United States Patent [19]

Silvern et al.

[11] **3,741,677**

[45] **June 26, 1973**

[54] **FLOW CONTROL APPARATUS FOR A CENTRIFUGAL COMPRESSOR**

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[22] Filed: **Oct. 12, 1971**

[21] Appl. No.: **188,244**

[52] **U.S. Cl.** **415/52**, 415/27, 415/DIG. 1

[51] **Int. Cl.** **F01d 1/12**

[58] **Field of Search** ..... 415/52, 53, 27, DIG. 1

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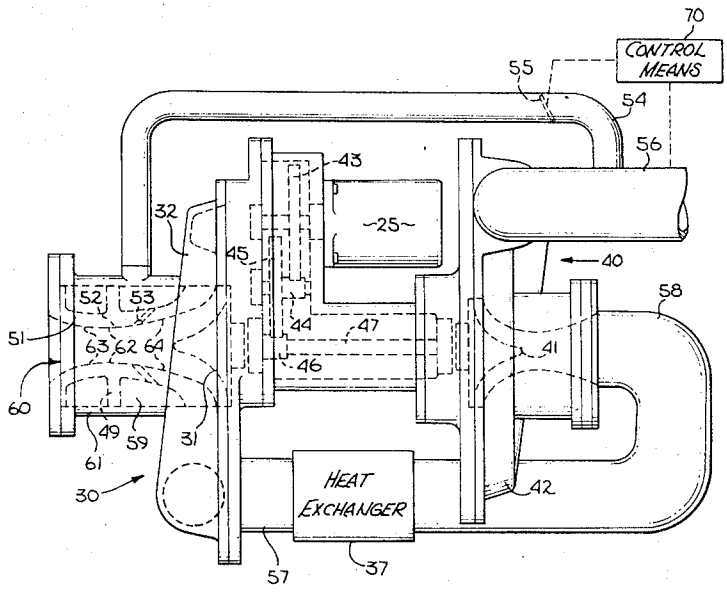
[57] **ABSTRACT**

A control apparatus used for controlling a centrifugal compressor during low flow and overload conditions is disclosed. A manifold disposed in the inlet to the compressor includes passageways which allow fluid such as air from a higher stage of compression to be directed in a direction generally opposed to prevailing flow direction in the inlet thereby throttling the inlet flow. The manifold defines a sonic nozzle which throttles the inlet air during overload conditions.

8 Claims, 4 Drawing Figures



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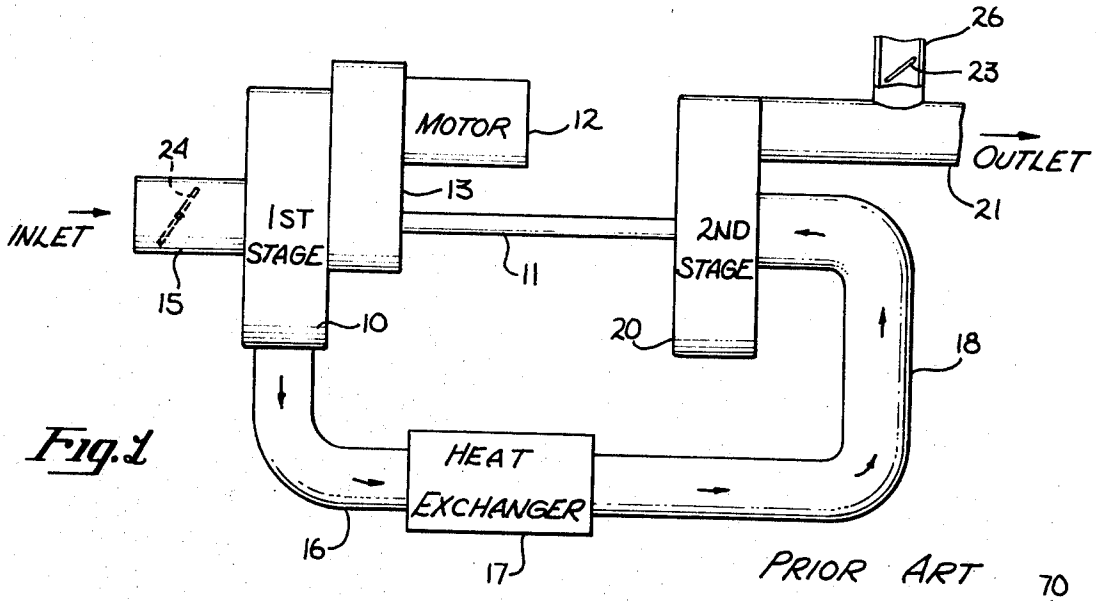

