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ZERO SUPERHEAT REFRIGERATION COMPRESSION SYSTEM
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- (56) Prior Art Documents
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- (57) Claim

1. A method of operating a refrigeration system, comprising the steps of:
 - (a) providing a refrigeration system comprising a condenser for cooling and liquefying refrigerant, an evaporator and a valve connected between the condenser and the evaporator for controlling the refrigerant flow from the condenser to the evaporator so as to maintain the operation of the evaporator at a nominal zero superheat level;
 - (b) providing a centrifugal compressor, said compressor comprising a gas tight casing having an inlet portion and a compression portion, said inlet portion having an inlet opening gaseously coupled to said evaporator so as to receive a gaseous refrigerant, said inlet and compression portions each having a plurality of gas passages therethrough, said gas passages in said inlet portion being substantially parallel to the axis of said casing, said compression portion having an outlet opening that is located at the end of said casing which is opposite the end of said casing having said inlet opening, an electric motor assembly positioned within said inlet portion of said casing, a shaft disposed within and coaxial with the axis of said casing, said shaft being rotatably engaged with said motor assembly, at least one (1) centrifugal compression stage gaseously coupled to said inlet portion and to

- said outlet opening, said compression stage being drivingly engaged with said shaft and intermediate said inlet portion and said outlet opening;
- (c) axially flowing the refrigerant gas into said inlet portion and around said motor assembly substantially parallel to the axis of said casing;
 - (d) convectively transferring the heat dissipated by said motor assembly to the gaseous refrigerant flowing in said inlet portion so as to cool the motor assembly, evaporate any liquid in the gaseous refrigerant thereby permitting the evaporator to operate at a zero superheat level, and prevent gaseous refrigerant containing liquid from entering said compression stage;
 - (e) suctionally inducing the gaseous refrigerant from said inlet portion into said centrifugal compressor stage;
 - (f) centrifugally compressing the gaseous refrigerant within said compression stage; and
 - (g) exducing the compressed gaseous refrigerant from said compression stage into said outlet passage.

12. A multistage centrifugal compressor for use in a refrigeration system comprising a condenser for cooling and liquefying refrigerant, an evaporator and a valve connected between the condenser and the evaporator for controlling the refrigerant flow from the condenser to the evaporator so as to maintain the operation of the evaporator at a nominal zero superheat level, comprising:

- a casing having an inlet portion and a compression portion, said inlet portion having an inlet opening gaseously coupled to the evaporator so as to receive a gaseous refrigerant, said inlet and compression portions each having a plurality of gas passages therethrough, said gas passages in said inlet portion being substantially parallel to the axis of said casing, said compression portion having an outlet opening that is located at the end of said casing which is opposite the end of said casing having said inlet opening;
- an electric motor assembly positioned within said inlet portion of said casing so as to provide a transfer of heat dissipated by the motor assembly to the

gaseous refrigerant entering through said inlet opening whereby the gaseous refrigerant flowing in said inlet opening passes through and about said motor assembly substantially parallel to the axis of said casing so as to cool said motor assembly, the gaseous refrigerant being convectively heated by the heat dissipated by said motor assembly so as to evaporate any liquid remaining within the gaseous refrigerant thereby permitting the evaporator to operate at a nominal zero superheat level;

a shaft disposed within and coaxial with the axis of said casing, said shaft being

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rotatably engaged with said motor assembly;
a first rotor disposed within said compression portion and attached to said shaft so as to provide a first centrifugal compression stage, said first compression stage being gaseously coupled to said gas passages of said inlet portion; and
a second rotor disposed within said compression portion and attached to said shaft so as to provide a second centrifugal compression stage, said second centrifugal compression stage being gaseously coupled to said first centrifugal compression stage, said second centrifugal stage being intermediate said first centrifugal compression stage and said outlet opening, said second centrifugal compression stage being gaseously coupled to said outlet opening.



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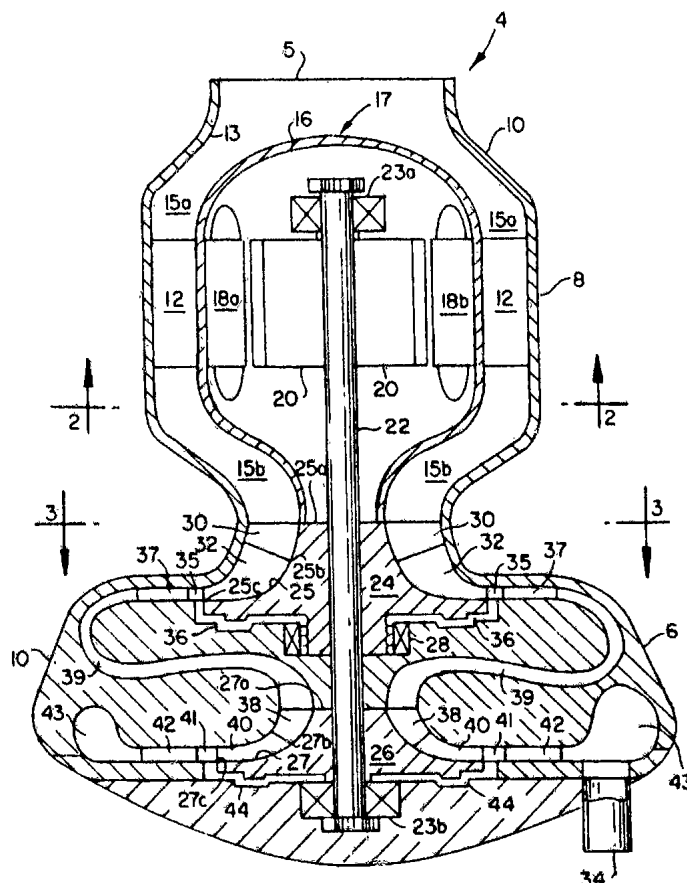
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(21) International Application Number: PCT/US94/04801 (22) International Filing Date: 28 April 1994 (28.04.94) (30) Priority Data: 08/058,392 4 May 1993 (04.05.93) US (71) Applicant: ECOAIR CORPORATION [US/US]; Suite 2023, Five Science Park Drive, New Haven, CT 06511 (US). (72) Inventor: POWELL, James, W.; 1805 Little Meadow Road, Guilford, CT 06437 (US). (74) Agents: DeLIO, Anthony, P. et al.; DeLio & Peterson, 121 Whitney Avenue, New Haven, CT 06511 (US).		(81) Designated States: AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, ES, FI, GB, HU, JP, KP, KR, KZ, LK, LU, LV, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SK, UA, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>

