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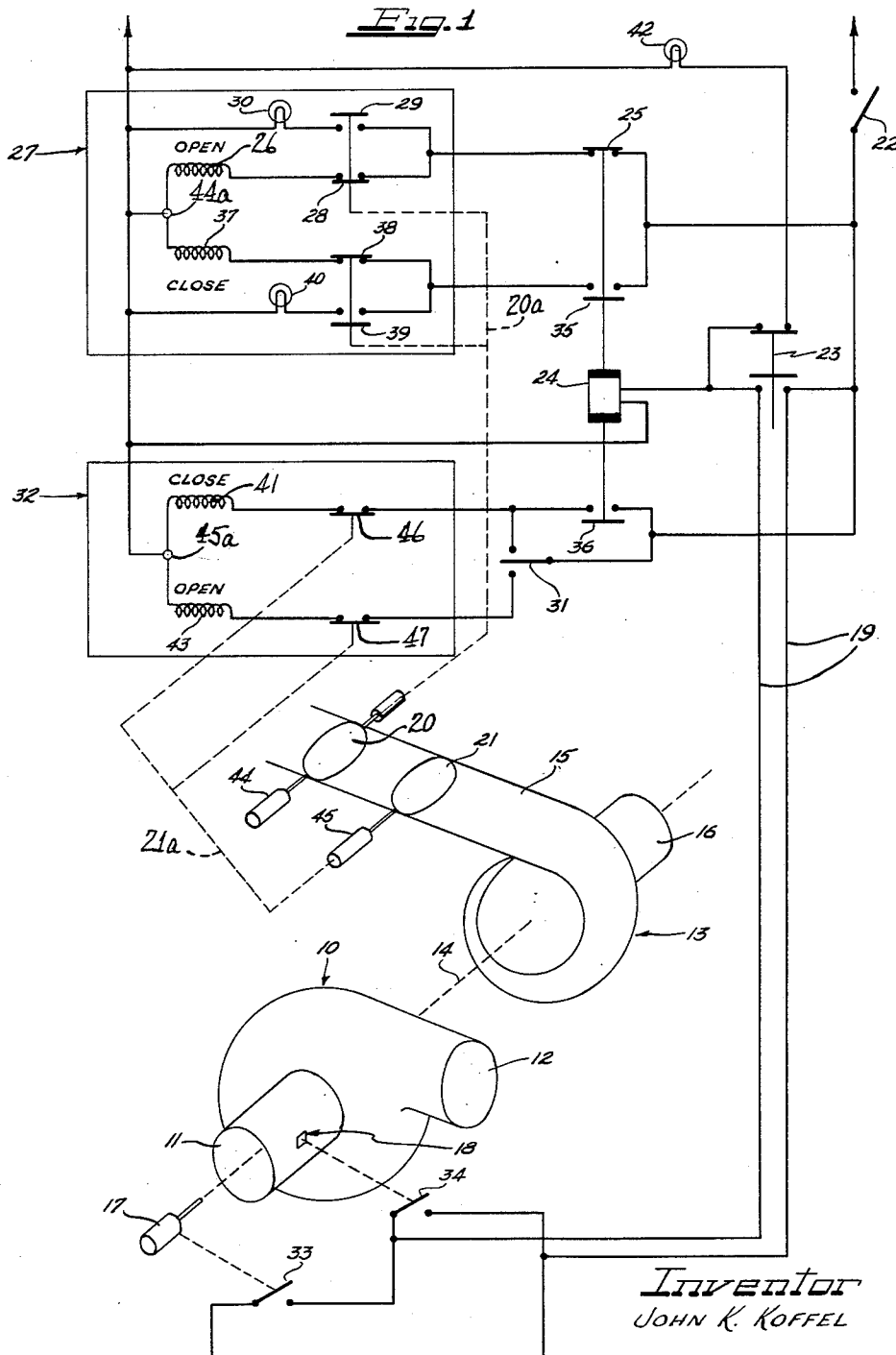
J. K. KOFFEL

2,929,547

METHOD AND APPARATUS FOR DETECTION AND PREVENTION
OF OVERSPEED AND SURGE CONDITIONS IN A COMPRESSOR

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3 Sheets-Sheet 1



INVENTOR
JOHN K. KOFFEL

64 *Tele. Shannon, Morris, Gross & Simpson ATTYS.*

March 22, 1960 J. K. KOFFEL 2,929,547
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Filed March 8, 1955 3 Sheets-Sheet 2

