March 12, 1963 H. J. WOOD 3,080,712

COMPRESSOR ANTI-SURGE CONTROL FOR A GAS TURBINE ENGINE

Filed Feb. 5, 1959 5 Sheets-Sheet 1

FIG.1.

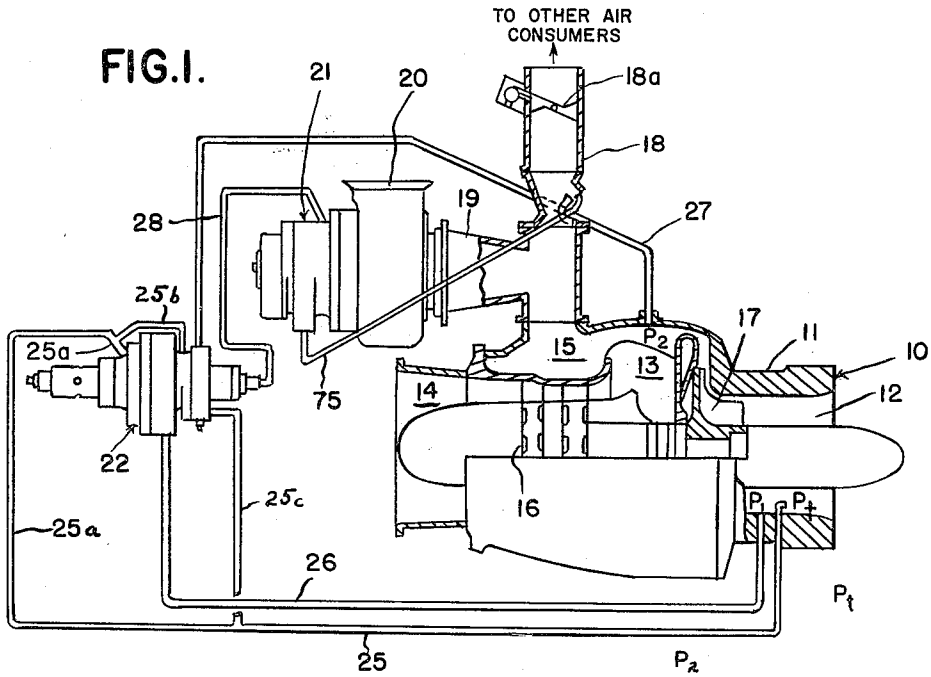
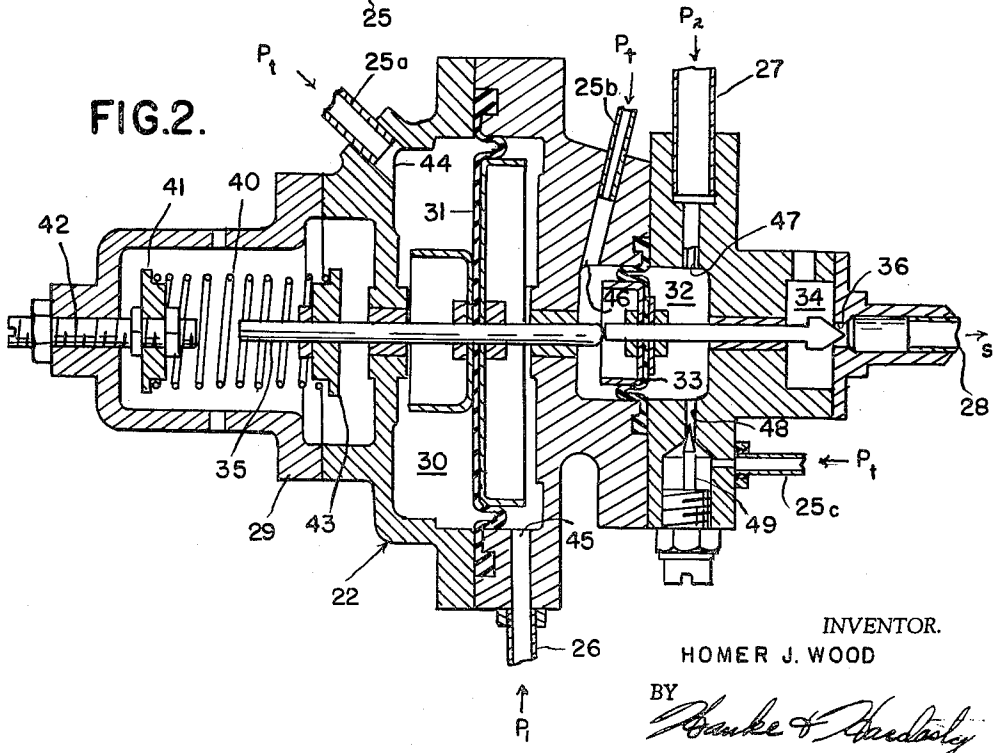


FIG.2.



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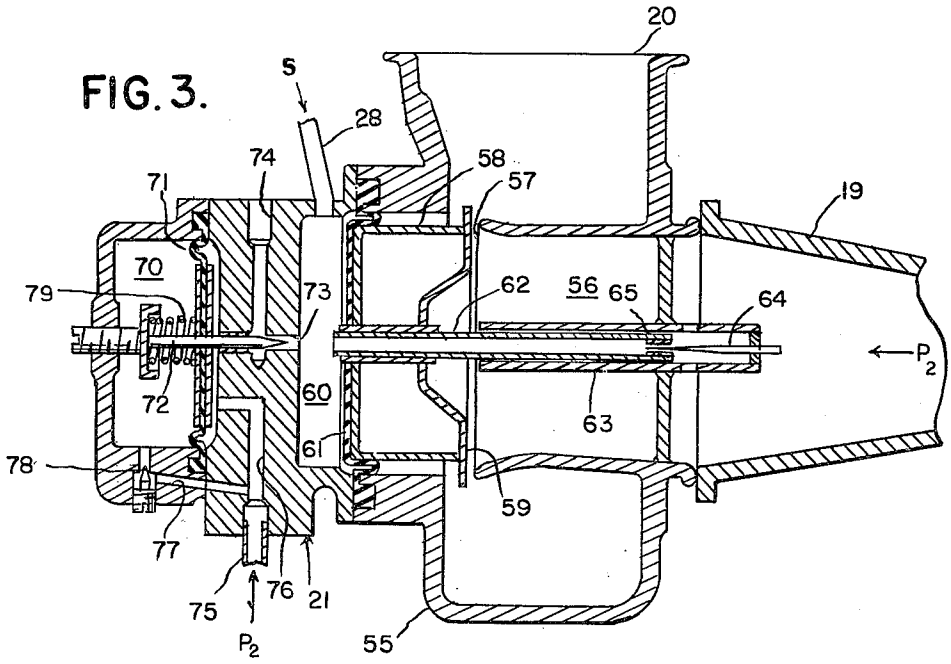
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COMPRESSOR ANTI-SURGE CONTROL FOR A GAS TURBINE ENGINE