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(54) Title: ZERO SUPERHEAT REFRIGERATION COMPRESSION SYSTEM

(57) Abstract

A zero superheat refrigeration apparatus and method uses a multistage centrifugal compressor (4) which has a casing (10) with an axial inlet portion (8) at one end gaseously coupled to receive refrigerant from an evaporator (58), at two-stage motor driven compression portion (6), and an outlet opening (34) gaseously coupled to deliver compressed refrigerant to a condenser (52). An electric motor assembly (17) is positioned within the inlet portion (8) of the casing (10) and includes vanes (12) to transfer heat dissipated by the motor assembly (17) to the refrigerant. The refrigerant cools the motor assembly (17) and the heat from the motor assembly (17) evaporates any liquid refrigerant droplets, allowing the evaporator (58) to operate at a zero superheat condition. A shaft (22), which is coaxially arranged in the casing (10), couples the motor assembly (17) to a first rotor (24) providing a first compression stage and to a second rotor (26) providing a second compression stage. The geometric shape of the casing (10) allows vehicle center line mounting.



Description

ZERO SUPERHEAT REFRIGERATION COMPRESSION SYSTEM

5 Technical Field

This invention relates generally to air conditioning compressor systems and more particularly, to multistage centrifugal compressors designed to operate with a gaseous refrigerant entering at a nominal zero superheat level.

10 Background Art

Presently, there is a need for small sized centrifugal compressors which are efficient and capable of being integrated in all types of systems, most typically, automotive systems. To make such small centrifugal compressors practical, it is necessary to use refrigerants which have lower vapor pressures and higher specific
15 volumes than are encountered in conventional refrigerant systems, which typically employ piston, vane or scroll compressors. Furthermore, recent international legislation engendered by environmental concerns over the issues of global warming and ozone depletion have mandated the elimination of freons including those used in the multi-billion dollar air conditioning/refrigeration industry.
20 Substitute refrigerants that have more beneficial environmental indices, such as R134 (a replacement for R12 which is widely used in the automotive industry) have been proposed for use in conventional air conditioning /refrigeration systems. Recently developed refrigerants, such as R134, have much higher specific volumes than conventional R12 and R22 fluids. Use of such recently developed refrigerants,
25 however, requires a higher operating pressure ratio across the compressor which cannot be readily achieved with a single centrifugal compressor stage. Typically, conventional compressor systems utilize two (2) centrifugal stages and an electric motor intermediate the two (2) stages. Such systems are disclosed in U.S. Patents Nos.: 2,793,506, 3,859,815 and 4,105,372. The refrigerant enters the first, or low
30 pressure, compression stage where it is partially compressed. The partially compressed gaseous refrigerant then passes through a diffuser and is collected in a scroll. The gaseous refrigerant then is transferred via an external tube to the inlet of the second, or high pressure, compression stage, where the compression is completed. There are significant deficiencies in these systems. It has been found
35 that significant aerodynamic losses are incurred in the collection of the gaseous refrigerant in the scroll and the transfer of the gaseous refrigerant through the outlet

of the low compression stage and into the inlet of the high compression stage. These aerodynamic losses are manifested through degradation of the coefficient of performance (COP) of the refrigerant cycle.

Additionally, in conventional systems, the motor assembly is typically cooled by extracting a small amount of liquid refrigerant from the condenser and flashing it in passages in the motor assembly. The vaporization heat of the motor assembly supplies the requisite cooling. However, it has been found that degradation of the COP of the refrigerant cycle occurs when the gaseous refrigerant is returned to the main flow of the gaseous refrigerant at an intermediate station in the compressor, or at a point downstream of the compressor. Alternatively, the gaseous refrigerant can be injected back into the suction line which couples the evaporator outlet and the compressor input. Superficially, this would appear to augment necessary superheat in the cycle and thus, not cause degradation in the refrigerant cycle. However, it has been found that since the compressor inlet in this type of cycle is sub-atmospheric, the suction line between the evaporator and the compression inlet must be very short to avoid excessive inlet pressure losses. Consequently, the evaporator and the compressor must be closely coupled, thereby making it very difficult to inject this waste refrigerant into the system at this point without incurring additional losses due to the compressor inlet distortion.

Conventional centrifugal compressors typically utilize D.C. (direct current) or low frequency A.C. (alternating current) electric motors. However, it has been found that vehicle performance is adversely affected by the heavy weight and voluminous size of these motors.