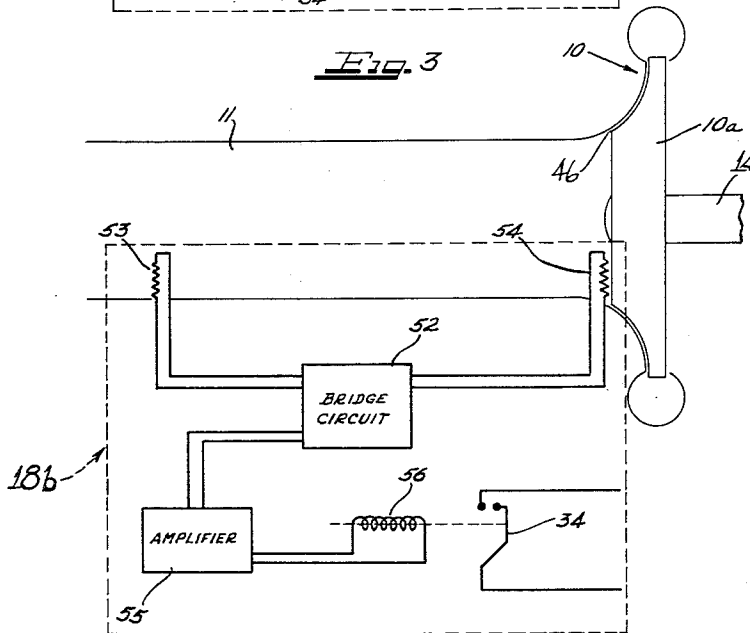
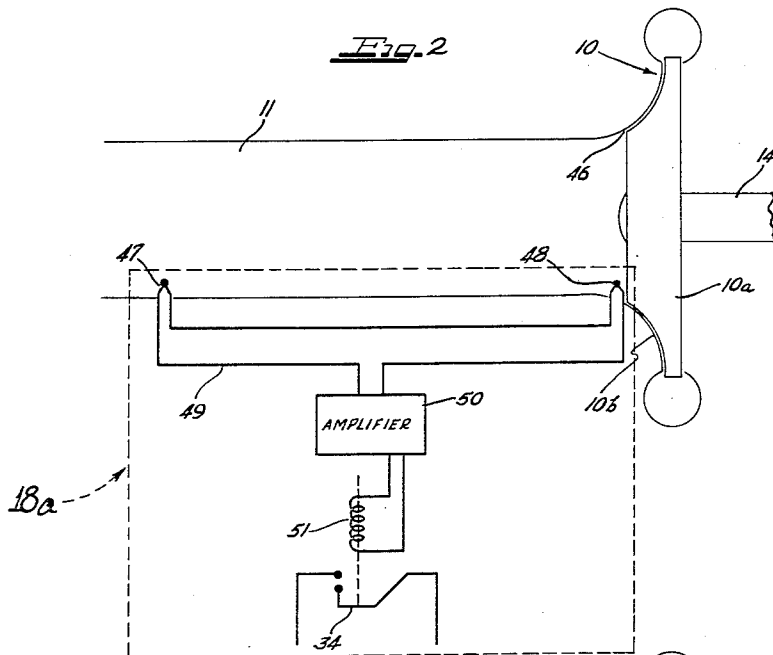
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Inventor
JOHN K. KOFFEL

by *Phil, Sherman, Morris, Ladd & Lind* Attys.