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FIG. 3.



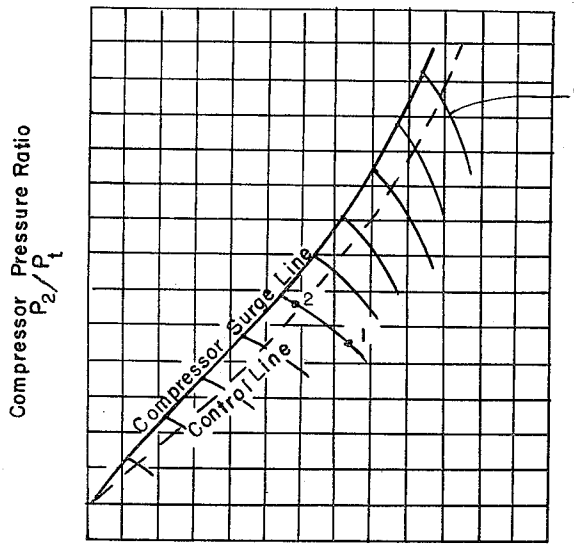


FIG. 4.

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COMPRESSOR ANTI-SURGE CONTROL FOR A GAS TURBINE ENGINE

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FIG.5.

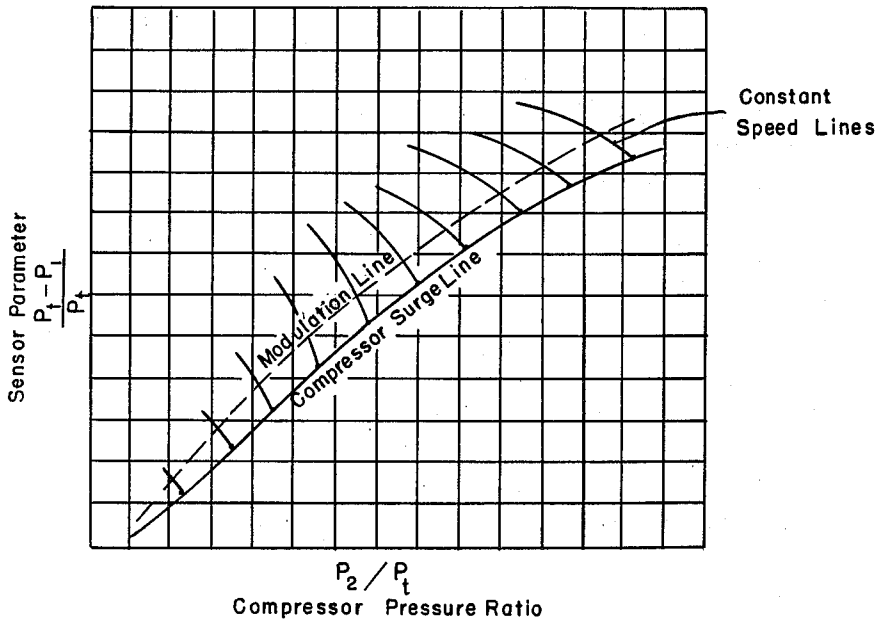


FIG.7.

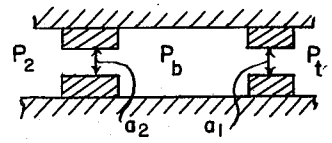
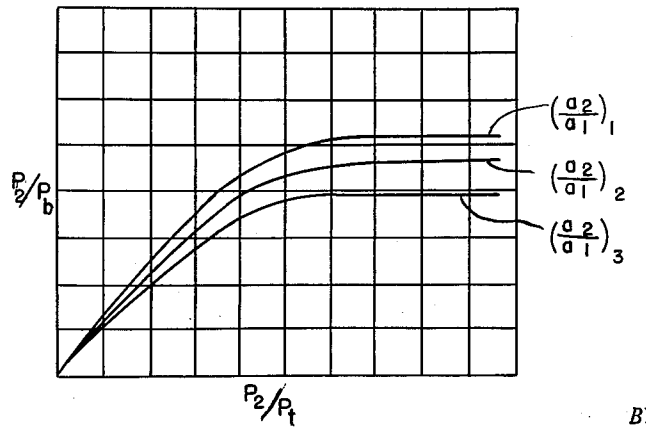


FIG.6.