It has also been found that the utilization of transfer tubes to execute the transition of the refrigerant from the low pressure compression stage to the high pressure compressor stage imposes significant restrictions with respect to the design geometry of the compressor system and its integration into other systems, such as automobile engines. Such restrictions are contrary to automobile industry design criteria which specifies that primary air conditioning components be on or substantially adjacent the vehicle center line. Hence, compressor systems having a left side/right side drive capability would be preferred over systems having design geometry of the conventional systems. It is possible to design a substantially cylindrical configuration for the systems disclosed in the above mentioned U.S. Patents, however, the diameter of the compressor would significantly increase. Additionally, it has been found that the relatively large wetted surface area in such a

configuration would contribute to unacceptable high pressure losses and thus, cause a deleterious impact on the refrigerant cycle.

Finally, it has been found that conventional compressors may allow gaseous refrigerant containing liquid to enter the compression stages. In conventional systems, the only remedy for this is to operate the evaporator at a level significantly above zero superheat level. However, this degrades the overall system performance because it is an energy-inefficient remedy.

Bearing in mind the problems of the prior art, it is therefore an object of the present invention to provide a new and improved centrifugal compressor having two (2) sequentially arranged centrifugal compression stages.

It is another object of the present invention to provide a new and improved centrifugal compressor that is smaller in size than conventional compressors.

It is a further object of the present invention to provide a new and improved centrifugal compressor wherein the electrical motor assembly is cooled by gaseous refrigerant directly emitted by an evaporator.

It is another object of the present invention to provide a new and improved centrifugal compressor wherein the processes of convection and conduction are utilized to heat the incoming gaseous refrigerant so as to remove any liquid therefrom, thereby permitting the evaporator to operate at a zero superheat level.

It is another object of the present invention to provide a new and improved centrifugal compressor wherein the geometric shape of the compressor allows it to be integrated into an automobile engine system at a point on or substantially adjacent the vehicle center line.

Disclosure of Invention

The above and other objects, which will be apparent to those skilled in the art, are achieved in the present invention which is directed to a method of operating a refrigeration system, comprising the steps of:

- (a) providing an evaporator from which a refrigerant flows at a nominal zero superheat level;
- (b) providing a centrifugal compressor, the compressor comprising a gas tight casing having an inlet portion and a compression portion, the inlet portion having an inlet opening gaseously coupled to the evaporator so as to receive a gaseous refrigerant, the inlet and compression portions each having a plurality of gas passages therethrough, the compression portion having an

- outlet opening that is located at the end of the casing which is opposite the end of the casing having the inlet opening, an electric motor assembly positioned within the inlet portion of the casing, a shaft disposed within and coaxial with the axis of the casing, the shaft being rotatably engaged with the motor assembly, at least one (1) centrifugal compression stage gaseously coupled to the inlet portion and to the outlet opening, the compression stage being drivingly engaged with the shaft and intermediate the inlet portion and the outlet opening;
- 5
- (c) flowing the refrigerant gas into the inlet portion and around the motor assembly;
- 10
- (d) transferring the heat dissipated by the motor assembly to the gaseous refrigerant flowing in the inlet portion so as to cool the motor assembly, evaporate any liquid in the gaseous refrigerant thereby permitting the evaporator to operate at a zero superheat level, and prevent gaseous refrigerant containing any liquid from entering the compression stage;
- 15
- (e) suctionally inducing the gaseous refrigerant from the inlet portion into the centrifugal compressor stage;
- (f) centrifugally compressing the gaseous refrigerant within the compression stage; and
- 20
- (g) exducing the compressed gaseous refrigerant from the compression stage into the outlet passage.

In a related aspect, the present invention is direct to a method of operating a refrigeration system, comprising the steps of:

- (a) providing an evaporator from which a refrigerant flows at a nominal zero superheat level;
- 25
- (b) providing a centrifugal compressor, the compressor comprising a gas tight casing having an inlet portion and a compression portion, the inlet portion having an inlet opening gaseously coupled to an evaporator so as to receive a gaseous refrigerant, the inlet and compression portions each having a plurality of gas passages therethrough, the compression portion having an outlet opening that is located at the end of the casing which is opposite the end of the casing having the inlet opening, an electric motor assembly positioned within the inlet portion of the casing, a plurality of vanes disposed within the inlet portion intermediate the casing and the motor assembly, the vanes contacting the motor assembly so as to provide a heat conduction
- 30
- 35

- relationship with the motor assembly and to define a plurality of gas passages intermediate the vanes, a shaft disposed within and coaxial with the axis of the casing, the shaft being rotatably engaged with the motor assembly, a first rotor disposed within the compression portion and attached to the shaft so as to provide a first centrifugal compression stage, the first compression stage being gaseously coupled to the gas passages of the inlet portion, and a second rotor disposed within the compression portion and attached to the shaft so as to provide a second centrifugal compression stage, the second compression stage being gaseously coupled to the first centrifugal compression stage, the second compression stage being intermediate the first centrifugal compression stage and the outlet opening, the second compression stage being gaseously coupled to the outlet opening;
- 5
- 10
- (c) flowing the refrigerant into the inlet portion and around the motor assembly;
- 15
- (d) conductively transferring the heat dissipated by the motor assembly to the vanes;
- (e) convectionally transferring the heat of the vanes to the gaseous refrigerant flowing between the vanes so as to cool the motor assembly, evaporate any liquid in the gaseous refrigerant thereby permitting the evaporator to operate at a zero superheat level, and prevent gaseous refrigerant containing any liquid from entering the first and second compression stages;
- 20
- (f) suctionally inducing the gaseous refrigerant from the inlet portion into the first centrifugal compressor stage;
- (g) centrifugally compressing the gaseous refrigerant within the first compression stage;
- 25
- (h) exducing the compressed gaseous refrigerant from the first compression stage;
- (i) suctionally inducing the compressed gaseous refrigerant exduced from the first compression stage into the second compression stage;
- 30
- (j) centrifugally compressing the compressed gaseous refrigerant within the second compressor stage; and
- (k) exducing the doubly centrifugally compressed gaseous refrigerant into the outlet passage of the compression portion.