Fig. 1

PRIOR ART

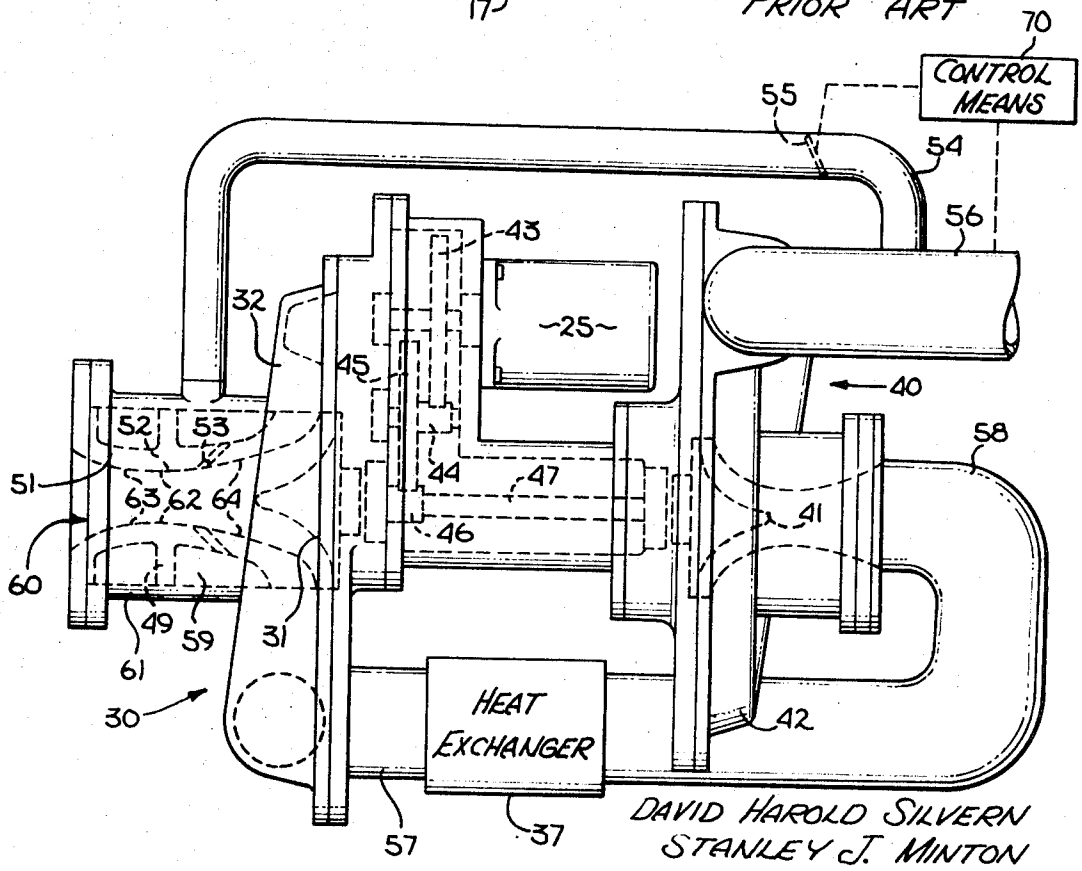

Fig. 2