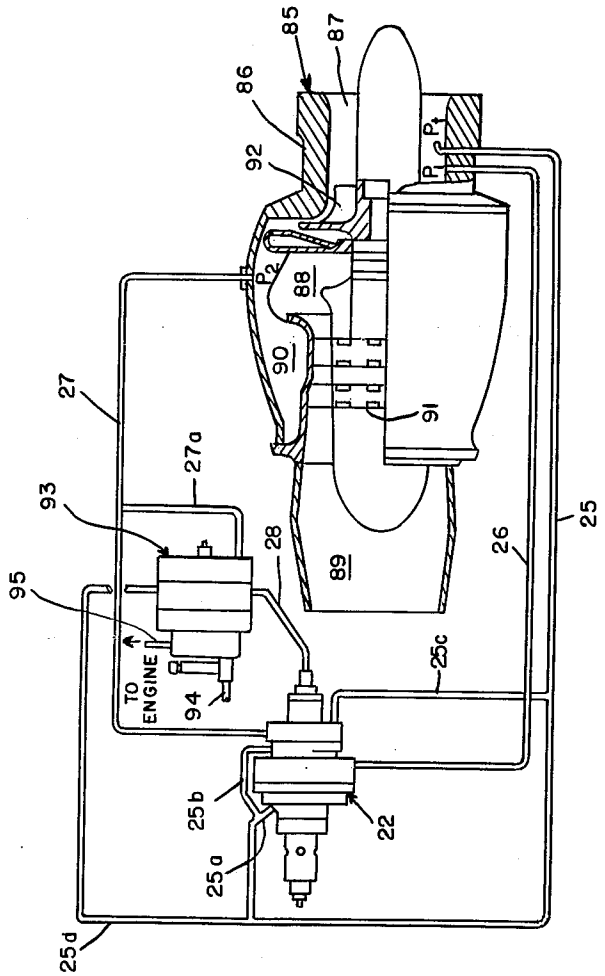
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March 12, 1963 H. J. WOOD 3,080,712

COMPRESSOR ANTI-SURGE CONTROL FOR A GAS TURBINE ENGINE

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FIG.8.



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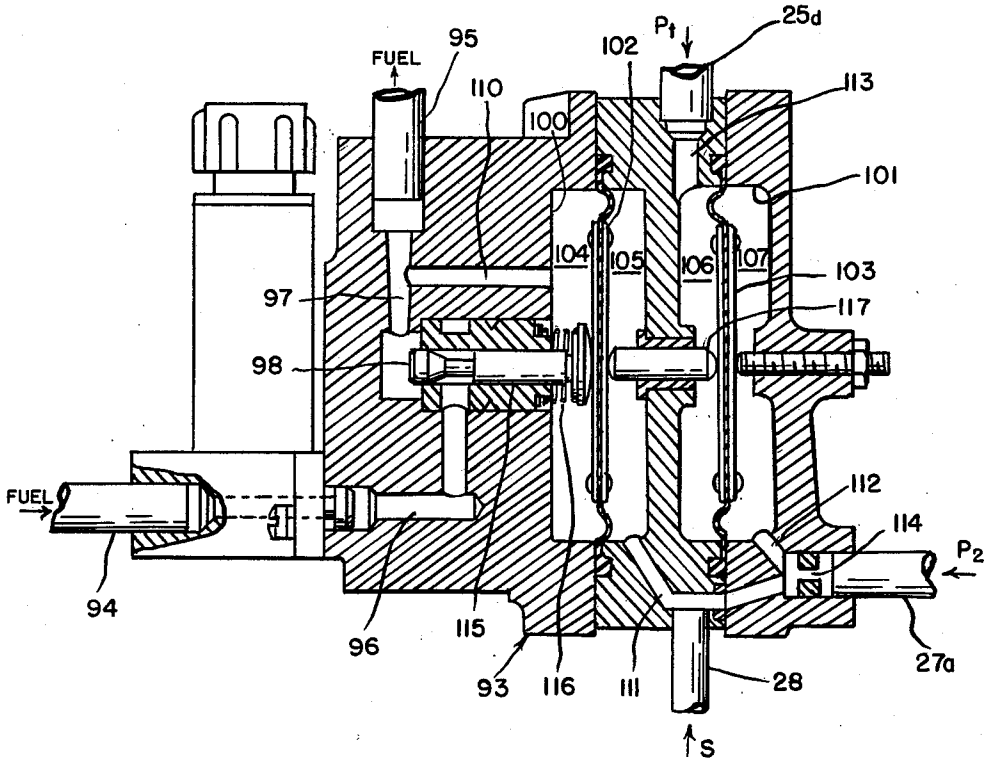
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COMPRESSOR ANTI-SURGE CONTROL FOR A GAS TURBINE ENGINE

Filed Feb. 5, 1959 5 Sheets-Sheet 5

FIG.9.



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United States Patent Office 3,080,712 Patented Mar. 12, 1963

3,080,712

COMPRESSOR ANTI-SURGE CONTROL FOR A GAS TURBINE ENGINE

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Filed Feb. 5, 1959, Ser. No. 791,447
18 Claims. (Cl. 60—39.29)

This invention relates to control systems for gas turbine engines, and more particularly to a pneumatic surge control sensor system operable to prevent compressor surge by discharging controlled amounts of compressor airflow.

Compressor surge in gas turbine engines results in violent pulsations of gas flow and pressure. These upset the operating cycle to the extent that gross deterioration of engine performance immediately occurs, and excessive gas temperatures are likely to result. In addition, the pressure variations are so violent that physical damage to the engine may result. Although it is possible to build engines which can withstand surge conditions, or which develop only mild pressure pulsations, undesirable increases in weight and cost are involved. It is a further characteristic of many gas turbines that the most efficient operating point occurs quite close to the compressor surge range, and to avoid surging difficulties by moving the operating point results in undesirable deterioration of performance.

For gas turbine engines used primarily for compressing air for use by other equipment, certain special problems are involved in addition to those encountered in other gas turbines with respect to compressor surge difficulties. In particular, such engines must face very abrupt shut-off of the compressed air demand flow. This results in the very rapid establishment of a condition tending to produce surge. This condition is often called "shock surge," in recognition of the shock effect of a sudden shut-off of air delivery.

Heretofore, little has been accomplished in finding an effective, yet inexpensive and simplified method of avoiding compressor surge conditions.

An object of the present invention is to improve performance of gas turbine engines by preventing compressor operation from reaching surge conditions.

Another object of the invention is to control gas turbine engine operation by providing a system for controlling compressor pressure ratios and airflow.

A further object of the invention is to prevent compressor surge in a gas turbine engine by providing a new pressure sensitive control system operable to discharge controlled amounts of compressor airflow.

Yet another object of the invention is to simplify gas turbine engine controls by providing an automatically operating compressor surge prevention system.

Still a further object of the invention is to prevent compressor surge conditions in a gas turbine engine by providing an automatic pressure sensitive pneumatic valve system operated through a surge sensor which is responsive to compressor operation.