In a another aspect, the present invention is directed to a multistage centrifugal compressor, comprising a casing having an inlet portion and a

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compression portion. The inlet portion has an inlet opening gaseously coupled to an evaporator so as to receive a gaseous refrigerant. The inlet and compression portions each have a plurality of gas passages therethrough. The compression portion has an outlet opening that is located at the end of the casing which is

5 opposite the end of the casing having the inlet opening. An electric motor assembly is positioned within the inlet portion of the casing so as to provide a transfer of heat dissipated by the motor assembly to the gaseous refrigerant entering through the inlet opening. The gaseous refrigerant flowing in the inlet opening passes through and about the motor assembly so as to cool the motor assembly. The gaseous

10 refrigerant is heated by the heat dissipated by the motor assembly so as to evaporate any liquid within the gaseous refrigerant thereby permitting the evaporator to operate at a zero superheat level. A shaft is disposed within and is coaxial with the axis of the casing. The shaft is rotatably engaged with the motor assembly. A first rotor is disposed within the compression portion and is attached

15 to the shaft so as to provide a first centrifugal compression stage. The first compression stage is gaseously coupled to the gas passages of the inlet portion. A second rotor is disposed within the compression portion and attached to the shaft so as to provide a second centrifugal compression stage. The second centrifugal compression stage is gaseously coupled to first centrifugal compression stage. The

20 second centrifugal stage is intermediate the first compression stage and the outlet opening, and is gaseously coupled to the outlet opening.

In a further aspect, the present invention is directed to a multistage centrifugal compressor, comprising a casing having an inlet portion and a compression portion. The inlet portion has an inlet opening gaseously coupled to

25 an evaporator so as to receive a gaseous refrigerant. The inlet and compression portions each have a plurality of gas passages therethrough. The compression portion has an outlet opening that is located at the end of the casing which is opposite the end of the casing having the inlet opening. An electrical motor assembly is positioned within the inlet portion of the casing so as to provide a

30 transfer of heat dissipated by the motor assembly to the gaseous refrigerant entering the inlet opening. A plurality of vanes are disposed within the inlet portion intermediate the casing and the motor assembly. The vanes are attached to and radially extend from the inner wall of the casing. The vanes contact the motor assembly so as to provide a heat conduction relationship with the motor assembly

35 and to define a plurality of gas passages intermediate the vanes. A shaft is disposed

within and is coaxial with the axis of the casing. The shaft is being rotatably engaged with the motor assembly. A first rotor is disposed within the compression portion and is attached to the shaft so as to provide a first centrifugal compression stage. The first compression stage is gaseously coupled to the gas passages of the inlet portion. A second rotor is disposed within the compression portion and is attached to the shaft so as to provide a second centrifugal compression stage. The second centrifugal compression stage is gaseously coupled to the first centrifugal compression stage. The second centrifugal compression stage is intermediate the first centrifugal compression stage and the outlet opening. The second centrifugal compression stage is gaseously coupled to the outlet opening. The motor assembly and the plurality of vanes cooperate in effecting a transfer of the heat dissipated by the motor assembly to the gaseous refrigerant entering the inlet passage whereby the heat dissipated by the motor assembly is conductively transferred to the vanes and the heat of the vanes is convectionally transferred to the gaseous refrigerant flowing between the vanes so as to cool the motor assembly, evaporate any liquid in the gaseous refrigerant thereby permitting the evaporator to operate at a zero superheat level, and prevent gaseous refrigerant containing liquid from entering the first and second compression stages

20 **Brief Description of the Drawings**

For a fuller understanding of the invention, reference is made to the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a top plan view of the multistage centrifugal compressor of the present invention.

25 Fig. 2 is a front elevational cross-sectional view taken along line 2-2 of Fig. 1.

Fig. 3 is a front elevational view taken along line 3-3 of Fig. 1.

Fig. 4 is a block diagram of a refrigerant system utilizing the compression system of the present invention.

30 **Modes for Carrying Out the Invention**

The compressor system of the present invention may be utilized in the air conditioning/refrigeration control system disclosed in commonly assigned U.S. Patent No. 5,203,179, the disclosure of which is herein incorporated by reference. Referring to Fig. 1, the two-stage centrifugal refrigeration compressor 4 of the present invention is enclosed in casing 10. In a preferred embodiment, casing 10 is

made of aluminum. However, other non-corrosive metals could also be utilized, such as stainless steel. The overall geometric shape of casing 10 is substantially cylindrical. Compressor 4 is comprised of inlet portion 8 and compression portion 6. Inlet passage 5 is gaseously coupled to an evaporator (not shown) and receives a gaseous refrigerant. Electric motor assembly 17 is positioned within inlet portion 8 of compressor 4. Motor assembly 17 is a high frequency, high speed motor. To obtain the necessary high speeds, such as 75,000 RPM (revolutions per minute), without brushes, high frequency power at 3750 Hz is supplied to the motor. The high frequency power can be obtained from either a high frequency mechanically driven generator or from a suitable inverter. Since the motor operates in the refrigerant atmosphere, rotating shaft seals are not required. Motor assembly 17 is comprised of housing 16, stator sections 18a, 18b and rotor 20. Rotor 20 rotates about elongated shaft 22. Shaft 22 is couplingly engaged to bearings 21a and 21b and extends for substantially the entire length of casing 10. Bearing 21a is positioned within motor assembly 17.

