(12) UK Patent Application (19) GB (11) 2 192 231 (13) A

(43) Application published 6 Jan 1988

(21) Application No 8715310

(22) Date of filing 30 Jun 1987

(30) Priority data
(31) 881435 (32) 2 Jul 1986 (33) US

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(51) INT CL[4]
F04D 29/08

(52) Domestic classification (Edition J):
F1C 104 204 503 513 515 521 D
U1S 1966 F1C

(56) Documents cited
GB A 2052635 GB 1190796 EP A1 0012895
GB 1412150 GB 1120275 WO A1 86/03809

(58) Field of search
F1C
Selected US specifications from IPC sub-class F04D

(54) Centrifugal compressor control

(57) In a centrifugal compressor having a number of fixed vanes 48 on its outlet side, an axially movable sleeve 41 is provided upstream of the vanes. The sleeve can be moved by fluid pressure in a conduit 65 controlled by valve 51. The compressor also has inlet guide vanes 12 which are adjustable by a control system (33, Fig. 1) in a refrigeration system.

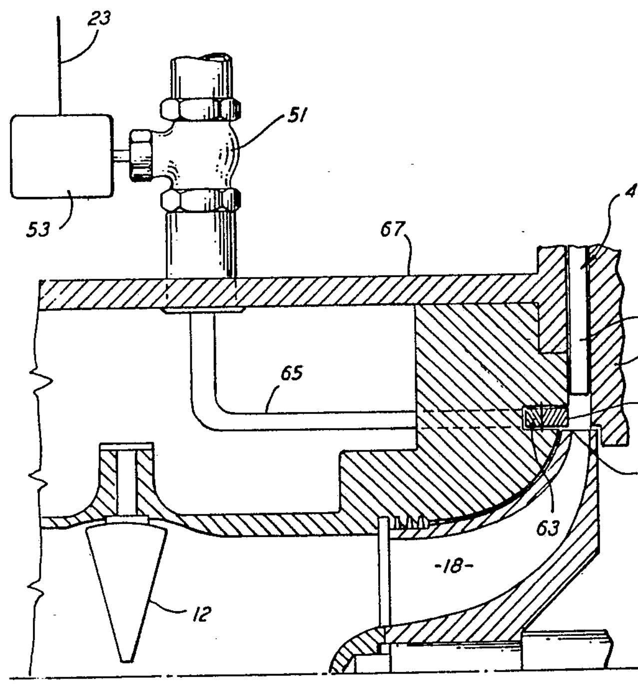

FIG. 2

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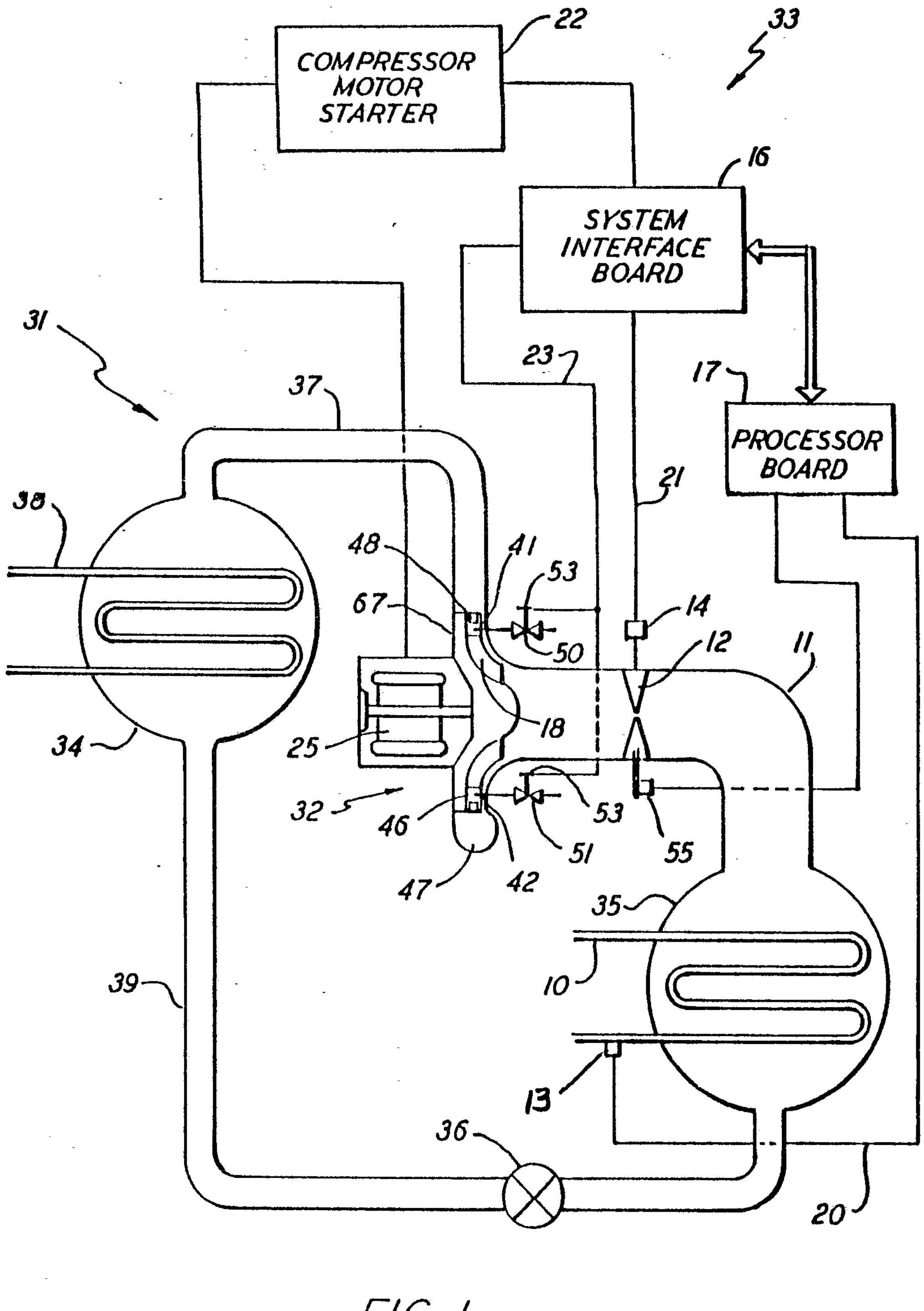
COMPRESSOR MOTOR STARTER
SYSTEM INTERFACE BOARD
PROCESSOR BOARD
22
33
16
17
31
23
21
37
38
48
41
53
67
14
12
11
50
18
25
34
32
46
53
51
55
47
42
35
10
39
13
36
20