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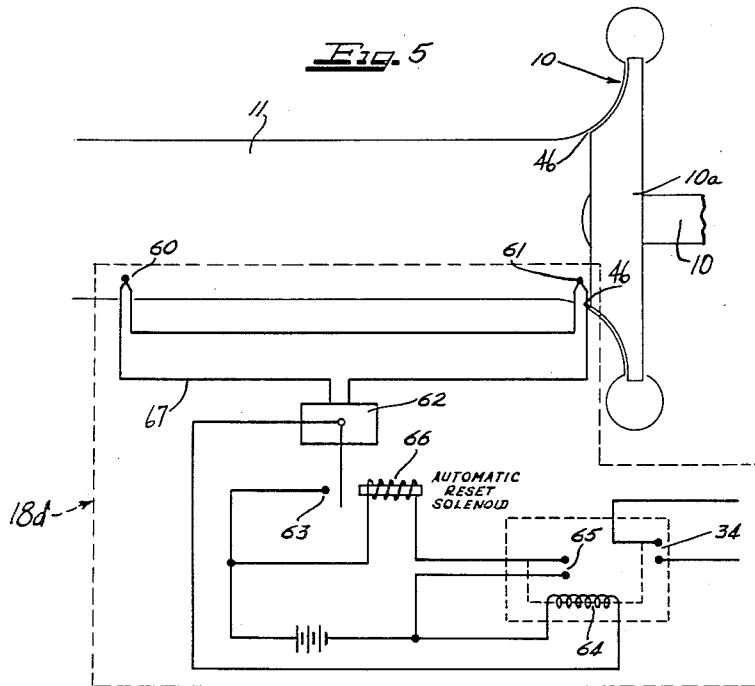
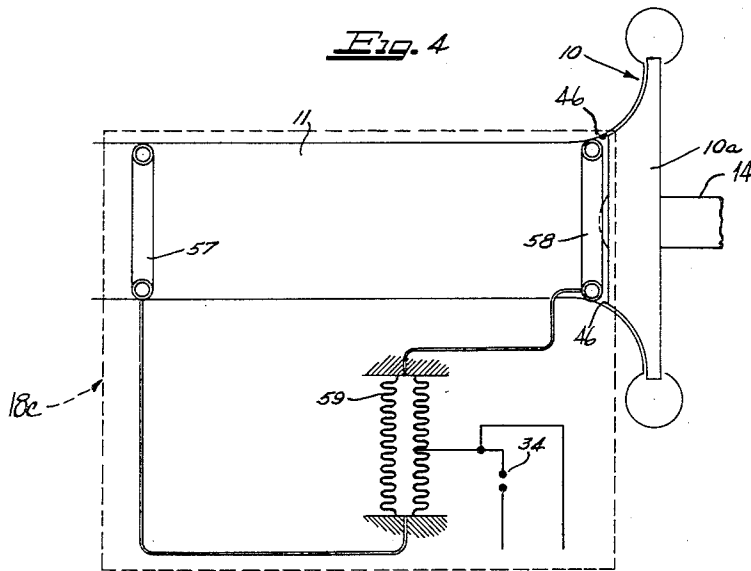
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3 Sheets-Sheet 3



Inventor
JOHN K. KOFFEL

Lie, Sherman, Merani, Gross & Ringler

by

Attys.

1

2,929,547

METHOD AND APPARATUS FOR DETECTION AND PREVENTION OF OVERSPEED AND SURGE CONDITIONS IN A COMPRESSOR

John K. Koffel, Cleveland Heights, Ohio, assignor to Thompson Ramo Wooldridge Inc., a corporation of Ohio

Application March 8, 1955, Serial No. 492,899

9 Claims. (Cl. 230—115)

This invention relates to rotating fluid compressors which may include by way of illustrative example compressors of the centrifugal fluid type, and more particularly to a method and apparatus for detecting and preventing surging conditions in such compressors.

In the illustrated form of the invention, a centrifugal type fluid compressor is driven by a prime mover such as a turbine, whereby a temperature sensitive surge detection device located in the air inlet to the compressor regulates the speed of the turbine driving the compressor by controlling the amount of driving medium supplied to said turbine.

In the operation of centrifugal type fluid compressors, when the flow is decreased to a small percentage of the total, a peculiar action known as surging, back flow, or pulsation takes place, meaning thereby that the air surges to and fro in the compressor and in the conduits connected thereto. Such surging is highly objectionable as it causes excessive pressure and flow pulsations, vibration and noise, interferes with the operation of the apparatus supplied with the fluid being pumped or compressed, and decreases the overall efficiency of operation.

The novel features of the present invention are based upon the principle that recirculation of high pressure air at the compressor discharge is a function of the compressor tip speed, pressure ratio, and impeller clearances. It is a well known phenomena that as the compressor pressure ratio increases, the amount of air flowing from a centrifugal compressor discharge through the impeller passages and clearance space to the impeller inlet increases, and the compression of air through the impeller causes this temperature to increase, and because of the back flow through the impeller passages and clearance space, the compressor inlet temperature measured immediately ahead of the impeller varies radially, increasing from the compressor axis to the extreme inlet diameter. The temperature difference between the incoming air and the temperature measured immediately ahead of the impeller has been found to be a function of the tip speed and overall compressor pressure ratio. Based upon these findings, this inherent situation is used to measure a temperature differential, which is a function again of the compressor tip speed and pressure ratio and adiabatic efficiency; hence, surging conditions in the compressor will exist at a predetermined temperature differential.

In accordance with the present invention, to prevent the compressor from surging, a suitable external mechanism or circuit, which is temperature sensitive, is provided to actuate the inlet valve controlling the turbine driving medium of the turbine which drives the compressor. The temperature sensitive device is set to actuate the turbine inlet valve at a compressor-inlet-temperature difference slightly below the temperature difference at which the compressor would surge.

Accordingly, it is an important object of this invention to provide means for detecting surge conditions in centrifugal type fluid compressors.