Referring to Fig 2, stationary vanes 12 are interposed between motor assembly housing 16 and inner wall 13 of casing 10. Vanes 12 are attached to and radially extend from inner wall 13. Vanes 12 contact motor assembly housing 16 so as to provide a heat conduction relationship with motor assembly housing 16. In a preferred embodiment, the longitudinal axes of vanes 12 are substantially parallel to the axis of casing 10. Gas passages 14 are formed between vanes 12. Vanes 12 are preferably fabricated from Lamilloy™ which is a multi-layered light-weight porous material specifically designed for cooled airframe and propulsion systems that are exposed to high gas temperature and/or high heat-flux environments. Lamilloy™ has been designed and fabricated from many different materials such as iron, cobalt and nickel base alloys as well as intermetallics and single crystal alloys.

One object of the present invention is to provide for simultaneous motor cooling and liquid removal from the gaseous refrigerant which flows into inlet passage 5 from the evaporator. Such liquid removal from the gaseous refrigerant permits the evaporator to operate at zero superheat level. This is accomplished by the transfer of heat from the motor assembly to the incoming gaseous refrigerant flowing into gas passages 14 from gas passages 15a. The heat dissipated by motor assembly 17 is transferred to the gaseous refrigerant via a two-step process which comprises the steps of: (1) conduction and (2) convection. Conduction is defined as the transfer of heat between two bodies in direct contact. Referring to Fig. 2,

during operation of compressor 4, rotor 20 and stators 18a, 18b dissipate heat. The heat dissipated by rotor 20 radiates and hence, heats housing 16 and stator section 18a, 18b. Stator sections 18a and 18b contact housing 16 so as to provide a heat conduction relationship. The heat dissipated by stators sections 18a, 18b, and the heat transferred to stators 18a, 18b from rotor 20, is conductively transferred to housing 16. The heat of housing 16 is conductively transferred to vanes 12 thereby heating vanes 12. The heat of vanes 12 is convectionally transferred to the gaseous refrigerant flowing in passages 14 which are formed by vanes 12. The transfer of the heat of vanes 12 to the gaseous refrigerant achieves three goals:

- (1) cooling motor assembly 17,
- (2) evaporating any liquid in the gaseous refrigerant thereby permitting the evaporator to operate at a zero super heat level, and
- (3) preventing gaseous refrigerant containing liquid from entering compression portion 6 of compressor 4.

The heat transfer process described above acts as secondary evaporation process which evaporates any residue liquid contained in the gaseous refrigerant that was not completely evaporated within the evaporator. Thus, no liquid-containing gas enters compressor portion 6, and the evaporator need not operate above a zero superheat level.

Once the gaseous refrigerant passes through gas passages 14, the gas travels through gas passages 15b, which are downstream of vanes 12. Referring to Fig. 1, rotor 24 is disposed within compression portion 6 and attached to shaft 22 so as to provide a first centrifugal compression stage. Air gap 36 facilitates rotation of rotor 24 about shaft 22. Rotor 24 is couplingly engaged to bearings 28. Rotor 24 has gas-facing surface 25 thereon which defines a volute inducer airfoil 30 extending over the entire gas-facing surface 25, and exducer airfoil 32, which is partially coextensive with inducer airfoil 30. Referring to Fig. 3, inducer airfoil 30 comprises main blades 46, which extend over the entire gas-facing surface 25 (from edge 25a to edge 25c). Exducer airfoil 32 comprises splitter blades 48 which extend from midpoint 25b of gas facing surface 25 to edge 25c and thus, is only partially coextensive with airfoil 30. In a preferred embodiment, the ratio of the number of inducer blades to the number of exducer blades is 2 to 1 (2/1). Inducer airfoil 30 suctionally induces gaseous refrigerant from passage 15b into the first compression stage. Exducer airfoil 32 outputs the centrifugally compressed gaseous refrigerant through airgap 35 and over guide vanes 37. Vanes 37 remove turbulence in the

flow of gaseous refrigerant leaving the first compression stage and entering gas passage 39.

Rotor 26 is disposed within compression portion 6 and attached to shaft 22 so as to provide a second centrifugal compression stage. Air gap 44 facilitates rotation of rotor 26 about shaft 22. Rotor 26 has gas-facing surface 27 thereon which defines a volute inducer airfoil 38 extending over the entire gas-facing surface 27 (from edge 27a to edge 27c), and a volute exducer airfoil 40 which extends from gas-facing surface midpoint 27b to edge 27c. Thus, airfoil 40 is only partially coextensive with inducer airfoil 38. Although Fig. 3 is a front elevation view of rotor 24, Fig. 3 also represents a front elevational view of rotor 26. However, the diameter of rotor 26 is less than that of rotor 24. Similar to rotor 24, inducer airfoil 38 comprises a set of main blades and exducer airfoil 40 comprises a set of splitter blades. The ratio of the number of main blades to splitter blades is 2 to 2 (2/1). Inducer airfoil 38 suctionally induces gaseous refrigerant from passage 39 into the second compression stage. Exducer airfoil 40 outputs the doubly centrifugally compressed gaseous refrigerant through airgap 41 and guide vanes 42. Vanes 42 remove turbulence in the flow of gaseous refrigerant leaving the second compression stage and entering gas passage 43. The doubly compressed gaseous refrigerant exits gas passage 43 via exit nozzle 34.

