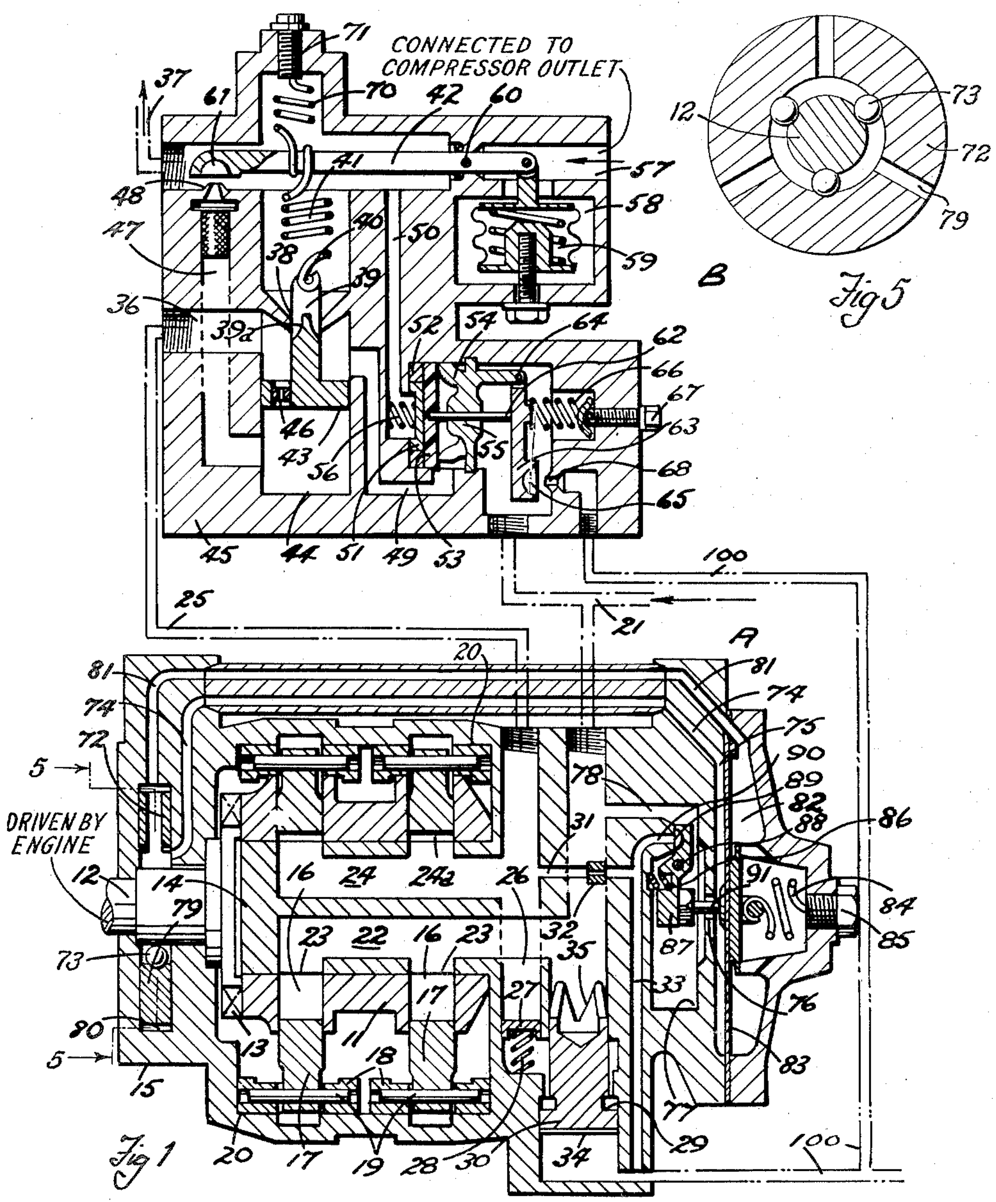

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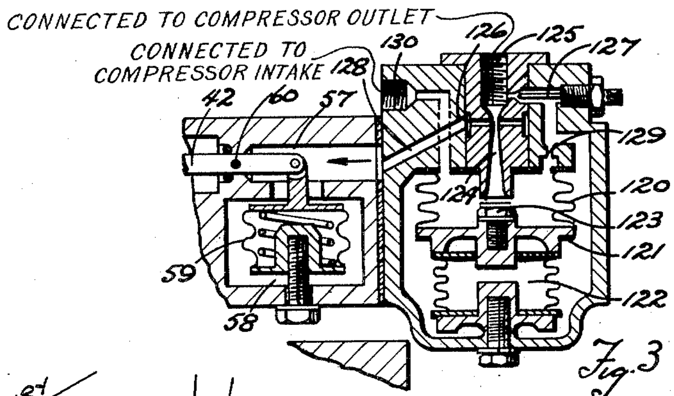

Fig. 3

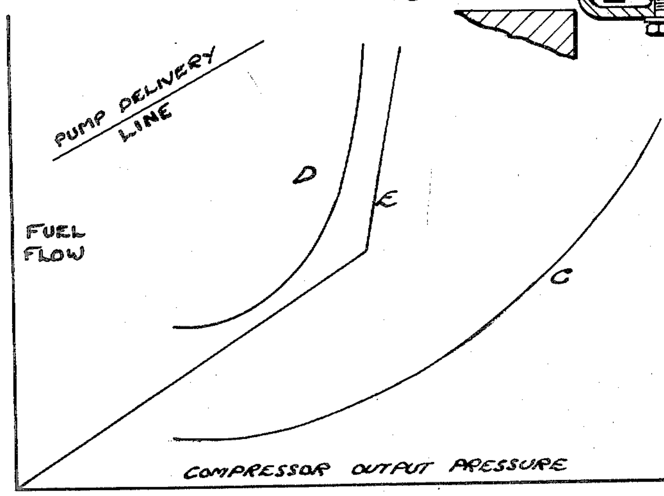

Fig. 2

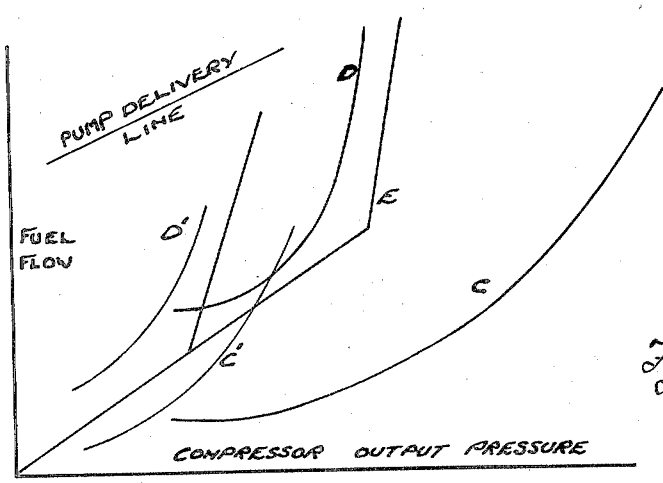

Fig. 4

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SYSTEM FOR REGULATING THE SUPPLY OF LIQUID FUEL TO A GAS TURBINE

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1 Claim. (Cl. 60—39.28)

This invention relates to a system, for regulating the supply of liquid fuel to a gas turbine engine, of the kind including a constant-delivery, engine-driven pumping unit the effective delivery of which is controlled by a pressure-responsive control plunger, without any spring control, which serves as a spill valve and which has the effective delivery pressure applied to one face, whilst the opposite end of the chamber in which the control plunger works is connected to the end at which the effective delivery pressure is supplied through a restrictor orifice, and it also communicates with a passage (hereinafter referred to as the control passage) the pressure in which can be regulated dependently upon operating conditions. To increase the effective delivery the pressure in the control passage must be increased.