Yet a further object of the invention is to increase the operating efficiency of gas turbine compressors by providing a control system enabling the compressor to operate at the highest effective pressure ratio at all operating ranges.

Still another object of the invention is to prevent surge conditions in gas turbine engines by providing a new pressure sensitive control system operable to modify fuel flow to the engine.

For a more complete unedrstanding of the invention, reference may be had to the accompanying drawings

illustrating a preferred embodiment of the invention in which like reference characters refer to like parts throughout the several views and in which

FIG. 1 is a diagrammatic view of a preferred control system embodying the invention as applied to a preferred gas turbine engine.

FIG. 2 is a longitudinal cross-sectional view of a preferred pneumatic sensor construction as embodied in the system of FIG. 1.

FIG. 3 is a longitudinal cross-sectional view of a preferred servo valve construction as embodied in the system of FIG. 1.

FIG. 4 is a compressor map for purposes of explaining the surge control concept of the invention.

FIG. 5 is another compressor map utilizing different parameters.

FIG. 6 is a diagram illustrating the aerodynamic relationship of two orifices in series.

FIG. 7 is a diagrammatic cross-section of a portion of a chamber in the sensor of FIG. 2.

FIG. 8 is a diagrammatic view of another preferred modification of the invention using the sensor of FIG. 2 for controlling engine fuel flow.

FIG. 9 is a cross-sectional view of a preferred fuel control valve as used in the modification of FIG. 8.

In the embodiment of the invention represented in FIG. 1 a preferred gas turbine engine **10** is illustrated as comprising a housing **11** having an air inlet **12**, a combustion chamber or combustor **13**, an exhaust nozzle **14**, and a compressor air chamber **15**, the housing **11** supporting a turbine **16** and a compressor **17** operable to supply compressed air to the chamber **15**, the compressed air being used in the turbine and also stored for selective delivery through a discharge pipe **18** having a butterfly valve **18***a* for delivery to any compressed air consumer. It will be noted that the compressor is operable to deliver more air than is consumed by the turbine **16**. Connected with the discharge pipe **18** is a bypass pipe **19** having a discharge stack **20** for exhausting excess compressed air as controlled by a servo valve **21**, shown in more detail in FIG. 3 as will be described later.

The servo valve is generally controlled by a surge control sensor **22** illustrated more fully in FIG. 2, as will also be described later. Suitable pressure probes and communicating pressure conduits are also provided.

In order to fully comprehend the function and operation of the present system, an understanding of the known theoretical operating characteristics of an air compressor, such as is utilized in a gas turbine engine, is first necessary. FIG. 4 illustrates, generally, a compressor map on which operation of any compressor may be diagrammed in terms of corrected compressor airflow and compressor pressure ratio, where:

P_2/P_t is the pressure ratio across the compressor; that is, compressor discharge pressure (P_2) per compressor inlet total pressure (P_t), and $W_a\sqrt{\theta}/\delta$ is corrected compressor airflow, where W_a is uncorrected compressor airflow, θ is ambient temperature correction to NACA std., and δ is barometric correction to NACA std.

Note.—In gas turbine engines not in motion, as where used solely to compress air for use by other equipment, compressor inlet total pressure would be equivalent to atmospheric pressure.

With compressor operation described in terms of corrected parameters, the compressor map of FIG. 4 then fixes compressor performance for all inlet conditions and enables one to predict compressor performance for varying inlet conditions.

Compressor surge is a phenomenon associated with the operation of all compressors. For example, assuming NACA standard ambient temperature and barometric

conditions, a compressor operating at a given speed, regardless of its power source, to deliver a certain airflow W_a at some given pressure ratio P_2/P_t (point 1 on the map), and a large air valve downstream of the compressor, a partial closing of the air valve while maintaining compressor speed will reduce compressor airflow W_a and the operating point of the compressor will shift to point (2) on the map. Upon continued closing of the air valve and consequent reduction of airflow, the compressor will reach a state of unstable operation, commonly called compressor surge, and on the compressor map will substantially occur when the operating point reaches a line such as the solid line of FIG. 4. To the left of this line is the unstable operating line, and to the right will be seen typical lines of different constant speeds of the compressor.

With the compressor as part of the compressed air producing gas turbine engine **10** shown in FIG. 1, the combustor **13** and turbine **16** will act on the compressor **17** in a similar manner as the theoretical valve mentioned above; for example, at a given speed, held by any means such as a governor (not shown), an increase in fuel flow to the combustor **13** will raise the temperature of the air (and consequently its volume) and thereby act to decrease compressor air flow, moving the operating point on the compressor map of FIG. 4 toward the surge line. Opening of the butterfly valve **18***a* would increase compressor air flow, moving the operating point on the compressor map away from the surge line. Closing of the butterfly valve **18***a* would again decrease compressor air flow, again moving the operating point on the compressor map toward the surge line.

It will be apparent, then, that a control system operable to bleed off the proper controlled amounts of air will function to maintain compressor operation somewhere to the right of the surge line, and preferably no closer to the surge line than a predetermined value, such as is illustrated by a dash line in FIG. 4. In other words, the control system will function in such a manner that any tendency of the compressor to operate at surge will immediately be offset by increasing compressor airflow so that the operating point of the compressor will remain to the right of the surge line of FIG. 4.

Thus it is seen that corrected compressor airflow is the critical determining factor with which the control system is concerned. In seeking to develop a suitable control system, it was found that corrected compressor airflow could be sensed by measuring static and total pressure at the inlet to the compressor.

$$\text{Mathematically, } \frac{P_t-P_1}{P_t}=f\left(\frac{W_a\sqrt{\theta}}{\delta}\right)$$

where:

P_t=Compressor inlet total pressure
P_1=Compressor inlet static pressure
W_a=Compressor airflow
θ=Ambient temperature correction to NACA std.
δ=Barometric correction to NACA std.