2

It is a further object of this invention to provide a method of detecting surge conditions in centrifugal type fluid compressors by measuring the temperature difference between the incoming air to the compressor inlet and the air immediately ahead of the compressor impeller.

Another object of this invention is to provide a method of obtaining a compressor surge detection signal in centrifugal type fluid compressors by converting heat energy to electrical or pressure energy.

Another object of this invention resides in the provision of a temperature sensitive apparatus for centrifugal type fluid compressors to be disposed in the air inlet of a compressor for providing a compressor surge detection signal.

A further object of this invention is to provide a temperature sensitive apparatus for obtaining a compressor surge detection signal in centrifugal type fluid compressors by strategically locating a pair of differentially connected thermopiles, thermocouples, or pressurized capillary tubes in the compressor air inlet.

Still another object of this invention resides in the provision of a temperature sensitive apparatus for obtaining a compressor surge detection signal in centrifugal type fluid compressors comprising a pair of resistors located strategically in the air inlet of the compressor and being associated with a bridge circuit, said resistors having the characteristic of varying their resistance greatly over the desired temperature range expected to be encountered.

Another object of this invention is to provide an apparatus for preventing surge conditions in turbine driven controlled fluid type compressors.

Still another object of this invention is to provide an apparatus for use with turbine driven centrifugal fluid type compressors which, after the detection of a pre-surge or surge condition in the compressor, will immediately stop the supply of driving medium to the turbine, thereby immediately reducing the speed of the compressor and avoiding a surge condition which may become destructive if left uncontrolled.

Another object of this invention is to provide, for use with turbine driven centrifugal type fluid compressors, a device employed to provide a signal which closes or modulates the turbine inlet air supply upon the detection of a pre-surge condition in the compressor.

Still another object of this invention is to provide, for use with turbine driven centrifugal type fluid compressors, a device employed to provide a signal for actuating an emergency shut-off valve to the turbine inlet and at the same time to close the turbine throttle valve, thus avoiding a compressor surge condition and allowing the turbine controls to be reset to a lower, safe operating condition for the compressor without completely shutting down the unit.

A further object of this invention is to provide a means for preventing overspeed conditions in compressors.

A still further object of the invention is to provide an automatic compressor surge control utilizing as a controlling variable a temperature gradient measured at the compressor inlet independent of the absolute temperature of the fluid moving through the inlet.

Other objects, features and advantages will be apparent from the following detailed disclosures, taken in conjunction with the accompanying drawings, in which:

Figure 1 is a partly schematic and partly perspective view of a turbine driven centrifugal compressor in association with a valve control circuit, in accordance with the principles of the present invention;

Figure 2 is a more or less diagrammatic view of a temperature sensitive surge detection device according to

3

the invention, which may be embodied in the surge controls and the system of Figure 1;

Figure 3 is a more or less diagrammatic view of a modified temperature sensitive surge detection device according to the invention for use with the system of Figure 1;

Figure 4 is a more or less diagrammatic view of another modified version of a temperature sensitive surge detection device, according to the invention, for use with the system of Figure 1; and

Figure 5 is a more or less diagrammatic view of still another modified version of the temperature sensitive surge detection device, according to the invention, for use with the surge control system of Figure 1.

The surge control sensing system of the present invention is primarily useful with rotating fluid compressors, and will be described as associated with a centrifugal type compressor, although, of course, it is to be understood that the invention may be used for other purposes if desired.

Also, the present invention is primarily intended to be used with turbine driven centrifugal compressors, although it is obvious that other forms of drive means may be used, but the invention will be described in association with the turbine driven compressors.

Referring to Figure 1, a conventional centrifugal type fluid compressor 10, having an air inlet 11 and a discharge or outlet 12 is driven by a turbine 13 of the usual type through a shaft 14. The turbine 13 is provided with an inlet 15 and a discharge or outlet 16. A suitable driving medium, such as gaseous fluid, may be introduced into the turbine inlet to drive the turbine 13 and be discharged through the turbine outlet 16. In driving the compressor 10, air is received in the air inlet 11, compressed by the impeller or wheel 10a and discharged at a higher temperature and higher pressure air from the outlet 12.

In centrifugal compressors, it is imperative that overspeed and surge conditions do not prevail in order to maintain safe and efficient operation and prevent damage to equipment using fluid compressors. In the present invention, an overspeed generator 17 driven by shaft 14 guards against overspeed of the compressor 10 and turbine 13, while a surge detection arrangement, generally designated by the numeral 18, and as shown is disposed in the compressor air inlet conduit 11, prevents surging conditions from developing in the compressor 10 by controlling speed and power input to the prime mover.