Such a pumping unit is provided with means to control the fuel flow at a predetermined maximum engine speed in order to prevent over-speeding of the engine, the means acting upon the pressure in the control passage, or in another control passage provided in parallel therewith.

The main object of the invention is to prevent the engine from stalling, due to overfuelling, when the throttle control is rapidly opened.

The invention comprises the combination with a regulating system of the kind specified in the first paragraph of this specification, of an air/fuel ratio device through which the effective delivery of the pumping unit is passed, the device having a variable choke adapted to set up a pressure difference between the inlet and outlet sides of the choke without the choke being affected by the said pressure difference, and the pressure difference is applied for actuating a valve for the control passage, or for another control passage in parallel therewith, the choke being actuated responsively to a function of the output pressure of the compressor of the engine.

In the drawings:

Figure 1 shows, diagrammatically, one form of apparatus for carrying the invention into practice;

Figure 2 is a graph illustrating the corresponding operating conditions;

Figure 3 shows, diagrammatically, a modified apparatus;

Figure 4 is a graph illustrating the operating conditions of the apparatus in Figure 3; and

Figure 5 is a section on the line 5—5 of Figure 1.

In Figure 1 is shown a constant delivery, engine-driven pumping unit, indicated generally at A, and an air/fuel ratio device at B.

The pump has a rotor 11 which is concentrically fast with a driven shaft 12, the two being formed separately but having a toothed engagement at 13 to lock them together. The bore of the rotor, also concentric with the shaft, is journalled on a core 14 which is fast at one end with the pump body 15. The rotor has radial bores 16 in which work pistons 17 having, at their heads, slippers 18 which are journalled on transverse pins 19 of the pistons and make frictional contact with a bore 20 of the pump body, this bore being eccentric with respect

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to the shaft. Thus, as the shaft 12 is rotated, the slippers, in riding round the bore 20, cause the pistons 17 to be reciprocated in the radial bores 16 of the rotor.

Fuel is fed from a line 21 to a duct 22 in the core, from which duct it is delivered through ports 23 to the radial bores 16 when the pistons are at their radially outmost position, and rotation of the rotor causes the fuel in the bore 16, on the return stroke of the pistons, to be delivered, through other ports 24*a* to a duct 24 in the core, to a pressure line 25.

Within the pump body there is a duct 26 which communicates with the delivery duct 24 and contains a piston-type valve 27 which is biassed against the delivery pressure by a spring 28. When the pump delivery reaches a predetermined pressure, the valve 27 opens to deliver fuel, through a lateral port, to react on an axial end wall 29 of a peripheral groove in the movable member 30 of a spill or by-pass valve. The delivery duct 24 also communicates, through a duct 31 having a constriction 32, with a duct 33 leading to an opposite end face 34 of the spill valve member 30, whereby, when the pressure in the delivery duct 24 exceeds a predetermined value, the pressure drop across the constriction causes the spill valve member 30 to control the opening of the lateral port communicating with the inlet duct 22. Thus the member 30 can have a hollow end with V-shaped castellations 35 the spaces between which, when the member 30 is appropriately moved, establish the communication between the ducts 24 and 22.

The pump delivers through the line 25 to a chamber 36 of the air/fuel ratio device B. This chamber communicates with a line 37, from which the combustion chamber burners of the engine are supplied, through a constriction 38 which is normally open but only to an extent controlled by a valve member 39 which is movable responsively to a function of the pressure of the compressor output. The valve member 39 is generally cylindrical, being a sliding fit in the constriction 38, and it is slotted on opposite sides to form curved portions 39*a*, the axial position of which in the constriction controls the effective area of the passage through the latter, the constriction 38 and member 39 thus constituting a variable choke.

