Dec. 7, 1954 P. S. HOPPER 2,696,345

METHOD OF CONTROLLING SUPERCHARGER TO AVOID PULSATION

Filed Oct. 14, 1949

Fig. 1.

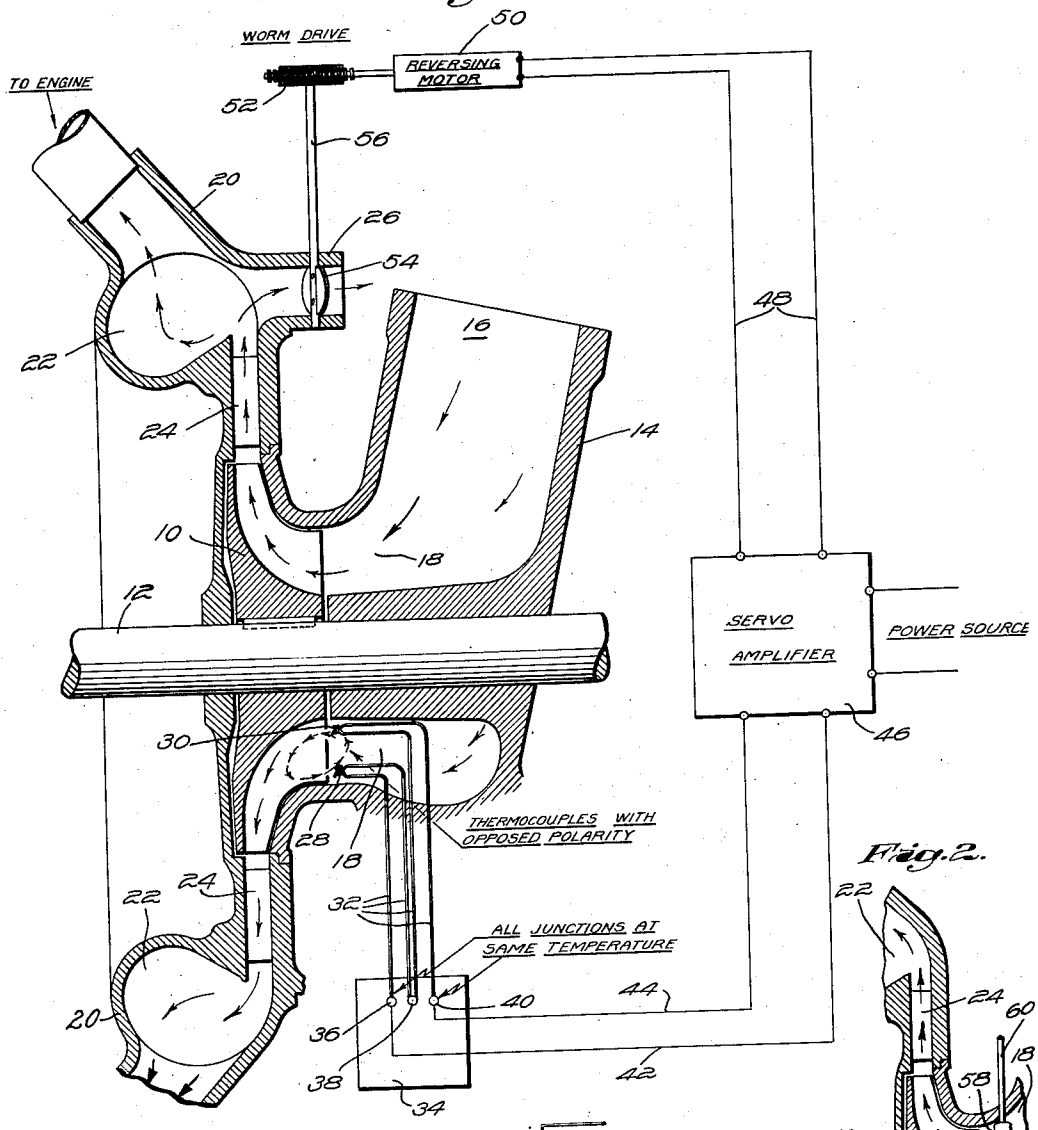
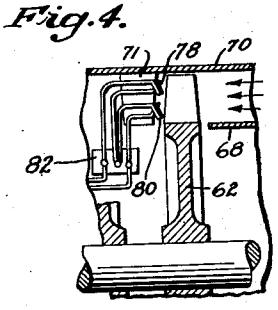


Fig. 2.