A signal is relayed by the overspeed generator 17 or the surge detection apparatus 18 in the event of a preoverspeed or overspeed, or a pre-surge or surge condition existing in the compressor 10 to control means which in this form of the invention are embodied in an electrical valve control circuit, generally designated by numeral 19, which, in turn, actuates a turbine shut-off valve 20 and a turbine modulating or throttle valve 21 to eliminate and/or simultaneously decrease the supply of driving medium to the turbine 13. Both valves 20 and 21 may be of any suitable type, such as butterfly valves, and are suitably positioned in the turbine inlet duct 15.

In the operation of the valve control circuit 19, which includes a turbine shut-off valve control 27 and a turbine modulating valve control 32, a main or line switch 22 is manually closed to actuate the circuit. Switch 23 is manually operated and of the two-gang type, and in the position shown in Figure 1, the relay 24 is deenergized. With the switch 23 in the position shown, switch 25 will be closed and coil 26 of the turbine shut-off valve control 27 is energized until the shut-off valve 20 reaches a fully opened position, whereupon simultaneously switch 28 opens and switch 29 closes to deenergize opening coil 26 and energize a lamp 30 on the control panel indicating that the turbine shut-off valve is fully opened.

A switch 31 may be laterally pivoted up or down to

4

respectively cause the closing or opening of the turbine modulating or throttle valve 21.

During the normal running operation of the compressor 10, the turbine shut-off valve 20 will be fully open, while the turbine modulating valve 21 will be at least partially open, and the valve control circuit 19 will appear as shown in Figure 1 except that the switch 29 will be closed while switch 28 will be open.

Although the details of the illustrated overspeed device are not shown, the general operation will be described for clarification purposes.

The overspeed generator 17 is set to prevent the overspeed of compressor 10 and at a predetermined speed will generate sufficient current to close the usual type relay (not shown) and actuate the contacts of switch 33, of the valve control circuit 19. In other words, the overspeed generator 17 detects a pre-overspeed or overspeed condition of the compressor and signals the closing of switch 33 to energize the valve control circuit 19.

Similarly, a pre-surge or surge condition is detected by the apparatus 18 which sends a signal to a means for closing switch 34 to energize the valve control circuit 19.

The closing of either switch, 33 or 34, will energize the relay 24, whereupon the switch 25 will be opened, while switches 35 and 36 will be closed. The closing of switch 35 energizes a coil 37.

The coils 26 and 37 may be field windings of an electric servo motor, indicated at 44, while coils indicated at 41 and 43 may be field windings of an electric servo motor indicated at 45. Armatures 44a and 45a are parts of the servo motors 44 and 45, respectively.

Energization of the coils 26 and 37 drives the electric servo motor 44 thereby moving the butterfly valve 20.

The switches indicated at 28, 29, 38, 39 are mechanically linked as at 20a to the valve 20 and will be actuated upon movement thereof. When the turbine shut-off valve 20 reaches a closed position, switch 38 will automatically be moved upwardly opening the line to coil 37, and closing switch 39, thereby energizing the lamp 40 which indicates on a control panel that the turbine shut-off valve is fully closed.

When the switch 36 is closed the coil 41 is energized whereupon the turbine modulating valve 21 is closed. The motors 44 and 45 are selected to exhibit different operational speeds, for example, by having different gear ratios.

When the valve 21 is operated, a pair of switches 46 and 47 are actuated through a linkage shown at 21a.

The servo motor 45 is normally energized by the switch 31 which is manually operated. Energy is supplied to the coil 43 through the normally closed switch 47 to open the valve 21. When the valve 21 reaches its extreme open position, the switch 47 becomes normally open by the linkage 21a.

To close valve 21, energy is supplied through switch 31 which through normally closed switch 46 energizes coil 41. When valve 21 reaches a fully closed position, the switch 46 becomes normally open through the linkage 21a. This arrangement prevents grounding of the motor 45.

Thus, the turbine modulating valve 21 closes at a much slower rate than the turbine shut-off valve 20. Since the turbine shut-off valve closes in a very short period of time, and the turbine throttle valve 21 closes much slower, it is possible for a surge condition in the compressor to be avoided and the turbine flow control to be reset at a substantially lower, operating condition for the compressor without completely shutting down the unit. This feature is highly desirable in the case of turbine driven air compressors used on airplanes.

While a surge or overspeed condition exists in the compressor 10, an indicator lamp 42, preferably located on a control panel is energized.