FIG. 1

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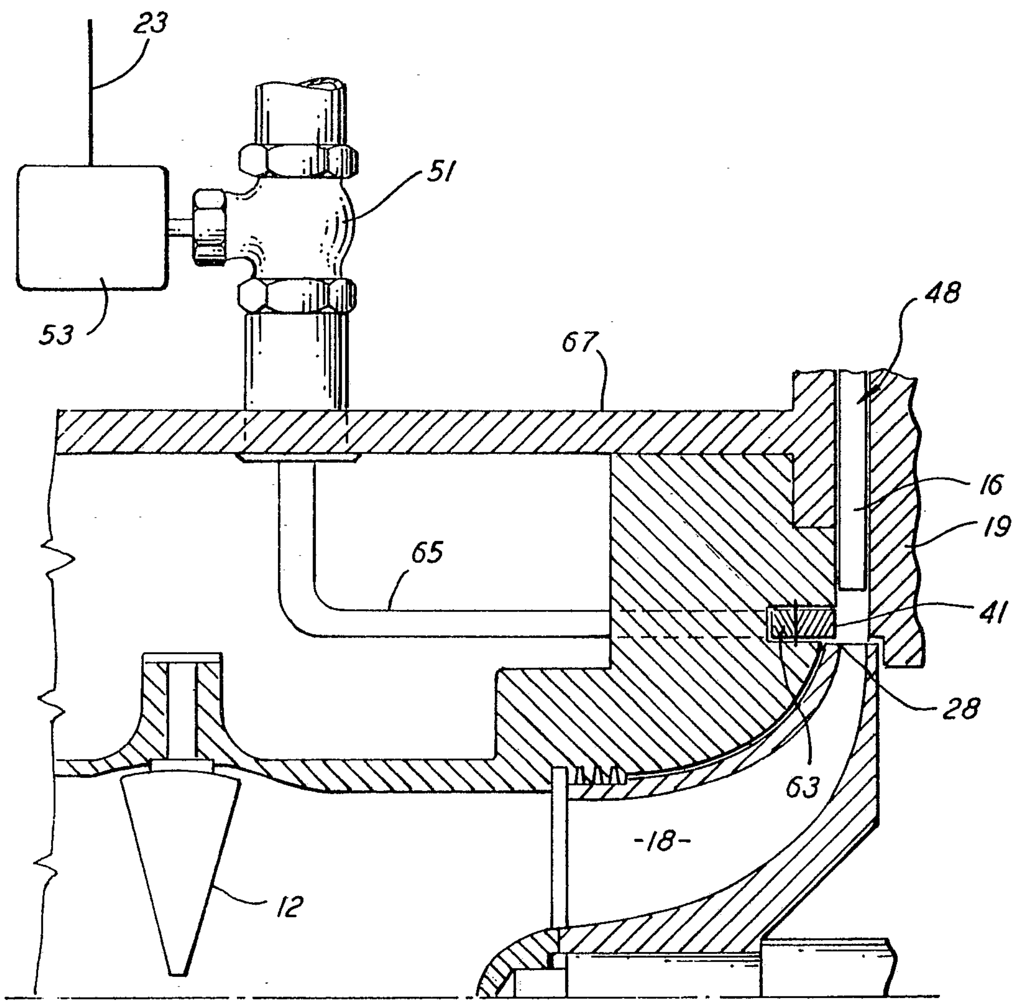