The slotting of the valve member 39 bifurcates it at the top, where a pin 40, which unites the arms formed by the bifurcation, serves as an anchorage for one end of a spring 41 of which the other end is fast with a lever 42 presently to be described. The valve member 39 is fast with a piston 43 working in a cylinder 44 formed in the body 45 of the air/fuel ratio device, and the piston has a small leak path indicated at 46. Movement of the piston 43 causes the valve member 39 to move in the constriction 38 and thus varies the effective area of the constriction and, therefore, the pressure drop from the chamber 36 to the line 37 (although this pressure drop is subsequently restored as hereinafter described). The fuel which passes through the leak path 46 fills the cylinder 44, and the latter has an outlet path 47 which communicates, through a controlled valve orifice 48 (presently to be described) with the line 37.

The pressure drop across the constriction 38 is applied by ducts 49, 50 to opposite sides of a piston 51 working in a ring-like cylinder 52. The piston 51 is fast with a resilient diaphragm 53, which is trapped between the adjacent end of the cylinder 52 and an interrupted peripheral flange 54 of a cup-like member 55 fast with the body 45, and the piston 51 is loaded by a spring 56 to balance the pressure difference when the latter is of a predetermined value.

If the engine throttle (not shown) be opened suddenly for accelerating the engine, there is a danger that the engine will be overfuelled and stall. To prevent this, it is arranged for the fuel supply to the engine, consequent on a sudden opening of the throttle, to be under the control of a function of the compressor output pressure.

This is done, as shown diagrammatically in Figure 1, by communicating the compressor output pressure through a duct **57** into a chamber **58** in which there is a pressure-sensitive capsule **59**. Thus, when the compressor output commences to increase consequent on the throttle opening movement, the capsule is compressed, causing the lever **42** to move about its pivot **60** in the body **45** to increase the clearance between a half-ball-valve member **61** and the valve orifice **48**. This relieves the pressure in the chamber **44** and enables the piston **43** to be depressed, responsively to the pressure in the chamber **36**, against the effort of the spring **41**. This depression of the piston **43** moves the valve member **39** to increase the effective area of the constriction **38** in step with the increasing compressor output pressure.

The depression of the piston **43** increases the tension in the spring **41** and thus applies a force to the lever **42** to restore the previous clearance between the half-ball-valve member **61** and the orifice **48**, but with the valve member **39** in a new position in which the effective area of the constriction **38** is increased.

At the same time, this further opening of the constriction reduces the pressure drop across it, and the new pressure drop is applied through the ducts **49** and **50** to cause the piston **51** to move, through a push rod **62**, an arm **63**, pivoted at **64** to the cup-like member **55**, moving a half-ball-valve member **65** towards the closed position.

The arm **63** is also acted upon by a spring **66** which, through a screw means **67**, enables the effort of the spring **56** to be adjusted.

When the arm moves the half-ball-valve **65** towards the closed position it constricts a valve orifice **68** partially to cut off a leak path, through a control passage **100**, from beneath the movable member **30** of the spill valve to pump supply line **21**. This causes the pressure beneath the spill valve member **30** to increase, thus moving it in the direction to reduce the leak path from the duct **26** to the pump intake. In this way a greater proportion of the pump delivery is supplied through the line **25** to the fuel burners and restores the predetermined pressure difference across the constriction **38**, permitting the piston **51** to recover and the half-ball-valve **65** to assume a position, relative to the orifice **68**, for maintaining the fuel flow from the pump which re-established the pressure difference across the constriction **38**.

During acceleration of the engine, the increasing compressor output tends to operate the valve **48**, **61** in the opening direction, whereby to allow the piston **43** to move for opening more widely the constriction **38**. The resultant temporary drop in the pressure difference across the constriction **38**, however, is applied by the piston **51** for decreasing the passage of the fuel through the orifice **68** back to the line **21** from the line **100** whereby the pump is caused to deliver a greater proportion of its output to the line **25** to restore the pressure drop across the constriction **38**. In these conditions the supply of fuel to the line **37** is increased to maintain an air/fuel ratio which is at all times below the stalling characteristic of the engine.

The lever **42** besides being biassed downwardly by the spring **41** is also biassed upwardly by a spring **70** with an adjustable anchorage **71**, whereby the effort of the spring **41** can be adjusted.