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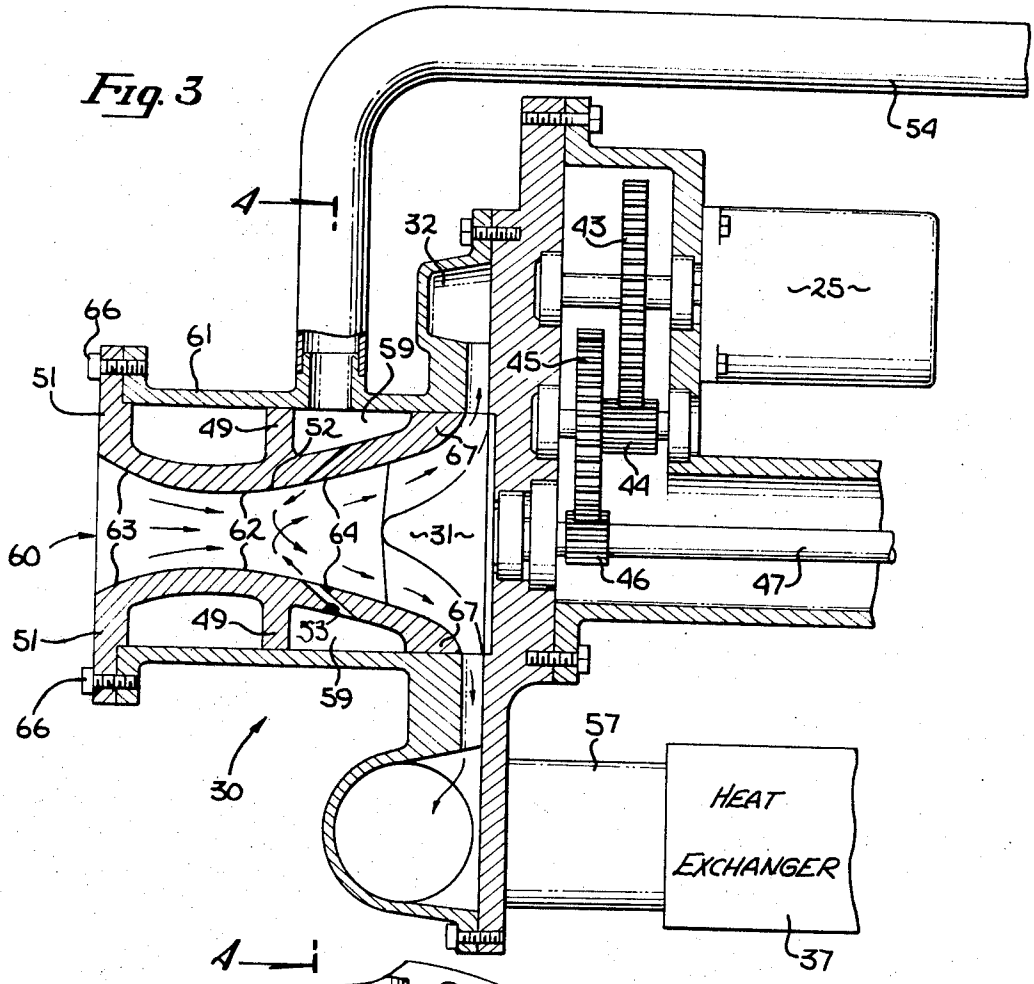
Fig. 3