Fig. 4.



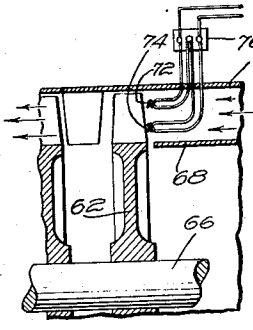


Fig. 3.

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METHOD OF CONTROLLING SUPERCHARGER TO AVOID PULSATION

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8 Claims. (Cl. 230—115)

This invention relates to an improved control apparatus for compressors, and more specifically to an improved control apparatus for compressors for aircraft engines.

High speed compressors are limited in range of operation due to a surging, or pulsation as it is sometimes termed, which is encountered at low values of load coefficient. This surging is essentially the result of a flow instability which occurs only when the slope of the compressor characteristic curve, i. e., pressure ratio versus mass flow, is positive. The slope of this characteristic curve in the surging range is not the same for all compressors and can be different in different installations. Operation within this range is undesirable because of the detrimental effects on compressor loading and on compressor efficiency. Various effects of surging which have been noted in tests include a definite increase in inlet-air temperature, a high degree of turbulence and definite prerotation at the compressor inlet annulus, and a large radial temperature gradient at the compressor inlet.

The remedy for surging is to alter the operating characteristics of the compressor. This can be done by varying the angle of attack of vanes mounted adjacent the compressor impeller inlet, or by the use of a bleed in the delivery conduit of the compressor through which a portion of the discharge flow is dissipated, or recirculated to the compressor inlet.

Surging is a cycle of events in which there is a recirculation of air through the compressor. The mixing of the heated air flowing back through the compressor with the cooler inlet air results in a temperature gradient in the air stream adjacent to the impeller, being particularly large at the compressor inlet annulus. It has been observed that any major surging is preceded by an initial recirculation, and by observing the temperature gradient at some point in the air stream adjacent to the compressor impeller it is possible to anticipate detrimental conditions of operation in time to alter the compressor operating characteristics and avoid these conditions.

An object of this invention is to extend the operating range of a compressor.

Another object of this invention is to provide a control which will assure surge-free operation of a compressor.

A further object of this invention is to provide a control which is responsive to changes in the radial temperature gradient existing in the air stream adjacent to a compressor impeller and will prevent detrimental operation of the compressor.

Although the novel features which are characteristics of this invention are set forth more in detail in the claims appended hereto, the nature and scope of the invention may be better understood by referring to the following description, taken in connection with the accompanying drawing forming a part thereof, in which a specific embodiment has been set forth for purposes of illustration.

In the drawing:

Fig. 1 is a vertical section through a centrifugal compressor utilizing the control apparatus.

Fig. 2 is a fragmentary view of an alternate arrangement of the control apparatus.

Fig. 3 is a vertical section through an axial flow compressor showing the thermocouples mounted on the inlet side of the first compressor stage.

Fig. 4 is a modification of Fig. 3, showing the thermocouples mounted on the delivery side of the first compressor stage.

Referring to Fig. 1 in detail, the compressor includes bladed impeller **10** mounted on drive shaft **12**, inlet casing **14**, and outlet casing **20**. Casing **14** defines inlet conduit **16** and inlet annulus **18** and surrounds impeller **10** to define therewith a continuation of the inlet conduit. Casing **20** defines delivery conduit **22** and is connected to an aircraft engine, not shown. The outer casing includes diffuser vanes **24** mounted within the delivery conduit adjacent to the delivery side of the impeller, and port **26** for bleeding air from the delivery conduit.

A pair of thermocouples **28** and **30** are mounted within the inlet annulus **18**. These thermocouples are located adjacent to and at approximately an equal distance from the impeller inlet face, and radially spaced apart so as to be responsive to a radial temperature gradient across the impeller inlet. The thermocouples are balanced, being wired in series and having opposed polarity, and their leads **32** are connected to a common junction box **34** in order that the three junctions **36**, **38** and **40** can be maintained at the same temperature. Junction **38** is common to the two thermocouples and junctions **36** and **40** are connected by leads **42** and **44**, respectively, to servo amplifier **46** which in turn is connected to a power source, not shown.

Servo amplifier **46** is connected by leads **48** to reversing motor **50** which operates worm drive **52** to regulate the position of bleed valve **54** within port **26**, the valve being drivingly connected to the worm drive by shaft **56**.