FIG. 2

SPECIFICATION

Movable ring for part-load control of vaned diffuser centrifugal compressor

This invention relates to centrifugal turbomachines, and, more specifically, to diffuser structure for use in such devices.

In centrifugal turbomachines such as gas compressors, the kinetic energy of the flowing medium which is issuing at high speed from the impeller is converted into pressure energy and the efficiency and stability of the compressor is dependent upon the means for converting the kinetic energy into static pressure. One of the major problems arising in the use of centrifugal gas compressors operating at fixed speeds for refrigeration systems, where the compression load varies over a wide range, is flow stabilization through the compressor. The compressor inlet, impeller, and diffuser passage must be sized to provide for the maximum volumetric flow rate desired. If, however, capacity control over the machine is accomplished by varying the position of a series of adjustable guide vanes located at the inlet of the machine, while the diffuser throat area is fixed the mass rate of flow of refrigerant delivered to the impeller is varied to meet the changing load demands made on the machine. However, at maximum flow, the refrigerant leaving the impeller may be more than the fixed diffuser can handle, thus the flow becomes choked at the diffuser throat. When there is a low volumetric flow rate through such a compressor, the diffuser may be too large and the flow becomes unstable. As the volumetric flow rate is decreased from a stable range, a range of slightly unstable flow is entered. In this slightly unstable range, flow in both the impeller and diffuser becomes separated from the wall along the entire length of the flow passage and there appears to be a partial reversal of flow in the diffuser passage creating noises and lowering the compressor efficiency. Below this slightly unstable range, the compressor enters what is known as surge, wherein there are periodic complete flow reversals in the diffuser passage, destroying the efficiency of the machine.

Many high-performance centrifugal stages employ a fixed vane diffuser section to achieve the kinetic energy conversion since a vaned diffuser is more efficient at designed incidence than a vaneless diffuser. The low flow limit corresponds to the onset of a surge or stall condition which occurs as the fluid flow from the impeller becomes more tangential as the flow decreases. This produces a large flow angle and magnitude with respect to the leading edge of the fixed diffuser vanes, creating a violent instability. The high flow limit corresponds to a choke condition caused as increasing fluid flow from the impeller becomes more radial and finally chokes the diffuser throat with very large kinetic energy loss. Since a vaneless diffuser has better off-design performance than a vaned diffuser, because it does not suffer from incidence loses, it is often chosen where there is considerable off-design operation.

Various techniques have been used to increase the range between the surge and choke limits of a compressor. Guide vanes in the inlet of the compressor have been employed to vary the flow direction and quantity of entering gas. Movable diffuser vanes have also been employed to permit alignment of the vanes with the changing flow direction as the flow rate changes.

Variable speed compressors wherein the speed of the impeller is varied to allow for changes in flow rates have been used with some success in the art. These variable speed machines, however, are very complex and thus expensive to build and operate. As a consequence they have not found wide general acceptance in the art and, in particular, the refrigeration industry.

An even more successful approach towards improving both the efficiency and operating range of a centrifugal compressor is through the use of a variable width vaned diffuser. In this particular application, the diffuser contains a movable wall that can be selectively positioned in regard to a fixed wall to control the flow of refrigerant therebetween. In the movable wall control the inlet guide vanes of the compressor are used in a conventional manner to regulate the mass flow of refrigerant through the machine while the diffuser wall position is varied to prevent surging. The movable wall vaned diffuser concept is used to maintain optimum incidence independent of load conditions. Squeezing the flow by moving the variable wall inwards, thus reducing the width of the diffuser, will result in a more radial flow direction since width reduction increases the radial velocity component (conservation of mass) but leaves the tangential component unaffected (conservation of annular momentum).

In accordance with the present invention, a fixed vane diffuser is provided in combination with an axially movable sleeve ring.