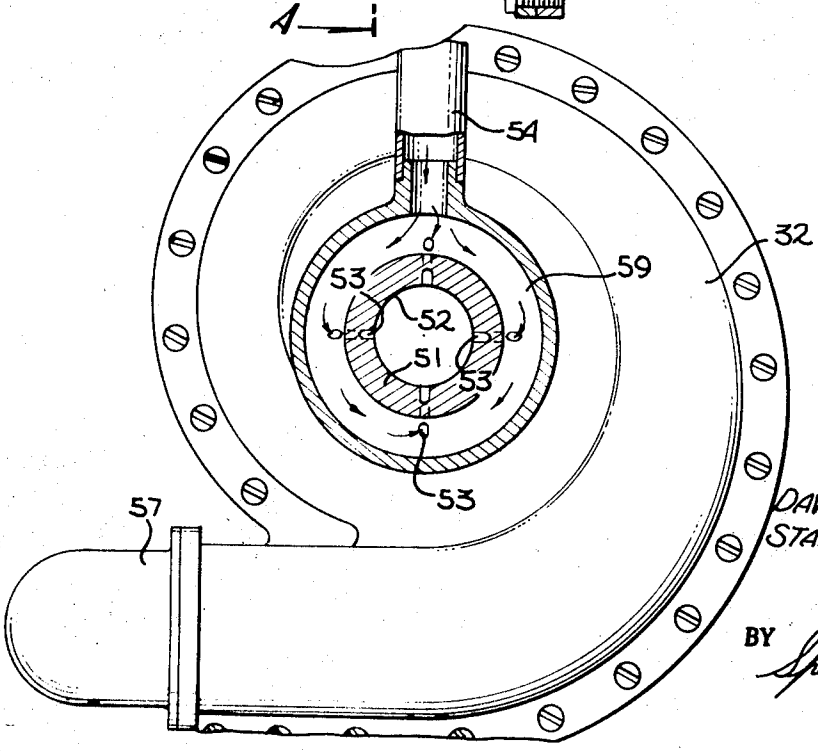


Fig. 4

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FLOW CONTROL APPARATUS FOR A CENTRIFUGAL COMPRESSOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to means for controlling flow in a centrifugal compressor.

2. Prior Art

Centrifugal compressors for compressing fluids such as air are well known in the art. In numerous applications it is necessary to supply compressed fluids at various flow rates. For example, where a plurality of of pneumatic tools are driven from a single compressor the requirement for air may be continuously changing. In such situations it is necessary to supply air at a relatively constant pressure, notwithstanding the demand on the compressor. While centrifugal compressors are efficient for a predetermined or optimum flow, they exhibit undesirable characteristics under low flow conditions, such as surging, and require controls if satisfactory operation is to be maintained at low flow conditions. Additionally, when the demand for fluid from the compressor exceeds the compressor's rated flow, that is, the flow rate at which the compressor may operate without becoming overloaded, controls are also required to prevent overloading.

Typical prior art methods for controlling a centrifugal compressor at a low flow condition and overload conditions require an expensive inlet valve. These methods are discussed herein in conjunction with FIG. 1.

SUMMARY OF THE INVENTION V

A flow control means for controlling flow in a centrifugal compressor during low flow and high flow conditions comprising a manifold disposed within the inlet of the compressor is described. The manifold includes a plurality of nozzles or passageways which permit fluid from a higher stage of compression to be injected or directed into the inlet of the compressor in a direction generally opposed to the prevailing flow direction in the inlet. The fluid so directed into the inlet causes a pressure drop in the inlet thereby throttling the inlet flow. A surface of the manifold which comprises the inlet to the compressor defines a sonic nozzle which automatically throttles the flow of air into the compressor during high flow conditions, thereby preventing overloading.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram illustrating a two-stage centrifugal compressor along with typical prior art methods for controlling the compressor during low flow and high flow conditions;

FIG. 2 is a plan view of a two-stage fluid compressor illustrating control means built in accordance with the present invention;

FIG. 3 is a partial cut-away view of the compressor of FIG. 2 which illustrates in detail the inlet to the first stage of compression; and

FIG. 4 is a cross-sectional view of the compressor of FIGS. 2 and 3 taken through section line 4—4 of FIG. 3.

DETAILED DESCRIPTION OF THE INVENTION

While the present invention will be described with reference to a centrifugal air compressor it will be obvious that the invention will work equally well where a compressible fluid other than air is utilized.