These conditions of operation are illustrated by Figure 2 in which fuel supply in gallons per hour is plotted against the compressor output pressure which, of course, at any given altitude is related to the engine speed. The curves C and D represent, respectively, the engine running and stall lines at sea level, and it will be seen that, with the engine running smoothly in the lower speed range, a sudden opening of the throttle could result in a sufficient supply of fuel to stall the engine before the latter could accelerate sufficiently for adequately increasing the compressor output for burning the extra fuel. The control exerted by the invention is represented by curve E from which it will be seen that the increased supply of fuel, consequent on a sudden opening of the fuel valve, is restricted to a value beneath that at which there is a danger of stalling the engine.

From medium engine speeds upwards, the stall curve rises steeply and, so that high accelerations from such speeds can be obtained, it is arranged that the valve member **39** shall, in that speed range, be in a position in which the constriction **38** offers a minimum of resistance to the fuel flow to the line **37**, and this is represented by the steeper portion of the curve E.

To prevent more fuel being supplied to the burners than the engine needs at a predetermined maximum speed, there is a disc **72** which is made rotatively fast with the pump shaft **12**, by angularly-spaced balls **73** engaging longitudinal grooves of the shaft and of the disc. The space between the balls **73** communicates, through a duct **74**, with the supply line **21** to the pump, the communication being through a diaphragm chamber **75**, a clearance space **76**, a chamber **77** and a duct **78**. The disc **72** has radial bores **79** in which a centrifugal pressure is developed and transmitted, through an annular gallery **80** in the body **15**, and a duct **81** to an opposed diaphragm chamber **82**.

The diaphragm **83** separating the chambers **77** and **82** is biassed by a tension spring **84**, having an adjustable anchorage **85**. A compression spring **86** biasses a lever **87** about its pivot **88** to close a valve **89** in a duct **90** leading from the duct **31** with the constriction **32**. When there is any tendency to over-speed and the pressure difference in the chambers **77** and **82** exceeds a predetermined figure, as controlled by the spring **84**, a stem **91** contacting the diaphragm **83** rocks the lever **87** to unseat the valve **89**, allowing some of the fluid in line **33** to return to the intake line through the chamber **77** and duct **78**. This reduces the pressure under the spill valve **30**, enabling it to by-pass a greater proportion of the pump output to the intake line. In these circumstances, therefore, the fuel flow is controlled by the pump speed only, overriding the air/fuel ratio control.

The previously described acceleration control, operating with the compressor output pressure only, does not operate satisfactorily at high altitudes owing to the air/fuel ratio control limiting the maximum speed of the engine. This is illustrated by Figure 4 in which the curves D1, C1 are the ones which correspond with curves D and C at a particular high altitude. It will be seen that the curve C1 is intercepted by the curve E so that the engine speed cannot rise above the value corresponding with the point of interception. With increasing altitude, therefore, it is necessary to modify the curve E by bringing its steeply rising portion nearer the origin so as to lie between the curves D1 and C1 as shown. This can be done by the pressure sensitive arrangement shown in Figure 3, which enables the air/fuel ratio control to act responsively to the compression ratio of the compressor.

The pressure sensitive arrangement of Figure 3 includes a pressure sensitive capsule **120** which has a common wall **121** with a second, and smaller capsule **122** which is evacuated. The wall **121** carries a movable valve member **123** which, at a predetermined compression ratio closes the outlet of a venturi passage **124** which otherwise establishes a communication between the interior of the capsule **120** and the compressor outlet through a duct **125**. The throat of the venturi passage communicates with an annulus **126** which, in turn, communicates through a duct **128** with the chamber **58**. Thus when the valve member **123** is in open position the static pressure in the venturi throat is transmitted to the chamber **58**, and when the valve **123** is in closed position the compressor output pressure is transmitted to the said chamber **58**.