It is an object of this invention to provide a method and apparatus for varying the capacity of a centrifugal compressor in order to provide a large range of stable flow rates.

It is another object of this invention to provide a centrifugal gas compressor having means therein to stabilize the gas flow therethrough at extremely low flow rates.

It is a further object of this invention to provide a centrifugal compressor in which the compressor efficiency is optimized over a wide range of flow rates.

It is another object of this invention to match the flow angle to the impeller blade angle.

It is an additional object of this invention to provide a centrifugal compressor having a diffuser with a movable sleeve ring for extending the stable operating range of the compressor by postponing rotating stall in the vaned diffuser.

It is still a further object of this invention to allow twisted diffuser vanes in combination with the movable sleeve ring.

It is a yet still further object of this invention to provide a centrifugal compressor that eliminates flow losses due to leakage through the clearance between the vanes and the slots in a movable wall, and eliminates contact and sticking between the movable wall and the vanes.

The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which there is illustrated and described a preferred embodiment of the invention.

Other objects and advantages of the present invention will be apparent from the following detailed description in conjunction with the accompanying drawings, forming a part of this specification, and in which reference numerals shown in the drawings designate like or corresponding parts throughout the same, and in which;

Figure 1 is a schematic illustration of a centrifugal compression refrigeration system with a movable ring of the present invention; and

Figure 2 is an elevational view, partly in section of a portion of the centrifugal compressor shown in Figure 1, incorporating the teachings of the present invention and showing the diffuser sleeve ring thereof in the open position.

Referring to Figure 1, a centrifugal vapor compression refrigeration system 31 is shown having a control system 33 for operating the refrigeration system 31. As shown in Figure 1, the refrigeration system 31 includes a compressor 32, a condenser 34, an evaporator 35, and an expansion device 36. In operation, compressed gaseous refrigerant is discharged from the compressor 32 through compressor discharge line 37 to the condenser 34 wherein the gaseous refrigerant is condensed by relatively cool condensing water flowing through tubing 35 in the condenser 34. The condensed liquid refrigerant from the condenser passes through refrigerant line 39 and expansion device 36 to the evaporator 35. The liquid refrigerant in the evaporator 35 is evaporated to cool a heat transfer fluid, such as water, flowing through tubing 10 in the evaporator 35. This cool heat transfer fluid is used to cool a building or is used for other such purposes. The gaseous refrigerant from the evaporator 35 flows through compressor suction line 11 back to the compressor 32 under the control of compressor inlet guide vanes 12. The gaseous refrigerant entering the compressor 32 and discharged from the compressor 32 to outlet scroll 47 and through the compressor discharge line 37 to complete the refrigeration cycle. This refrigeration cycle is continuously repeated during normal operation of the refrigeration system 31.

Also, as shown in Figure 1, the centrifugal compressor 32 of the refrigeration system 1 includes an electric motor 25 for driving the compressor 32 which is under the control of the control system 33. A1so,it may be seen that the compressor inlet guide vanes 12 are opened and closed by a guide vane actuator 14 controlled by the control system 33. Further, movable sleeve ring 47 and 42 controlled by control vanes 50 and 51 and actuator 53.

The control system 33 includes a compressor motor starter 22, a system interface board 16, and a processor board 17. Also, a temperature sensor 13 for sensing the temperature of the heat transfer fluid leaving the evaporator 35 through the tubing 10, is connected by electrical lines 20 directly to the processor board 17.

Preferably, the temperature sensor 13 is a temperature responsive resistance device such as a thermistor having its sensing portion located in the heat transfer fluid leaving the evaporator 35 with its resistance monitored by the processor board 17. Of course, as will be readily apparent to one of ordinary skill in the art to which the present invention pertains, the temperature sensor 13 may be any of a variety of temperature sensors suitable for generating a signal indicative of the temperature of the heat transfer fluid leaving the evaporator 35 and for supplying this generated signal to the processor board 17.

The processor board 17 may be any device or combination of devices, for receiving a plurality of input signals, for processing the received input signals according to preprogrammed procedures, and for producing desired output control signals in response to the received and processed input signals. For example, the processor board 17 may comprise a microcomputer, such as a model 8031 microcomputer available from Intel Corporation which has a place of business at Santa Clara, California.

The system interface board 16 includes a plurality of switching devices for controlling the flow of electrical power from a power supply (not shown), through the system interface board 16 to the guide vane actuator 14 the control valve actuator 53, and the motor 25 for driving the compressor 32. Each of the switching devices may be a model SC-140 triac available from General Electric Company which has a place of business at Auburn, New

York. However, as will be readily apparent to one of ordinary skill in the art to which the present invention pertains, switches other than triac switches may be used as the switching devices.