An alternative arrangement is shown in Fig. 2 in which the reversing motor **50** and worm drive **52** of Fig. 1 function to vary the angle of attack of vane **58** located within the inlet annulus **18**. This vane is drivingly connected to the worm drive by shaft **60**. While only one vane is shown for simplicity, it is to be understood that, as is common in the art, a series of such vanes would be provided around the inlet annulus.

When recirculation occurs within the vicinity of the impeller inlet indicating the onset of surge, the temperature of thermocouple **28** mounted adjacent the outer wall of the inlet annulus, will increase with respect to that of thermocouple **30**, mounted adjacent the inner wall of the inlet annulus, creating a potential difference between the thermocouples and causing a signal to be relayed to servo amplifier **46**. The servo amplifier in turn will respond to this signal by operating reversing motor **50** so as either to open bleed valve **54** or change the angle of attack of vanes **58**, whichever system is used. In either case the result is to alter the operating characteristics of the compressor, thus anticipating surge and avoiding its detrimental effects. When stable operating conditions have been established, and the radial temperature gradient at the impeller has become normal, the servo amplifier will function in response to this signal to restore either the bleed valve or the vanes to their original position.

Fig. 3 illustrates the use of the control apparatus in connection with an axial flow compressor, **62** indicating a bladed impeller mounted on drive shaft **66**. The inlet annulus is defined by inner casing **68** and outer casing **70**, the outer casing carrying stationary vanes **71**. A pair of balanced thermocouples **72** and **74** are mounted in a radial plane within the inlet annulus adjacent to the impeller and are connected to junction box **76**. These thermocouples function in the same manner as those described in connection with Fig. 1 to operate a bleed on the delivery side of the impeller or to vary the angle of attack of vanes mounted within the inlet annulus. Fig. 3 shows neither a bleed nor vanes, but it is understood that either arrangement could be used as taught in Fig. 1 and Fig. 2.

Rather than using temperature responsive elements mounted adjacent the impeller inlet, it would be possible to place these elements on the delivery side of the impeller. In Fig. 4, balanced thermocouples **78** and **80** are shown mounted downstream of impeller **62**, as on the stationary vanes **71**. These thermocouples are connected to junction box **82** and can be arranged to vary

the operating characteristics of the compressor in response to a potential difference therebetween.

It is to be understood that the invention is not limited to the specific embodiments herein illustrated and described, but may be used in other ways without departure from its spirit as defined by the following claims.

I claim:

1. A compressor including a rotatable impeller having an inlet side and a delivery side and casing means having inner and outer walls defining an annular conduit for the flow of air through said compressor, said walls extending upstream and downstream of said impeller, in combination with a surge control comprising essentially a plurality of temperature sensing elements mounted in said conduit adjacent to one of said impeller sides, said elements being spaced apart transversely of the conduit, substantially equally spaced from the impeller longitudinally of the conduit, with at least one of said elements being located adjacent said inner wall and at least one of said elements being located adjacent said outer wall of said casing, means cooperating with said conduit to affect the flow of air therethrough thereby altering the operating characteristics of said compressor, and an operative connection between said temperature sensing elements and said operating characteristic altering means including means responsive to a temperature difference between said elements for actuating said operating characteristic altering means.

2. A compressor including a rotatable impeller having an inlet side and a delivery side and casing means having inner and outer walls defining an annular conduit for the flow of air through said compressor, said walls extending upstream and downstream of said impeller, in combination with a surge control comprising essentially a pair of temperature sensing elements mounted in said conduit adjacent to one of said impeller sides, said elements being spaced apart transversely of the conduit, substantially equally spaced from the impeller longitudinally of the conduit, with one of said elements being located adjacent said inner wall and the other of said elements being located adjacent said outer wall of said casing, means cooperating with said conduit to affect the flow of air therethrough thereby altering the operating characteristics of said compressor, and an operative connection between said temperature sensing elements and said operating characteristic altering means including means responsive to a temperature difference between said elements for actuating said operating characteristic altering means.