Pressure from the duct **125** is also delivered, through an adjustable needle valve **127**, to the exteriors of the capsules **120** and **122**, the pressure in the chamber around the capsules acting on the capsule assembly in the direction for closing the valve member **123**. The air which has passed the needle valve **127** also passes into the interior of the capsule **120** through a restrictor orifice **129**, the interior of the said capsule **120** communicating, through a duct **130**, with the compressor intake.

During a rapid acceleration of the engine the pressure ratio of the compressor increases with speed, and while the valve **123** is in open position a lower pressure than the compressor output pressure is transmitted to the chamber **58** from the throat of the venturi **124**. This lower pressure is arranged to produce a fuel flow to the engine at all times below the stall line of the engine. At the same time, a reduced value of the compressor output pressure is also acting on the exterior of the capsule assembly **120**, **122** and at a value of the compressor pressure ratio at which a sudden increase in fuel flow will not produce stall conditions, this pressure closes the valve **123**. As the valve **123** closes, the pressure in the chamber **58** rises to the actual value of the compressor outlet pressure since the air flow through the venturi ceases, giving a larger opening of the constriction **38** and hence a suddenly increased fuel flow to the engine.

Since the valve **123** is closed responsively to the compressor pressure ratio, which in turn is related to the speed of the engine, the relationship of the sudden increase in fuel flow to the engine stall line at any altitude will not vary.

For matching the air/fuel ratio device to any particular engine, the needle valve **127** can be adjusted in order to secure that the valve **123** will close at an appropriate pressure ratio of the compressor.

What I claim as my invention and desire to secure by Letters Patent of the United States is:

A regulating system, for the supply of liquid fuel to a gas turbine engine including an air compressor and a burner for the fuel, comprising the combination of a constant-delivery pumping unit, to be driven from the engine, and an air/fuel ratio device for regulating the fuel supply dependently on the air available at the compressor outlet at both steady and fluctuating speeds, said unit including a delivery passage and a spill passage, a pressure-responsive control plunger for controlling said spill passage and thus the effective delivery through said delivery passage, a communication from said delivery passage to one face of said plunger, a communication, containing a restrictor orifice, from said delivery passage to an opposite face of said plunger, a valve in said air/fuel ratio device, a control passage communicating between said opposite face of said plunger and said valve of said air/fuel ratio device, a variable choke in said device, said choke in the path of a communication between said delivery passage and said burner, said choke adapted to set up a pressure difference between its inlet and outlet sides without said choke being affected by said pressure difference, means responsive to such pressure difference for actuating said valve of said device, a piston fast with a movable member of said choke, said piston having a leak path in parallel with said choke, a movable valve member controlling said leak path, a pressure sensitive device, said sensitive device being a pneumatic capsule which is biassed to an extended position, said capsule being in a chamber to which is led through a change-over device a pressure which is a function of the compressor output pressure, said change-over device including a pair of aligned, opposed pneumatic capsules of different sizes, a common wall at the adjacent ends of said pair of capsules, a coaxial duct in the larger capsule of said pair, a valve member fast with said common wall and coacting with the adjacent end of said duct, the remote end of said capsule to receive air at the compressor output pressure, said duct of venturi formation and having a lateral communication with said chamber, an envelope containing said pair of capsules, a restrictor through which the compressor output air passes with pressure reduction to be applied to the exterior of said pair of capsules, and a restrictor through which air from said envelope passes with further pressure reduction to the interior of the larger of said pair of capsules, the interior of the larger of said pair of capsules communicating with the compressor intake, whereby, above a predetermined pressure ratio of said compressor, the valve member fast with said common wall closes said adjacent end of said duct to cause the compressor output pressure to be applied to said chamber, and below said predetermined pressure ratio said valve member fast with said common wall opens said adjacent end of said duct to cause a lower pressure than that of said compressor output to be applied to said chamber, and a lever interconnecting said pressure sensitive device and said movable member whereby to vary the effective size of said leak path for enabling said movable member to adjust itself for maintaining constant the pressure difference between the inlet and outlet sides of said choke.

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