Upon the passing of surge or overspeed condition, and the opening of switches 33 and 34, relay 24 will be de-

energized, thereby closing switch 25 and opening switches 35 and 36. Then open coil 26 of the shut-off valve control 27 will be energized until the shut-off valve 20 is moved to the fully open position, whereupon the switch 29 will close and switch 28 will open energizing the open indicating lamp 30. Then by manually operating switch 31, the turbine modulating valve control 32 will again actuate the turbine throttle valve 21, to either energize the closed coil 41 or the open coil 43, thereby restoring control at a lower, safe operating condition for the compressor unit without completely shutting down thereof. As mentioned, switch 23 in the position shown in Figure 1, allows the relay 24 to be normally deenergized. If for any reason, such as in the case of an emergency, it is desired to override overspeed switch 33 and surge detecting switch 34, switch 23 may be moved to energize relay 24 and actuate valves 20 and 21.

Various temperature sensitive circuits or mechanisms may be employed to provide a signal which closes switch 34 to actuate valve control circuit 19 and close or modulate the turbine inlet air supply with the primary purpose of such a mechanism being to supply some kind of a signal prior to a compressor surge condition. For such temperature sensitive mechanisms are illustrated in Figures 2-5, inclusive, and these surge detection devices are designated respectively by the numerals 18a, 18b, 18c and 18d.

As already mentioned, the compression of air through the impeller of a centrifugal compressor causes its temperature to increase and because of the back flow through the impeller clearance space and passages, the compressor inlet temperature measured immediately ahead of the impeller is higher than the upstream temperature and varies radially, increasing from the compressor axis to the inlet outside diameter. Referring to Figure 2, the clearance space may be more accurately defined as that radial space designated by the numeral 46, between the impeller 10a and the inlet housing 10b; and it has been found that the temperature difference between the incoming air measured at a point in the inlet 11 substantially ahead of the impeller 10a, and the temperature of the compressor back flow measured immediately ahead of the impeller 10a is a function of the tip speed and overall compressor pressure ratio. Hence, from this measurement, it can be determined when the compressor will surge.

A surge sensing device of Figure 2 comprises a pair of thermopiles, 47 and 48, disposed in the compressor inlet 11, and differentially connected by suitable wiring such as indicated by the numeral 49. The signal output received from the differentially connected thermopiles 47 and 48 is amplified by amplifier 50 to operate a conventional current or voltage sensitive relay 51 and close the surge contacts 34. Thermopile 47 measures the temperature of the incoming air while thermopile 48 measures the temperature of the compressor back flow air adjacent the impeller 10a.

Another form of surge detection device 18b, as shown in Figure 3, comprises resistances disposed in the compressor inlet 11 which have the characteristics of varying their resistance greatly over the desired temperature range expected to be encountered, such as between -65° F. to 160° F. A balanced bridge circuit 52 having a resistor 53 exposed to the compressor inlet air temperature and a resistor 54 exposed to the higher temperature air resulting from the back flow through the clearance space of the compressor emits an electric difference signal independent of inlet temperature which is amplified electronically by amplifier 55 to actuate a conventional relay 56, of the current or voltage sensitive type, which in turn, closes the surge contacts 34.

Another type of temperature sensitive surge detection mechanism is illustrated in Figure 4 and indicated by the numeral 18c which comprises a pair of pressurized capillary tubes 57 and 58 connected to opposite sides

of a differential pressure switch 59, such as a bellows, by suitable means, such as capillary tubing. Capillary tube 57 is located upstream to sense the incoming air temperature, while capillary tube 58 is disposed immediately ahead of the compressor impeller preferably at the inlet outside diameter of 10a to sense the compressor back flow temperature wise. A temperature difference causes a pressure difference in the sealed capillary tubes having essentially constant volume and thereby actuates the pressure differential switch 59 to close the surge contacts 34. The capillary tubes may assume the form of a ring to conform to the extreme inside diameter of the compressor inlet 11.

Still another type of surge detection arrangement is illustrated in Figure 5, designated by the numeral 18d. A pair of thermocouples, 60 and 61, the former for measuring the temperature of incoming air, while the latter measures the temperature of the compressor back flow, are connected differentially to a galvanometer movement 62 by means of suitable wiring. The galvanometer 62 is capable of being actuated by a low microvolt input (less than 2 microvolts), and upon a surge condition will respond to a voltage differential in the thermocouple circuit 67 to close the switch 63 to a voltage supplied circuit to energize a coil 64. The energization of coil 64 will close surge contacts 34 and a set of contacts 65 of an automatic reset solenoid circuit. By action of a solenoid 66 in a reset solenoid circuit, switch 63 is opened, thus deenergizing the relay 64 which then allows the surge contact 34 and the automatic reset solenoid circuit contacts 65 to open. However, a suitable time delay mechanism (not shown) may be provided to effect a time delay in the opening of surge contacts or the closing of contact 65.