Referring to FIG. 1, a schematic for a prior art air compressor which includes a first stage of compression 10 and a second stage of compression 20 is illustrated. Each of these stages includes a rotor and diffuser, the rotors being driven by drive shaft 11, which is coupled to motor 12 through gear box 13. The inlet air to the compressor flows through inlet 15 and the outlet compressed air from the compressor leaves the diffuser of the second stage through line 21. The compressed air from the first steps of compression 10 is coupled to heat exchanger 17 through line 16; the heat exchanger 17 provides interstage cooling to remove the heat of compression from the first stage of compression 10, as is commonly done in air compressors. The cooled air from heat exchanger 17 is coupled to the inlet of the second stage of compression 20 by a line 18. A valve 24 is disposed in inlet 15 and is used to throttle the inlet air to the compressor. An exhaust line 26 is coupled into outlet 21 and includes a valve 23 disposed in the line 26.

The surge control means illustrated in FIG. 1 is utilized in the prior art with two distinct methods for controlling surging during low flow conditions. The first method involves throttling the inlet with valve 24 (only slightly) when the flow rate from outlet 21 begins to decrease. This is done when the flow from the compressor begins to decrease, but has not decreased to the point where surging would normally occur. This initial throttling is done to regulate the output pressure since there is a tendency in centrifugal compressors for the outlet pressure to rise when the flow decreases even where surging does not occur. When the flow from outlet 21 decreases to the point where surging would normally occur, valve 23 of exhaust line 26 is opened, allowing the output from the compressor to be exhausted into the atmosphere. By doing this the flow from the compressor may be maintained at a level where surging will not occur. The obvious problem with this scheme is that a great deal of power is wasted, since the compressor is operating at near optimum flow even where its output is not being utilized.

The surge control means illustrated in FIG. 1 is also utilized in the prior art for controlling surging without exhausting or wasting substantial amounts of compressed air. As in the previously described method, when the flow rate from outlet 21 drops below an optimum value but not low enough for surging to occur, valve 24 is slightly closed so as to maintain the outlet pressure at a desired level. When the flow from outlet 21 drops to a point where surging would normally occur, valve 24 is substantially closed and valve 23 is opened. When this occurs little or no compressed air flows from outlet 21 and the compressor is doing very little work since the inlet is throttled. With this method of surge control a one-way valve is typically coupled to outlet 21 so that air will not flow back into the compressor and a reservoir of compressed air is coupled to the outlet side of the one-way valve. Thus, when the flow drops to the point where surging would occur the compressor is, in effect, cut off from the outlet line and air from the reservoir is utilized. When the air in the reservoir is partially consumed, the flow from outlet 21 will again increase and the compressor will be allowed to run at its optimum flow until the reservoir is filled or until the demand on the compressor continues at its op-

timum flow rate. As will be seen, the presently disclosed surge control means is preferably utilized with this latter described distribution or utilization system which includes a reservoir.

During high flow conditions or possible overload conditions valve **24** is utilized to throttle inlet **15** so as to prevent an overload condition in the compressor. Thus, both prior art methods for preventing surging and the prior art method for controlling high flow require the use of the inlet valve **24.**

Referring to FIGS. **2, 3** and **4,** a centrifugal compressor is illustrated which includes a first stage of compression **30** and a second stage of compression **40.** The first stage of compression includes an inlet **60,** a rotor **31** and a volute diffuser **32.** The second stage of compression comprises a rotor **41,** a volute diffuser **42** and an outlet **56.** A line **57** couples the outlet of the first stage of compression **40** with a heat exchanger **37.** The heat exchanger serves the same function as described in conjunction with FIG. **1,** that is, the removal of the heat of compression from the first stage of compression **30.** The outlet air from the heat exchanger **37** is coupled to the inlet of the second stage of compression **40** through line **58.**

Both rotors **31** and **41** are directly coupled to a common drive shaft **47.** A pinion gear **46** is rigidly coupled to shaft **47.** The driving force for the compressor is motor **25** which is directly coupled to a bull gear **43.** Bull gear **42** cooperatively engages pinion gear **44** which is mounted on a common shaft with bull gear **45.** Bull gear **45** cooperatively engages the pinion gear **46,** thereby allowing the motor **25** to drive the rotors **31** and **41.**

The compressor illustrated in FIGS. **2, 3** and **4,** and in particular the rotors, diffusers, heat exchangers and interconnections may be manufactured utilizing known techniques. Additionally, while the present invention is described with a compressor having a volute diffuser, it will be obvious to one skilled in the art that the present invention may be used with other types of diffusers such as a radial vaneless diffusers, vane diffuser or a pipe diffuser.