3. A compressor including a rotatable impeller having an inlet side and a delivery side and casing means having inner and outer walls defining an annular conduit for the flow of air through said compressor, said walls extending upstream and downstream of said impeller, in combination with a surge control comprising essentially a pair of balanced thermocouples mounted in said conduit adjacent to one of said impeller sides, said thermocouples being substantially equally spaced from the impeller longitudinally of the conduit with one of said thermocouples being located adjacent said inner wall and the other of said thermocouples being located adjacent said outer wall of said casing, means cooperating with said conduit to affect the flow of air therethrough thereby altering the operating characteristics of said compressor, and an operative connection between said thermocouples and said operating characteristic altering means including means responsive to a potential difference between the thermocouples for actuating said operating characteristic altering means.

4. A compressor including a rotatable impeller having an inlet side and a delivery side and casing means having inner and outer walls defining an annular conduit for the flow of air through said compressor, said walls extending upstream and downstream of said impeller, in combination with a surge control comprising essentially a pair of thermocouples wired in series and of opposed polarity mounted in said conduit adjacent to one of said impeller sides, said thermocouples being substantially equally spaced from the impeller longitudinally of the conduit with one of said thermocouples being located adjacent said inner wall and the other of said thermocouples being located adjacent said outer wall of said casing, a servo amplifier operatively connected to the thermocouples and responsive to a potential difference therebetween, means cooperating with said conduit to affect the flow of air therethrough thereby altering the operating characteristics of said compressor, and a reversing motor operatively connected to the servo amplifier and to said operating characteristic altering means, said amplifier actuating said reversing motor whenever a radial temperature gradient across said conduit creates a potential difference between said thermocouples.

5. A compressor including a rotatable impeller having an inlet side and a delivery side and casing means having inner and outer walls defining an annular conduit for the flow of air through said compressor, said walls extending upstream and downstream of said impeller, in combination with a surge control comprising essentially a pair of thermocouples wired in series and of opposed polarity mounted in said conduit adjacent to the inlet side of said impeller, said thermocouples being substantially equally spaced from the impeller longitudinally of the conduit with one of said thermocouples being located adjacent said inner wall and the other of said thermocouples being located adjacent said outer wall of said casing, means cooperating with said conduit to affect the flow of air therethrough thereby altering the operating characteristics of said compressor, and an operative connection between said thermocouples and said operating characteristic altering means including means responsive to a temperature difference between said thermocouples for actuating said operating characteristic altering means.

6. A compressor including a rotatable impeller having an inlet side and a delivery side and casing means having inner and outer walls defining an annular conduit for the flow of air through said compressor, said walls extending upstream and downstream of said impeller, in combination with a surge control comprising essentially a pair of thermocouples wired in series and of opposed polarity mounted in said conduit adjacent to the delivery side of said impeller, said thermocouples being substantially equally spaced from the impeller longitudinally of the conduit with one of said thermocouples being located adjacent said inner wall and the other of said thermocouples being located adjacent said outer wall of said casing, means cooperating with said conduit to affect the flow of air therethrough thereby altering the operating characteristics of said compressor, and an operative connection between said thermocouples and said operating characteristic altering means including means responsive to a temperature difference between said thermocouples for actuating said operating characteristic altering means.

7. A compressor including a rotatable impeller having an inlet side and a delivery side, casing means having inner and outer walls defining an annular conduit for the flow of air through said compressor, said walls extending upstream and downstream of said impeller, at least one bleed port located in said casing means adjacent to the delivery side of said impeller and valve means controlling the area of said bleed port, in combination with a surge control comprising essentially a pair of thermocouples mounted in said conduit adjacent to one of said impeller sides, said thermocouples being substantially equally spaced from the impeller longitudinally of the conduit with one of said thermocouples being located adjacent said inner wall and the other of said thermocouples being located adjacent said outer wall of said casing, and an operative connection between said thermocouples and said bleed port valve means including means responsive to a temperature difference between said thermocouples for actuating said valve means.

8. A compressor including a rotatable impeller having an inlet side and a delivery side, casing means having inner and outer walls defining an annular conduit for the flow of air through said compressor, said walls extending upstream and downstream of said impeller, a plurality of guide vanes mounted within said casing means adjacent to the inlet side of said impeller and means controlling the angle of attack of said guide vanes, in combination with a surge control comprising essentially a pair of thermocouples mounted in said conduit adjacent to one of said impeller sides, said thermocouples being substantially equally spaced from the impeller longitudinally of the conduit with one of said thermocouples being located adjacent said inner wall and the other of said thermocouples being located adjacent

said outer wall of said casing, and an operative connection between said thermocouples and said guide vane angle of attack controlling means including means responsive to a temperature difference between said thermocouples for actuating said angle of attack controlling means.

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