While various means have been disclosed for obtaining a suitable signal to prevent compressor surge, other means might also be employed. In the embodiments of the invention illustrated in Figures 2-5, there is a definite relation between the location of the two temperature sensing elements and the compressor surge characteristics; and for this reason, their location is critical and some optimum location must be determined by experimental testing. Generally, the element sensing the back flow through the compressor clearance space must be located immediately adjacent to the impeller inlet and as close to the inlet outside diameter as possible.

It will be understood that modifications and variations may be effected without departing from the scope of the novel concepts of the present invention, but it is understood that this application is to be limited only by the scope of appended claims.

I claim as my invention:

1. In combination, a centrifugal compressor having an inlet conduit, an impeller to pump fluid through said inlet conduit, variable speed motive means connected to rotate the impeller of said compressor, thermo-electric transducer means including a pair of differentially connected temperature sensitive pressurized capillary tubes in said inlet conduit and a switch, said tubes measuring the temperature difference existing between the incoming air and the air immediately ahead of the impeller and being connected to change the position of said switch in response to a temperature difference of a predetermined magnitude, an electrical circuit in which said switch is connected, said circuit also including means responsive to said change of position of said switch to vary the speed of said motive means rotating said impeller.

2. In combination, a centrifugal compressor having an inlet conduit, an impeller to pump fluid through said inlet conduit, variable speed motive means connected to rotate said impeller of said compressor, a first thermo-electric transducer positioned in said inlet conduit to provide a measure of the temperature of the incoming air in said inlet conduit, a second thermo-electric trans-

ducer positioned in said inlet conduit to provide a measure of the air immediately ahead of said impeller in said inlet conduit, said first and second thermo-electric transducers being differentially connected to a bridge circuit, said bridge circuit providing an electrical output signal the magnitude of which is a measure of the temperature differential existing between the incoming air and the air immediately ahead of the impeller, and an electrical circuit connected to said motive means to receive said signal and be responsive to a predetermined magnitude of said signal representing a preselected value of said temperature differential slightly below that at which the compressor would surge to vary the speed of said motive means connected to rotate said impeller of said compressor to prevent surging in said compressor.

3. Apparatus for preventing surging in a centrifugal compressor unit comprising, a compressor including an impeller, a turbine connected to drive said impeller, an air inlet conduit connected to said compressor to direct incoming air to said impeller, first and second differentially connected thermopiles located in said air inlet conduit and positioned and connected to provide an output signal which is a measure of the difference in temperature between the incoming air and the air immediately ahead of the compressor impeller, an amplifier connected in circuit to amplify said signal, a normally open switch means operatively connected with the output of said amplifier so as to be closed by said output when said signal reaches a predetermined magnitude, a valve operatively connected to control the amount of driving medium supplied to said turbine to control its speed, an electrical circuit including said switch means and completed by the closing thereof, said circuit also including means operatively connected to actuate said valve when said circuit is closed, said switch being connected to be closed when said predetermined magnitude of said signal indicates a temperature differential indicative of a condition immediately preceding that which would cause surging of said compressor.

4. Apparatus for preventing surging in a centrifugal compressor unit comprising, a compressor having a rotary impeller, a turbine connected to rotate said impeller, an air inlet conduit connected to said compressor and directing incoming air to said impeller, a pair of temperature responsive resistances located in the air inlet conduit and connected in a circuit for measuring the difference in temperature between the incoming air and the air immediately ahead of the compressor impeller, said resistances having the characteristics of varying their resistance greatly over a preselected temperature range, said circuit comprising a bridge circuit connecting said resistances, said bridge circuit providing an output signal which is a measure of said temperature difference, an amplifier operatively connected to amplify said output signal of said bridge circuit, a switch which is normally open and which is connected to be closed in response to a predetermined magnitude of the output of said amplifier, said switch being connected in an electrical circuit which is completed by the closing thereof, valve controlled means connected to said turbine to control the amount of driving medium supplied to the turbine so as to control the speed of said turbine, said electrical circuit including said switch being operatively connected to control said valve means in response to said predetermined magnitude of said amplifier output closing said switch.