The inlet to the first stage of compression includes a generally cylindrically shaped frame **61** into which an inlet control manifold **51** is axially disposed and rigidly held within the frame **61** by bolt **66.** The surface **52** of manifold **51** defines a continuous passageway which comprises the inlet **60** to the first stage of compression. An annular shaped rib **49** which is an integral part of manifold **51** abuts the interior of the frame **61.** The end **67** of the manifold **51,** which defines a circular band, also abuts the interior of frame **61.** A chamber **59,** having a generally annular shape, is formed between rib **49,** the portion of the manifold **51** between rib **49** and end **67,** and the interior of frame **61** between end **67** and rib **49.**

A plurality of orifices or passageways **53** are disposed through manifold **51** such that chamber **59** communicates with inlet **60.** The axes of the passageways **53** form an acute angle with the direction of the prevailing flow in the inlet **60.** Thus the passageways **53** act as nozzles through which air may be injected into the inlet **60** in a direction which generally opposes the prevailing flow direction within inlet **60.**

A line **54** is coupled between the outlet **56** of the second stage of compression **40** and the inlet **60** of the first stage of compression **30.** At one end line **54** communicates with outlet **56** while at its other end the line **54** communicates with chamber **59** of manifold **51.**

The surface **52** of manifold **51** furthest from rotor **31** defines a sonic nozzle **63.** Air entering inlet **60** is accelerated since the diameter of the inlet **60** is decreasing until it reaches throat **62** of nozzle **63.** The diameter of throat **62** is selected such that at the maximum desired flow for the compressor the air passing through throat **62** will be sonic, thereby providing an automatic throttling of the inlet air to the first stage of compression **30.** A conical diffuser **64** also defined by surface **52** of the manifold **51** is disposed between the throat **62** of nozzle **63** and the end **67** of the manifold **51.** This conical diffuser serves the function of converting the high velocity air passing through throat **62** to lower velocity air at a higher pressure before the air reaches the rotor **31.** The dimensions of sonic nozzle **63** of course will be a function of the maximum desired flow through the compressor and may be determined utilizing known techniques. Likewise the dimensions of the conical diffuser **64** may be determined utilizing known techniques. The manifold **51** and line **54** may be ordinary metal parts built utilizing known technology.

A control means **70** which controls valve **55,** is provided for controlling the flow between the outlet **56** and the inlet **60** through line **54.** The control means **70** senses the flow of air in outlet **56** and controls valve **55** as a function of the flow in the outlet. A Pitot tube disposed within outlet **56** may be utilized to control valve **55,** allowing the valve to be opened and closed as a function of the outlet flow from the compressor. Any other known means may be utilized to control valve **55** in the described manner.

When the air flowing through the compressor illustrated in FIGS. **2** and **3** begins to decrease below a predetermined level, valve **55,** which is controlled by control means **70,** begins to open, allowing air from outlet **56** to flow through line **54.** This air enters the chamber **59** of manifold **51** and is directed into the inlet **60** through the passageways **53.** As best illustrated in FIG. **3,** this air as it enters the inlet **60** is generally directed by the passageway **63** so that it substantially opposes the normal prevailing flow of air into the compressor. As this air encounters the flow of air in the inlet it is forced to change direction before entering the first stage of compression **30** and thereby causes the inlet air entering the compressor through nozzle **63** to be throttled.

For flow rates through the compressor lower than the predetermined or optimum rates but higher than a flow rate at which surging will occur, valve **55** is only partially opened. The throttling of the inlet, as in prior art compressors, for this condition is utilized to maintain the outlet pressure at a desired level. Generally as the flow through a centrifugal compressor decreases slightly, the outlet pressure increases. It is this characteristic which is counteracted by the initial opening of valve **55.**

When the flow through the compressor drops to a rate at which surging may occur valve **55** is completely opened. This substantially eliminates all flow from the outlet **56.** Thus, the disclosed surge control means is, in the presently preferred embodiment, used with a utilization system that includes a reservoir coupled to the outlet; this reservoir furnishes compressed air during the low flow conditions. A one-way valve may be used between the outlet **56** and the reservoir to prevent air

from entering the compressor through outlet **56**. When the supply in the reservoir drops, the flow through the compressor will increase and valve **55** will be closed or substantially closed.