Fig. 4 is a general block diagram of an air conditioning/refrigeration system that utilizes the compressor of the present invention. Refrigerant passes through line 50 to condenser 52 where it is cooled and liquefied. The now cooled and liquefied refrigerant passes through line 54 to variable expansion valve 56. Valve 56 controls the refrigerant flow rate to maintain a desired superheat in the refrigerant when it exits evaporator 58 in a gaseous state. The now gaseous refrigerant exits evaporator 58 through line 60 and passes into compressor 4 where it first enters inlet portion 8. Through the aforementioned processes of conduction and convection, any liquid contained in the gaseous refrigerant is removed before the gaseous refrigerant enters the compression portion 6 of compressor 4. This removal of any liquid from the gaseous refrigerant acts as a secondary evaporation process. Hence, valve 56 may be set so as to allow evaporator 58 to operate at a zero superheat level. The now liquid-free gaseous refrigerant then passes into compression portion 6, which is comprised of sequential centrifugal compression stages 62 and 64.

Thus, the objects set forth above are achieved by compressor 4 which:

(a) utilizes two (2) sequentially arranged centrifugal compression stages positioned within casing 10 thereby eliminating the need for external transfer and bypass tubes or piping;

5 (b) is light in weight and small in size due to the utilization of a lightweight, high frequency and high speed motor assembly 17;

(c) provides for motor cooling without extracting liquid refrigerant from the condenser;

10 (d) removes any liquid from the gaseous refrigerant flowing in inlet portion 8 thereby preventing any liquid from entering compression portion 6 and permitting evaporator 58 to operate at a zero superheat level; and

(e) has a geometric design and a left side/right side drive capability which facilitates integration of compressor 4 into automobile systems, and which allows it to be located on or substantially adjacent the vehicle centerline.

15 It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above constructions without departing from the spirit and scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

20 While the invention has been illustrated and described in what are considered to be the most practical and preferred embodiments, it will be recognized that many variations are possible and come within the scope thereof, the appended claims therefore being entitled to a full range of equivalents.

25 Thus, having described the invention, what is claimed is:

Claims

- 1 1. A method of operating a refrigeration system, comprising the steps of:
- 2 (a) providing a refrigeration system comprising a condenser for cooling and
- 3 liquefying refrigerant, an evaporator and a valve connected between the
- 4 condenser and the evaporator for controlling the refrigerant flow from the
- 5 condenser to the evaporator so as to maintain the operation of the
- 6 evaporator at a nominal zero superheat level;
- 7 (b) providing a centrifugal compressor, said compressor comprising a gas tight
- 8 casing having an inlet portion and a compression portion, said inlet portion
- 9 having an inlet opening gaseously coupled to said evaporator so as to
- 10 receive a gaseous refrigerant, said inlet and compression portions each
- 11 having a plurality of gas passages therethrough, said gas passages in said
- 12 inlet portion being substantially parallel to the axis of said casing, said
- 13 compression portion having an outlet opening that is located at the end of
- 14 said casing which is opposite the end of said casing having said inlet
- 15 opening, an electric motor assembly positioned within said inlet portion of
- 16 said casing, a shaft disposed within and coaxial with the axis of said casing,
- 17 said shaft being rotatably engaged with said motor assembly, at least one (1)
- 18 centrifugal compression stage gaseously coupled to said inlet portion and to
- 19 said outlet opening, said compression stage being drivingly engaged with
- 20 said shaft and intermediate said inlet portion and said outlet opening;
- 21 (c) axially flowing the refrigerant gas into said inlet portion and around said
- 22 motor assembly substantially parallel to the axis of said casing;
- 23 (d) convectively transferring the heat dissipated by said motor assembly to the
- 24 gaseous refrigerant flowing in said inlet portion so as to cool the motor
- 25 assembly, evaporate any liquid in the gaseous refrigerant thereby permitting
- 26 the evaporator to operate at a zero superheat level, and prevent gaseous
- 27 refrigerant containing liquid from entering said compression stage;
- 28 (e) suctionally inducing the gaseous refrigerant from said inlet portion into said
- 29 centrifugal compressor stage;
- 30 (f) ~~centrifugally compressing the gaseous refrigerant within said compression~~
- 31 ~~stage; and~~
- 32 (g) ~~exducing the compressed gaseous refrigerant from said compression stage~~
- 33 ~~into said outlet passage.~~

AMENDED SHEET

1 2. The method of claim 1 further comprising a plurality of vanes disposed within
2 said inlet portion intermediate said casing and said motor assembly, said vanes
3 contacting said motor assembly so as to provide a heat conduction relationship with said
4 motor assembly and to define a plurality of gas passages intermediate said vanes.

1 3. The method of claim 2 wherein step (d) further comprises the steps of:
2 (a) conductively transferring the heat dissipated by said motor assembly to
3 said vanes; and
4 (b) convectionally transferring the heat of said vanes to the gaseous
5 refrigerant flowing between said vanes.