In other words, for any given value of corrected compressor airflow

$$\frac{W_a\sqrt{\theta}}{\delta}$$

there exists one and only one value of the compressor inlet ratio

$$\frac{P_t-P_1}{P_t}$$

Thus it is possible to construct a compressor map using

$$\frac{P_t-P_1}{P_t}$$

in place of

$$\frac{W_a\sqrt{\theta}}{\delta}$$

This map is illustrated in FIG. 5, and illustrates the concept that it will be possible by making a mechanical comparison of compressor pressures, to establish an operating or modulation line (dotted line in FIG. 5), since

$$\frac{P_t-P_1}{P_t}=f\left(\frac{P_2}{P_t}\right)$$

That is, by sensing and correctly balancing compressor pressures in a suitably constructed control system, means may be provided to bleed air from the compressor in such a manner as will tend to maintain a preferred parameter

$$\frac{P_t-P_1}{P_t}$$

for any operation of the compressor.

Referring to FIGS. 1, 2 and 3, the preferred control system comprises the sensor **22** and the servo **21**, a compressor inlet total pressure (P_t) sensing conduit **25**, a compressor inlet static pressure (P_1) sensing conduit **26**, and a compressor discharge pressure (P_2) sensing conduit **27**, the signal from the sensor **22** to the servo **21** being transmitted through a signal pressure (S) conduit **28**.

The sensor **22** preferably comprises a multiple part housing **29** having a sensor chamber **30** divided by a compressor inlet pressure sensing diaphragm **31** of area A_2, a second sensor chamber **32** divided by a compressor pressure ratio sensing diaphragm **33** of area A_1, and a control chamber **34**. The diaphragms **31** and **33** are connected to a control pin **35** operable to control the opening of a port **36**, connecting the control chamber **34** with the signal pressure (S) conduit **28**, in proportion to the magnitude of pressure area differential existing across the stacked diaphragms **31** and **33**. The pin **35** is preferably biased toward the closed position by a relatively weak spring **40** bearing between a plate **41**, adjustable by any means such as an adjusting screw **42**, and a plate **43** connected to the control pin **35**. For purposes of the following explanation, the small force of the spring **40** will not be included.

One side of the chamber **30** is openly connected through a port **44** to a branch **25***a* of the conduit **25**, and the other side of the chamber **30** is openly connected through a port **45** with the conduit **26**, such that the diaphragm **31** will be responsive to the differential between compressor inlet total pressure P_t and static pressure P_1 to a degree dependent on the diaphragm area A_2.

One side of the chamber **32** is openly connected through a port **46** with another branch **25***b* of the conduit **25**. The other side of the chamber **32** is subject to an intermediate pressure P_b developed between series-connected orifices **47** (openly connected with the conduit **27**) and **48** (openly connected with a third branch **25***c* of the conduit **25**).

The area a_1 of the orifice **48** is preferably adjustable by means of a needle valve **49**, while the area a_2 of the orifice **47** is preferably fixed. Thus the diaphragm **33** will be responsive to the differential between compressor inlet total pressure P_t and the intermediate pressure P_b to a degree dependent on the diaphragm area A_1.

It can be shown that the sensor operation is in accord with the conditions required by the compressor map FIG. 5; that is, if properly constructed, the sensor will axially actuate the pin to open and close the port **36** in correspondence to the parameter

$$\frac{P_t-P_1}{P_t}=f\left(\frac{P_2}{P_t}\right)$$

This may be shown as follows:

Referring to the pressures acting on the connected diaphragms **31** and **33**, the force balance equation

$(P_t-P_1)A_2=(P_b-P_t)A_1$ describes the function of the sensor **22**. Dividing by P_t and A_2;

$$\frac{P_t-P_1}{P_t}=\left(\frac{P_b-P_t}{P_t}\right)\frac{A_1}{A_2}$$

Since any constant may be selected for the ratio

$$\frac{A_1}{A_2}$$

it remains only to show that

$$\frac{P_b-P_t}{P_t}=f_1\left(\frac{P_2}{P_t}\right)$$

$$\frac{P_b-P_t}{P_t}=\frac{P_b}{P_t}-1$$

and P_b is the intermediate pressure measured between the two orifices **48** and **47** connected in series. FIG. 7 illustrates the series connected orifices, and the diagram of FIG. 6 illustrates generally the aerodynamic relationship for various orifice area ratios

$$\frac{a_2}{a_1}$$

Thus, for a given ratio

$$\frac{a_2}{a_1}$$

$$\frac{P_b}{P_2}=f_2\left(\frac{P_2}{P_t}\right)$$

$$P_b=P_2f_2\left(\frac{P_2}{P_t}\right)$$

$$\frac{P_b}{P_t}=\frac{P_2}{P_t}f_2\left(\frac{P_2}{P_t}\right)=f_3\left(\frac{P_2}{P_t}\right)$$

$$\therefore\frac{P_b}{P_t}-1=f_4\left(\frac{P_2}{P_t}\right)$$

By choosing the proper values of a_2 and a_1,

$$f_4\left(\frac{P_2}{P_t}\right)$$

can be made to equal

$$f_1\left(\frac{P_2}{P_t}\right)$$

so that

$$\frac{P_b-P_t}{P_t}=f_1\left(\frac{P_2}{P_t}\right)$$

In constructing the sensor **22**,

$$\frac{a_2}{a_1}$$

and

$$\frac{A_1}{A_2}$$

are selected so that, for values of

$$\frac{P_2}{P_t}$$

it is possible to determine the value of

$$\frac{P_t-P_1}{P_t}$$

that the sensor will regulate to, which will be the selected modulation line in FIG. 5.

In accomplishing this function, the servo valve **21**, shown in FIG. 3, operates to bleed excess compressor air from the by-pass pipe **19** through the stack **20** in response to the signal from the sensor **22**.