5. Apparatus for preventing surging in a centrifugal compressor unit comprising, a compressor including an impeller, a turbine connected to rotate said impeller, an air inlet conduit connected to said compressor to direct incoming air to said impeller, a pair of temperature responsive pressurized capillary tubes located in said air inlet conduit and positioned to measure the difference in temperature between the incoming air and the air immediately ahead of the compressor impeller, said tubes

having the characteristic of varying their pressure as a function of temperature over a preselected temperature range, a normally open pressure actuated switch means connected to be actuated to a closed position in response to a pressure indicative of a predetermined temperature difference between said incoming air and said air immediately ahead of the compressor impeller, an electric circuit including said switch and connected to be completed by closing of said switch, valve controlled means connected to said turbine to control the amount of driving medium supplied to said turbine, said electrical circuit including means to control said valve means in response to closing of said switch when said predetermined temperature difference reaches said predetermined magnitude indicating a condition immediately preceding that which causes surging of said compressor.

6. Apparatus for preventing surging in a centrifugal compressor unit comprising, a compressor having a rotary impeller, a turbine connected to said impeller to impart drive thereto, valve controlled means connected to said turbine to supply driving medium thereto, an air inlet conduit directing incoming air to said impeller, first and second thermocouples located in said air inlet conduit for measuring the difference in temperature between the incoming air and the air immediately ahead of said compressor impeller, said thermocouples being connected in a first circuit to provide an electrical signal proportional to the magnitude of said temperature differential, said circuit including a galvanometer movement, a normally open switch connected to be closed by said circuit in response to a predetermined magnitude of said signal, a second electrical circuit including said switch and completed by the closing of said switch, said second circuit also including means connected to actuate said valve means to control the amount of driving medium supplied to said turbine.

7. Apparatus for preventing surging in a centrifugal compressor unit comprising, a compressor including an impeller, a turbine connected to drive said impeller, a turbine inlet duct for supplying a driving medium to said turbine, a shut off valve in said inlet duct, a throttle valve in said inlet duct, an air inlet conduit directing incoming air to said impeller, first and second thermo-electric transducers operatively connected and positioned to derive an electrical signal which is a measure of the difference in temperature in said conduit between said incoming air and the air immediately adjacent said impeller, an electrical circuit including a normally open switch, means connected to said switch and responsive to a predetermined magnitude of said derived signal for closing said switch, said electrical circuit being completed by the closing of said switch, said electrical circuit also including means actuated by the completion of said circuit for operating said shut off valve and said throttle valve in said turbine inlet to vary the speed of said compressor to prevent surging therein.

8. In combination with a centrifugal compressor having an air inlet leading to an impeller driven by a turbine the speed of rotation of which is controllable by inlet valve means in a conduit supplying driving medium to said turbine, first and second thermo-electric transducers connected and positioned to derive an electrical signal which is a measure of the temperature difference in said inlet between incoming air in said impeller inlet and air immediately ahead of said impeller, means connected to said valve to control said valve means in response to a predetermined magnitude of said signal corresponding to a predetermined magnitude of said temperature difference to vary the speed of said turbine and thus prevent surging in said compressor, speed sensing means driven by said turbine and connected to provide a second electrical signal which is a measure of the speed of rotation of said turbine, and electrical circuit means connected to said valve means and connected to receive said signal to be responsive to a predetermined magnitude of said

second signal to control the speed of said turbine to prevent overspeeding of said compressor.

9. In combination, a compressor having an air inlet leading to a compressor impeller, a turbine connected to rotate said impeller, conduit means connected to supply driving medium to said turbine, valve means mounted in said conduit for controlling the amount of driving medium supplied to said turbine and for thereby controlling the speed of said turbine, first and second temperature sensitive devices so positioned in said compressor air inlet and so connected as to provide an output signal which is a direct measure of the temperature differential between the incoming air and the air in the compressor backflow, an electrical circuit including a normally open switch, means operatively connected to close said switch in response to a predetermined magnitude of said output signal corresponding to a predetermined magnitude of said temperature differential indicating a condition immediately preceding that at which said compressor would surge, said electrical circuit being connected to be com-

pleted by closing of said switch, said electrical circuit including means actuated by completion of said circuit and operatively connected to said valve means to actuate to vary the amount of driving medium supplied to said turbine and hence vary the speed of said turbine.

References Cited in the file of this patent

UNITED STATES PATENTS

10	1,655,683	Standerwick	Jan. 10, 1928
	2,442,049	Lee	May 25, 1948
	2,463,566	Saldin	Mar. 8, 1949
	2,521,244	Moore	Sept. 5, 1950
	2,689,680	Lovesey	Sept. 21, 1954
15	2,705,047	Williams	Mar. 29, 1955
	2,705,590	Lovesey et al.	Apr. 5, 1955
	2,790,120	Ducoff	Apr. 23, 1957

FOREIGN PATENTS

20	1,088,725	France	Sept. 15, 1954
----	-----------	--------	----------------