When valve **55** is open, and substantially all the flow from the compressor is recirculated through passageways **53** and the first and second stages of compression, the compressor is unloaded, and hence does not consume much power. The change of direction of the air injected into the inlet to the first stage of compression through passageways **53** causes a substantial drop in the inlet pressure to the first stage of compression. Tests have shown that the inlet air pressure to the first stage of compression drops by about 66 percent. This drop in pressure throttles the inlet air through inlet **60** and "unloads" the compressor. As illustrated in FIG. **3**, best results are achieved if the air injected into inlet **60** through passageways **53** is caused to change direction at the section of inlet **60** where the inlet diameter is the least. For the illustrated embodiments this would occur at throat **62**. It will be obvious that once the flow through the compressor reaches its optimum or near optimum rate valve **55** is closed by control means **70**.

When the flow through the compressor reaches the point that the air passing through throat **62** of nozzle **63** approaches or becomes sonic, an automatic throttling will occur. Thus, without the use of a valve within inlet **60** or means of sensing the flow through the compressor the inlet is automatically throttled.

It will be apparent that the control means described herein may be utilized in a compressor which includes any number of stages of compression. In such cases line **54** may be coupled to any higher stage of compression, thus allowing the air from the higher stage of compression to be directed into the inlet to a compressor.

Thus, a control means for controlling the flow of air through a centrifugal compressor has been described wherein the control means eliminates a prior art valve utilized within the inlet of the compressor and additionally, unloads the compressor during low flow conditions.

I claim:

1. In a centrifugal fluid compressor which includes an inlet to a stage of compression, an improvement in flow control means disposed in the inlet to said stage of compression comprising:

a nozzle means defining said inlet, including a first section adjacent to said inlet said first section defining a sonic nozzle and a second section adjacent to said stage of compression, said second section defining a diffuser such that fluid entering said stage of compression first passes through said sonic nozzle and thereafter passes through said diffuser before entering said stage of compression, whereby said nozzle means provides overload control means for said centrifugal compressor.

2. The improvement defined in claim **1** wherein said nozzle means defines a continuous surface.

3. The improvement defined in claim **2** wherein said diffuser is a conical diffuser.

4. The improvement defined in claim **2** wherein said nozzle means includes a manifold disposed in said inlet, said manifold having an inlet coupled to a higher stage of compression for receiving fluid from said higher stage of compression and a plurality of passageways disposed through said manifold such that said manifold inlet communicates with said inlet to said stage of compression such that fluid from said higher stage of compression may be injected into said inlet.

5. The improvement defined in claim **4** wherein said passageways are disposed in said manifold such that they from an acute angle with the prevailing flow in said inlet such that fluid flowing through said passageways generally opposes the flow of fluid through such inlet.

6. In a centrifugal fluid compressor which includes at least one stage of compression comprising an inlet, rotor and diffuser and at least one higher stage of compression, flow control means comprising:

a line coupled at one end to said higher stage of compression;

a manifold disposed in said inlet and defining a sonic nozzle in said inlet, said manifold including a manifold inlet coupled to the other end of said line and a plurality of passageways which communicate with said manifold inlet and said inlet of said one stage of compression, said passageways being disposed such that they form an acute angle with the prevailing flow in said inlet such that fluid flowing through said line into said inlet generally opposes the flow of fluid through such inlet into said one stage of compression.

7. The flow control means defined in claim **6** wherein the end of said manifold adjacent to said rotor of said one stage of compression defines a conical diffuser.

8. The flow control means defined in claim **7** including control means for controlling the flow of fluid through said line into said manifold.

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