The servo valve preferably comprises a housing **55** having an inlet chamber **56** openly connected with the by-pass pipe **19** and terminating in an annular valve seat **57**. A poppet valve **58** having an annular closure member **57** adapted to seat on the valve seat **57** is positioned in a control chamber **60**. A diaphragm **61** is secured to the poppet valve **58** and the housing **55** so that the valve **58** will operate axially as determined by a pressure differential existing between the chambers **56** and **60** to open and close the valve. A tube element **62** is carried by the poppet valve **58** and slides axially within a sleeve **63** supported by the housing **55**. The sleeve **63** carries a needle valve element **64** which extends into the end of the tube element **62**, acting to open and close an orifice **65** as determined by the position of the poppet valve **58**. The tube **62** thus variably communicates the inner end of the chamber **60** with the discharge pressure P_2 of the compressor. The chamber **60** communicates at all times with the conduit **28** which is connected with the sensor **22** and transmits the sensor signal S.

In substance, when the sensor valve port **36** is open, pressure in the chamber **60** is bled out through the conduit **28** relative to the degree to which the sensor signal port **36** is opened by the pin **35** (see FIG. 2), permitting the poppet valve **58** to open and bleed compressor discharge air out the stack **20**. As the poppet valve **58** opens, however, the area of the orifice **65** will increase to bleed compressor discharge pressure P_2 through the tube **62** into the chamber **60** tending to close the poppet valve **58**, the effective area on the chamber **60** side of the diaphragm **61** being greater than the effective area on the chamber **56** side as shown.

In effect, the pressure existing in the chamber **60** will take an intermediate pressure valve between S and P_2, which is a function of the degree to which the sensor port **36** is opened. Consequently, the position of the poppet valve **58** in the servo is a function of the bleed area of the port **36** in the sensor, which in turn, due to the pressure differential existing across the stack diaphragms of the sensor **22**, will take on values such as to maintain

$$\frac{P_t-P_1}{P_t}=f\left(\frac{P_2}{P_t}\right)$$

in accordance with the discussion given previously, tending to maintain operation of the compressor on the control line shown in the compressor map of FIG. 4.

It will be apparent that when the butterfly valve **19** (FIG. 1) is opened for delivery of compressed air to the user, compressor airflow will increase, the surge sensor **22** will operate to cut-off bleed through the port **36**, the poppet valve **58** of the servo valve **21** will close fully, and no air will bleed through the by-pass pipe **19**. Thus the compressor will be able to operate to the right of the control line of FIG. 4 to produce the required airflow. However, as the butterfly valve **18***a* is closed, compressor airflow decreases, and when an imbalance is sensed by the sensor **22**, indicating an approach toward surge conditions, the sensor port **36** will open to bleed the servo chamber **60** and open the poppet valve **58** to the necessary degree as described above.

The servo valve **21** also preferably performs the additional function of preventing shock surge due to rapid closing of the buterfly valve **18***a*. For most purposes, a compressor delivery valve such as that illustrated should be operable to move from full open to full closed in about 0.2 second. A second control chamber **70** is provided in the servo valve housing **55**, and is divided by a diaphragm **71** which carries a needle valve element **72** extending into a port **73** which communicates the chamber **60** with atmosphere via a passage **74**. A conduit **75** connects with a passage **76** in the housing **55**, the passage **76** opening to the inner end of the chamber **70**. The conduit **75** is connected, as shown in FIG. 1, with the pipe **18** upstream of the butterfly valve **18***a*. Upon sudden closing of the butterfly valve, an immediate pressure rise is sensed through the conduit **76** and transmitted promptly to the inner side of the diaphragm **71**, which moves outwardly, the needle valve **72** opening the port **73**, bleeding the chamber **60** to open the poppet

valve **58** as previously described, providing for an immediate increase in compressor airflow to prevent sudden operation toward the surge line of the compressor map FIG. 4, which the sensor **22** would not have time to counteract. A passage **77** connects the passage **75** with the outer end of the chamber **70**, the passage **77** being provided with an adjustable orifice **78** so that the increased pressure P_2 will be subsequently transmitted to the outerside of the diaphragm **71** to shortly equalize pressures and permit the diaphragm **71** to be urged inward by a spring **79** or other means to close the port **73** as the sensor **22** takes over control of the poppet valve **58**.

Although it is practical to use a control system of the general idea illustrated in FIG. 1 for shaft power or jet engines, a more likely modification utilizes the basic surge sensor **22** to modulate a fuel servo valve rather than an air valve. In FIG. 8 a preferred gas turbine jet engine **85** illustrating such a modification comprises a housing **86** having an air inlet **87**, a combustion chamber or combustor **88**, a jet exhaust nozzle **89**, and a compressed air chamber **90**, the housing **86** supporting a turbine **91** and a compressor **92** operable to supply compressed air to the chamber **90** for use in the combustor **88** only.

The sensor **22** is the same as that previously described, as well as the compressor inlet total pressure (P_t) sensing conduit **25** with its branches **25***a*, **25***b* and **25***c*, the compressor inlet static pressure (P_1) sensing conduit **26**, the compressor discharge pressure (P_2) sensing conduit **27**, and the sensor signal pressure conduit **28**. However, the conduit **28** is suitably connected to and transmits the sensor signal to a fuel servo valve **93** which is preferably constructed on the lines suggested in FIG. 9, having a fuel inlet **94** suitably connected with the supply of a fuel pump (not shown) and a fuel outlet **95** delivering metered fuel to the engine, the fuel flowing through passages **96** and **97** in the valve **93** and modulated by means of a poppet valve **98**.

The valve **93** is provided with a pair of compartments **100** and **101** respectively divided by diaphragms **102** and **103** into respective control chambers **104**, **105**, **106** and **107**. Chamber **104** is connected by a passage **110** with the fuel passage **97**, chambers **105** and **107** are connected respectively by passages **111** and **112** with the sensor signal pressure conduit **28**, and chamber **106** is connected by a passage **113** with a branch conduit **25***d* sensing compressor inlet total pressure P_t from the conduit **25**. A conduit **27***a* connects the passages **111** and **112** with the compressor discharge pressure (P_2) sensing conduit **27**, and includes a restricted orifice **114**.

The poppet valve **98** is operably connected by means of a pin **115** with the diaphragm **102**, being urged toward the closed position by a relatively weak spring **116**. The two diaphragms **102** and **103** are operably connected in series by means of a pin **117**.