1 4. The method of claim 1 wherein said gas passages of said inlet portion and
2 said compression stage are gaseously coupled directly to one another at a point
3 within said casing without the utilization of transfer tubes external to said casing.

1 5. The method of claim 1 wherein said casing has a substantially cylindrical
2 shape.

1 6. The method of claim 1 further including a pair of bearings, each of which
2 being couplingly engaged with a corresponding end of said shaft, said bearings
3 being arranged in said casing in a manner such that said compression stage and said
4 motor assembly are intermediate said bearings.

1 7. The method claim 1 wherein the direction of the flow of gaseous refrigerant
2 entering said inlet opening and exiting said outlet opening is substantially parallel to
3 the axis of said casing.

1 8. The method of claim 7 wherein said vapor passages are axisymmetrically
2 formed within said casing.

1 9. The method of claim 8 wherein the longitudinal axes of said vanes are
2 substantially parallel to the axis of said casing.

1 10. The method of claim 1 wherein said compression stage is comprised of a
2 rotor disposed within said compression portion and attached to said shaft so as to
3 provide a centrifugal compression stage.

1 11. A method of operating a refrigeration system, comprising the steps of:

2 (a) providing a refrigeration system comprising a condenser for cooling and
3 liquefying refrigerant, an evaporator and a valve connected between the
4 condenser and the evaporator for controlling the refrigerant flow from the
5 condenser to the evaporator so as to maintain the operation of the
6 evaporator at a nominal zero superheat level;

7 (b) providing a centrifugal compressor, said compressor comprising a gas tight
8 casing having an inlet portion and a compression portion, said inlet portion
9 having an inlet opening gaseously coupled to the evaporator so as to receive
10 a gaseous refrigerant, said inlet and compression portions each having a
11 plurality of gas passages therethrough, said compression portion having an
12 outlet opening that is located at the end of said casing which is opposite the
13 end of said casing having said inlet opening, the direction of flow of gaseous
14 refrigerant entering said inlet opening and exiting said outlet opening being
15 substantially parallel to the axis of said casing, an electric motor assembly
16 positioned within said inlet portion of said casing, a plurality of vanes
17 disposed within said inlet portion intermediate said casing and said motor
18 assembly, said vanes contacting said motor assembly so as to provide a heat
19 conduction relationship with said motor assembly and to define a plurality
20 of gas passages intermediate said vanes, the longitudinal axes of said vanes
21 being substantially parallel to the axis of said casing, a shaft disposed within
22 and coaxial with the axis of said casing, said shaft being rotatably engaged
23 with said motor assembly, a first rotor disposed within said compression
24 portion and attached to said shaft so as to provide a first centrifugal
25 compression stage, said first compression stage being gaseously coupled to
26 said gas passages of said inlet portion, and a second rotor disposed within
27 said compression portion and attached to said shaft so as to provide a
28 second centrifugal compression stage, said second compression stage being
29 gaseously coupled to said first centrifugal compression stage, said second
30 compression stage being intermediate said first centrifugal stage and said
31 outlet opening, said second compression stage being gaseously coupled to
32 said outlet opening.

- 33 (c) flowing the refrigerant into said inlet portion and around said motor
34 assembly;
- 35 (d) conductively transferring the heat dissipated by said motor assembly to said
36 vanes;
- 37 (e) convectionally transferring the heat of said vanes to the gaseous refrigerant
38 flowing between said vanes so as to cool the motor assembly, evaporate any
39 liquid in the gaseous refrigerant thereby permitting the evaporator to operate
40 at a zero superheat level, and prevent gaseous refrigerant containing liquid
41 from entering said first and second compression stages;
- 42 (f) suctionally inducing the gaseous refrigerant from said inlet portion into said
43 first centrifugal compressor stage;
- 44 (g) centrifugally compressing the gaseous refrigerant within said first
45 compression stage;
- 46 (h) exducing the compressed gaseous refrigerant from said first compression
47 stage;
- 48 (i) suctionally inducing the compressed gaseous refrigerant exduced from said
49 first compression stage into said second compression stage;
- 50 (j) centrifugally compressing the compressed gaseous refrigerant within said
51 second compressor stage; and
- 52 (k) exducing the doubly centrifugally compressed gaseous refrigerant into said
53 outlet passage of said compression portion.

- 1 12. A multistage centrifugal compressor for use in a refrigeration system
2 comprising a condenser for cooling and liquefying refrigerant, an evaporator and a
3 valve connected between the condenser and the evaporator for controlling the
4 refrigerant flow from the condenser to the evaporator so as to maintain the operation
5 of the evaporator at a nominal zero superheat level, comprising:
- 6 a casing having an inlet portion and a compression portion, said inlet portion
7 having an inlet opening gaseously coupled to the evaporator so as to receive
8 a gaseous refrigerant, said inlet and compression portions each having a
9 plurality of gas passages therethrough, said gas passages in said inlet portion
10 being substantially parallel to the axis of said casing, said compression
11 portion having an outlet opening that is located at the end of said casing,
12 which is opposite the end of said casing having said inlet opening;
- 13 an electric motor assembly positioned within said inlet portion of said casing so
14 as to provide a transfer of heat dissipated by the motor assembly to the

15 gaseous refrigerant entering through said inlet opening whereby the gaseous
16 refrigerant flowing in said inlet opening passes through and about said
17 motor assembly substantially parallel to the axis of said casing so as to cool
18 said motor assembly, the gaseous refrigerant being convectively heated by
19 the heat dissipated by said motor assembly so as to evaporate any liquid
20 remaining within the gaseous refrigerant thereby permitting the evaporator
21 to operate at a nominal zero superheat level;
22 a shaft disposed within and coaxial with the axis of said casing, said shaft being
23 rotatably engaged with said motor assembly;
24 a first rotor disposed within said compression portion and attached to said shaft
25 so as to provide a first centrifugal compression stage, said first compression
26 stage being gaseously coupled to said gas passages of said inlet portion; and
27 a second rotor disposed within said compression portion and attached to said
28 shaft so as to provide a second centrifugal compression stage, said second
29 centrifugal compression stage being gaseously coupled to said first
30 centrifugal compression stage, said second centrifugal stage being
31 intermediate said first centrifugal compression stage and said outlet opening,
32 said second centrifugal compression stage being gaseously coupled to said
33 outlet opening.