The switching devices on the system interface board 16 are controlled in response to control signals received by the switching devices from the processor board 17. In this manner, the guide vane actuator 14, the control valve actuator 53, operating control valves 50 and 51, and the motor 25 driving the compressor 32 are controlled by the processor board 17.

The guide vane actuator 14 and control valve actuator 53 may be any devices suitable for driving the guide vanes 12 toward either there fully open or fully closed position or opening or closing control valves 50 and 51 in response to electrical power signals received via electrical lines 21 or 23, respectively. For example, the guide vane actuator 14 and control valve actuators 53 may be an electric motor, such as a model MC-351 motor available from the Barber-Coleman Company having a place of business in Rockford, Illinois, for driving the guide vanes 12 and control valves 50 and 51 toward either their fully open or fully closed position depending on which one of two switching devices on the system interface board 16 is actuated in response to control signals received by the switching devices from the processor board 17. The guide vane actuator 14 and control valve actuators 53 may be controlled to drive the guide vanes 14 and control valves 50 and 51 toward their fully open or fully closed position according to any one of a variety of control schemes designed to control the capacity of the refrigeration system 31 to match the load placed on the refrigeration system 31, and to match the flow angle with the vane angle at the vanes diffuser inlet. Preferably, valves 50 and 51 are operated in response to the position of guide vanes 12, sensed by sensing means 55. Sensing means 55 may be limit switcher or a control linkage actuated by the guide vane in response to the movement of the guide vane 12 to predetermined positions, indicating restricted flow through compressor 32. The compressor motor starter 22 is a device for supplying electrical power from the power supply 23 to the electric motor 25 of the compressor 2 to start up and run the motor 25. For example, the compressor motor starter 22 may be a conventional wyedelta (Y-) contactor type motor starter. Of course, as will be readily apparent to one of ordinary skill in the art to which the present invention pertains, the compressor motor starter 22 may be any one of a variety of systems for supplying electrical power from the power supply 23 to the electric motor 25 of the compressor 32 to start and run the motor 25.

The control valves 50 and 51, and actuators 53 may be any devices suitable for moving the movable rings 41 and 42 in an axially direction in the diffuser passage 46, which also houses fixed guide vanes 48.

According to the present invention, as shown in Figure 2, movable ring 41 is supported for movement within recess 28 and diffuser passage 16 between an open position and a full throttling position. In the full throttling position, movable sleeve ring 41 throttles vapor flow through diffuser passage 16, and, preferably, in the open position, the movable sleeve ring allows an unrestricted flow of vapor through the diffuser passage. Bias means 19 is provided between movable sleeve ring 41 and piston 63 for urging movable sleeve ring 41 toward the full open position. Preferably, the bias means 19 includes resilient means such as a spring positioned within recess 28. Control valve 51 generally mounted on casing 67 provides a pressure force on piston 63 in a direction opposite the force of bias means 19 to move movable ring 41 toward the full throttling position. More specifically, as movable sleeve ring 41 moves forward, from left to right as viewed in the drawings, it is controlled by fluid pressure in conduit 65 which is controlled by control valve 51, which in turn is opened or closed by valve actuator 53. The movable sleeve ring 41 is positioned in close proximity with the fixed guide vanes 48 to minimize flow losses and give higher compressor efficienty at full load.

While this invention has been described with reference to a particular embodiment disclosed herein, it is not confined to the details set forth herein and this application is intended to cover any modifications or changes as may come within the scope of the invention.

CLAIMS

1. In a centrifugal compressor having a casing with an impeller rotatably mounted therein to move a working fluid from an inlet through an annular diffuser passage to an outlet scroll, the improvement comprising:

a fixed wall defining a portion of the annular diffuser passage;

a plurality of fixed vanes located in the annular diffuser passage and secured to said fixed wall;

a movable ring means located upstream of said plurality of fixed vanes, mounted for movement with respect to said fixed wall wherein said movable ring means throttles vapor flow through the diffuser passage from a full flow to a full throttle flow.

2. The diffuser means of claim 1 wherein said movable ring means is positioned immediately downstream of the impeller.

3. A method of controlling flow of a fluid through an annular diffuser passage at the outlet of an impeller of a centrifugal compres-

sor comprising the steps of:

fixing a plurality of guide vanes in a fixed position in the annular diffuser passage; and

movably positioning a movable ring in the annular diffuser passage wherein the flow angle of the fluid flowing through the annular diffuser passage is matched with the flow angle at the fixed vanes.

Printed for Her Majesty's Stationery Office
by Burgess & Son (Abingdon) Ltd, Dd 8991685, 1988.
Published at The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.