It will be apparent that the diaphragm **102** balances fuel pressure against a pressure intermediate the surge sensor signal pressure (S) and the compressor discharge pressure (P_2). The diaphragm **103** balances compressor inlet total pressure against the same intermediate pressure. In essence, the position of the poppet valve will be determined by the surge sensor signal pressure which varies relative to the opening of the sensor valve port **36**.

Thus, when the compressor approaches surge conditions, the sensor **22** operates as previously explained to open the valve port **36**. This decreases the pressure in the fuel valve chambers **105** and **107** and the poppet valve **98** moves toward a closed position to reduce fuel flow. Thermodynamically, reduced fuel flow to a turbine engine operates to reduce compressor discharge pressure and hence increases compressor airflow, and the operating point on the compressor map of FIG. 4 will move away from the surge line. Thus the result of reducing fuel flow is in substance, as far as its effect on the engine is concerned, the same as bleeding off excess compressed air as is done in the first modification described.

As the fuel poppet valve **98** closes, the fuel pressure in the chamber **104** will decrease correspondingly, so that, since the diaphragm **102** balances fuel pressure with a pressure depending on surge signal pressure (S), the poppet valve **98** will seek a stable position to provide that fuel flow which will not cause surge conditions.

It is apparent also that the present system will prevent excess fuel flow during acceleration. Since increased fuel flow on acceleration causes a rise in the temperature of the combustion mixture, its volume also increases, resulting in a decrease of compressor airflow. The surge sensor, as previously explained, operates to open the valve port **36** on such a decrease as the operating point moves toward surge conditions, and this again will cause the fuel poppet valve **98** to move toward a closed position to decrease fuel flow.

Although I have described only two preferred embodiments of my invention, it will be apparent to one skilled in the art to which the invention pertains that various changes and modifications may be made therein without departing from the spirit of the invention or the scope of the appended claims.

I claim:

1. A control system for a gas turbine engine having a fuel system and an air compressor characterized by a predictable tendency to develop compressor surge conditions at operating ranges producing a predetermined reduction of compressor airflow, an air inlet and an air discharge for said compressor, said control system comprising first means variably increasing compressor airflow to avoid said surge conditions a servo means operating said first means and a sensing means automatically controlling operating of said servo means in response to varying compressor airflow, said sensing means comprising an actuating means operably connected with said servo means and a pressure responsive means adjusting said actuating means in response to changes in the balance of two pressure differentials, one of said pressure differentials being the differential between compressor inlet total pressure and compressor inlet static pressure, the other of said pressure differentials being the differential between compressor inlet total pressure and a pressure intermediate compressor discharge pressure and compressor inlet total pressure.

2. A control system for a gas turbine engine having a fuel system and an air compressor characterized by a predictable tendency to develop compressor surge conditions at operating ranges producing a predetermined reduction of compressor airflow, an air inlet and an air discharge for said compressor, said control system comprising first means variably increasing compressor airflow to avoid said surge conditions a servo means operating said first means and a sensing means automatically controlling operation of said servo means in response to varying compressor airflow, said sensing means comprising a housing having two pressure sensitive elements, a movable actuator operably connecting said pressure sensitive elements with said servo means, one of said pressure sensitive elements moving said actuator in response to changes in pressure differential between a compressor inlet total pressure and compressor inlet static pressure, and the other of said pressure sensitive elements moving said actuator in response to changes in pressure differential between compressor inlet total pressure and a pressure intermediate compressor total pressure and compressor discharge pressure.

3. The control system as defined in claim 2 and in which said pressure sensitive elements are balanced in accordance with the force-balance equation

$$(P_t - P_1)A_2 \text{ equals } (P_b - P_t)A_1$$

in which P_t represents compressor inlet total pressure, P_1 represents pressure inlet static pressure, P_b represents the

pressure intermediate compressor total pressure and compressor discharge pressure, A_2 represents the total effective area of the first mentioned pressure sensitive element, and A_1 represents the total effective area of the second mentioned pressure sensitive element.

4. A control system for a gas turbine engine having a fuel system and an air compressor characterized by a predictable tendency to develop compressor surge conditions at operating ranges producing a predetermined reduction of compressor airflow, an air inlet and an air discharge for said compressor, said control system comprising first means variably increasing compressor airflow to avoid said surge conditions a servo means operating said first means and a sensing means automatically controlling operation of said servo means in response to varying compressor airflow, said sensing means comprising a housing having a first pressure chamber and a second pressure chamber, a movable pressure sensitive element disposed in each of said chambers and each element having a predetermined total effective area, a movable actuator operably connecting said pressure sensitive elements with said servo means, a compressor inlet total pressure sensing means, a compressor inlet static pressure sensing means, and a compressor discharge pressure sensing means, means connecting said first pressure chamber on one side of the pressure sensitive element with said total pressure sensing means and means connecting said first pressure chamber on the other side of the pressure sensitive element with said static pressure sensing means, means connecting said second pressure chamber on one side of the pressure sensitive element with said total pressure sensing means, means connecting said second pressure chamber on the other side of the pressure sensitive element with said total pressure sensing means and including a restricted orifice having a predetermined area, and means connecting said second pressure chamber on said other side of the pressure sensitive element with said discharge pressure sensing means and including a second restricted orifice, the pressure in said other side of the last mentioned pressure sensitive element being the intermediate pressure measured between said orifices and dependent on the ratio of the areas of said orifices.

5. The control system as defined in claim 4 in which said pressure sensitive elements comprise axially movable diaphragm members, and said actuator axially connecting said diaphragm members in series.

6. The control system as defined in claim 4 and having means variably adjusting the area of one of said orifices to vary said intermediate pressure and thereby adjust the operating pressure differential acting on the last mentioned pressure sensitive element.

7. A control system for a gas turbine engine having a fuel and an air compressor characterized by a predictable tendency to develop compressor surge conditions at operating ranges producing a predetermined reduction of compressor airflow, an air inlet and an air discharge for said compressor, said control system comprising first means variably increasing compressor airflow to avoid said surge conditions a servo means operating said first means and a sensing means automatically controlling operation of said servo means in response to varying compressor airflow, said servo means comprising a housing having a bleed air outlet, an air inlet openly connected with said compressor discharge, a bleed valve means operable to bleed controlled amounts of compressed air from said air outlet and disposed intermediate said outlet and inlet, a pressure control chamber, and a pressure sensitive element operably connected with said bleed valve and disposed intermediate said inlet and said control chamber, said pressure sensitive element actuating said bleed valve in response to changes in pressure differential between compressor discharge pressure and the pressure in said control chamber, and said sensing means comprising means transmitting a variable pressure to said control chamber relative to changes in compressor airflow.

8. The control system as defined in claim 7 and in which said servo means includes means variably openly connecting said control chamber to compressor discharge pressure, said last mentioned means being operable relative to bleed valve operation to modify relative to the position of said bleed valve the control chamber pressure as transmitted from said sensing means.

9. A control system for a gas turbine engine having a fuel system and an air compressor characterized by a predictable tendency to develop compressor surge conditions at operating ranges producing a predetermined reduction of compressor airflow, an air inlet and an air discharge for said compressor, said control system comprising first means variably increasing compressor airflow to avoid said surge conditions a servo means operating said first means and a sensing means automatically controlling operation of said servo means in response to varying compressor airflow, and a second sensing means automatically operating said servo means in response only to a sudden decrease in compressor airflow.

10. The control system as defined in claim 9 and in which said servo means comprises an air bleed valve means operable to bleed controlled amounts of compressed air from said air outlet and pressure responsive means operably connected with said air bleed valve means, said second sensing means comprising a variable pressure transmitting means actuating said pressure responsive means only upon a sudden decrease in compressor airflow.

11. The control system as defined in claim 10 and in which said pressure responsive means comprises a pressure sensitive element actuating said air bleed valve in response to changes in a pressure differential between compressor discharge pressure and a pressure intermediate compressor discharge pressure and the pressure of said pressure transmitting means.

12. The control system as defined in claim 9 and in which said servo means comprises a housing having a bleed air outlet, an air inlet openly connected with said compressor discharge, a bleed valve means operable to bleed controlled amounts of compressed air from said air outlet and disposed intermediate said outlet and inlet, a pressure control chamber, and a pressure sensitive element operably connected with said bleed valve and disposed intermediate said inlet and said control chamber, said pressure sensitive element actuating said bleed valve in response to changes in pressure differential between compressor discharge pressure and the pressure in said control chamber, and said second sensing means comprising means transmitting a variable pressure to said control chamber relative only to a sudden decrease in compressor airflow.

13. The control system as defined in claim 12 and in which said second sensing means comprises a housing having a pressure chamber, a valve means variably connecting said servo means pressure control chamber with atmosphere, a pressure sensitive element operably connected with said valve means and disposed in said pressure chamber, means openly connecting said pressure chamber on one side of said pressure sensitive element with compressor discharge pressure such as will open said valve means upon increase of compressor discharge pressure, and a second means openly connecting said pressure chamber on the other side of said pressure sensitive element with compressor discharge pressure such as will equalize pressure on said pressure sensitive element, said second means including a restricted orifice operable to delay the aforesaid pressure equalization only after a sudden change of compressor discharge pressure and to permit the aforesaid pressure equalization upon other more gradual changes of compressor discharge pressure.

14. A control system for a gas turbine engine having a fuel system and an air compressor characterized by a pre-

dictable tendency to develop compressor surge conditions at operating ranges producing a predetermined reduction of compressor airflow, and air inlet and an air discharge for said compressor, said control system comprising first means variably increasing compressor airflow to avoid said surge conditions a servo means operating said first means and a sensing means automatically controlling operation of said servo means in response to varying compressor airflow said sensing means comprising an actuating means operably connected with said servo means and a pressure responsive means adjusting said actuating means in response to changes in the balance of two pressure differentials one of said pressure differentials being the differential between compressor inlet total pressure and compressor inlet static pressure, the other of said pressure differentials being the differential between compressor inlet total pressure and a pressure intermediate compressor discharge pressure and compressor inlet total pressure, said first means comprising a fuel control valve means operable to vary fuel flow to said engine and pressure responsive means actuated by said servo means and operably connected with said fuel control valve means whereby compressor airflow will be varied by varying fuel flow to said engine.

15. The control system as defined in claim 14 and in which said last mentioned pressure responsive means comprises a pressure sensitive element actuating said fuel control valve means in response to changes in a pressure differential between fuel pressure and a pressure intermediate compressor discharge pressure and the pressure of said first mentioned pressure responsive means.

16. The control system as defined in claim 15 and in which the aforesaid fuel pressure is taken downstream of said fuel control valve means.

17. The control system as defined in claim 16 and in which said second mentioned pressure responsive means includes a second pressure sensitive element modifying actuation of said fuel control valve means in response to changes in pressure differential between compressor inlet total pressure and the aforesaid intermediate pressure.

18. A control system for a gas turbine engine having a fuel system and an air compressor characterized by a predictable tendency to develop compressor surge conditions at operating ranges producing a predetermined reduction of compressor airflow, and air inlet and an air discharge for said compressor, said control system comprising first means variably increasing compressor airflow to avoid said surge conditions a servo means operating said first means and a sensing means automatically controlling operation of said servo means in response to varying compressor airflow said sensing means comprising an actuating means operably connected with said servo means and a pressure responsive means adjusting said actuating means in response to changes in the balance of two pressure differentials one of said pressure differentials being the differential between compressor inlet total pressure and compressor inlet static pressure, the other of said pressure differentials being the differential between compressor inlet total pressure and a pressure intermediate compressor discharge pressure and compressor inlet total pressure, said first means comprising a housing having a fuel inlet and a fuel outlet, a fuel control valve operable to vary fuel flow to said engine and disposed intermediate said inlet and outlet, a pressure control chamber, a pressure sensitive element operably connected with said fuel control valve and disposed in said pressure control chamber, and means openly connecting said fuel outlet with said control chamber on one side of said pressure sensitive element, said servo means being operable to transmit a variable pressure to said control chamber on the other side of said pressure sensitive element relative to changes in compressor airflow.

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