1 13. The multistage centrifugal compressor of claim ¹²_λ wherein said gas passages of
2 said inlet portion and said first compression stage are gaseously coupled directly to
3 one another at a point within said casing without the utilization of transfer tubes
4 external to said casing, and said first compression stage and said second
5 compression stage are gaseously coupled directly to one another at a point within
6 said casing without the utilization of transfer tubes external to said casing.

1 14. The multistage compressor of claim 12 wherein said casing has a
2 substantially cylindrical shape.

1 15. The multistage compressor of claim 12 further including a pair of bearings,
2 each of which being couplingly engaged with a corresponding end of said shaft, said
3 bearings being arranged in said casing in a manner such that said rotors and said
4 motor assembly are intermediate said bearings.

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1 16. The multistage compressor of claim 12 wherein the direction of the flow of
2 gaseous refrigerant entering said inlet opening and exiting said outlet opening is
3 substantially parallel to the axis of said casing.

1 17. The multistage centrifugal compressor of claim 16 wherein said gas passages
2 are axisymmetrically formed within said casing.

1 18. The multistage compressor of claim 12 further including a plurality of vanes
2 disposed within said inlet portion intermediate said casing and said motor assembly,
3 said vanes being attached to and radially extending from the inner wall of said
4 casing, said vanes contacting said motor assembly so as to provide a heat
5 conduction relationship with said motor assembly and to define a plurality of gas
6 passages intermediate said vanes, said gaseous refrigerant circulating within said gas
7 passages intermediate said vanes being heated by the heat transfer processes of
8 conduction and convection whereby the heat dissipated from said motor assembly is
9 conductively transferred to said vanes and the heat of said vanes is convectionally
10 transferred to the gaseous refrigerant circulating between said vanes so as to
11 evaporate any liquid in the gaseous refrigerant thereby permitting the evaporator to
12 operate at a zero superheat level.

1 19. The multistage centrifugal compressor of claim 18 wherein the longitudinal
2 axes of said vanes are substantially parallel to the axis of said casing.

1 20. The multistage centrifugal compressor of claim 12 wherein said first and
2 second rotors each have a gas-facing surface.

1 21. The multistage centrifugal compressor of claim 20 wherein said gas facing
2 surface of said first and second rotors define a volute inducer airfoil extending over
3 said gas-facing surface and an exducer airfoil partially coextensive with said inducer
4 foil, whereby said inducer airfoil of said first rotor suctionally induces the gaseous
5 refrigerant into said first compression stage and said exducer airfoil of said first rotor
6 outputs the centrifugally compressed gaseous refrigerant into said second
7 compression stage, and said inducer airfoil of said second rotor suctionally induces
8 the centrifugally compressed gaseous refrigerant outputted from said first
9 compression stage into said second compression stage, and said exducer airfoil of

10 said second compression stage outputs the doubly centrifugally compressed gaseous
 11 refrigerant into said outlet passage of said compression portion.

1 22. The multistage centrifugal compressor of claim 21 further including a first
 2 plurality of guide vanes intermediate said exducer airfoil of said first rotor and said
 3 second centrifugal compression stage for removing turbulence in the flow of gaseous
 4 refrigerant leaving said first compression stage and entering the said second
 5 compression stage.

1 23. The multistage centrifugal compressor of claim 22 further including a second
 2 plurality of guide vanes intermediate said exducer of said second compression stage
 3 and said outlet passage of said compression portion for removing turbulence in the
 4 flow of gaseous refrigerant leaving said second compression stage and entering said
 5 outlet passage.

1 24. A multistage centrifugal compressor for use in a refrigeration system
 2 comprising a condenser for cooling and liquefying refrigerant, an evaporator and a
 3 valve connected between the condenser and the evaporator for controlling the
 4 refrigerant flow from the condenser to the evaporator so as to maintain the operation
 5 of the evaporator at a nominal zero superheat level, comprising:
 6 a casing having an inlet portion and a compression portion, said inlet portion
 7 having an inlet opening gaseously coupled to an evaporator so as to receive
 8 a gaseous refrigerant, said inlet and compression portions each having a
 9 plurality of gas passages therethrough, said compression portion having an
 10 outlet opening that is located at the end of said casing which is opposite the
 11 end of said casing having said inlet opening, the direction of the flow of
 12 gaseous refrigerant entering said inlet opening and exiting said outlet
 13 opening being substantially parallel to the axis of said casing;
 14 an electrical motor assembly positioned within said inlet portion of said casing
 15 so as to provide a transfer of heat dissipated by said motor assembly to the
 16 gaseous refrigerant entering said inlet opening;
 17 a plurality of vanes disposed within said inlet portion intermediate said casing
 18 and said motor assembly, said vanes being attached to and radially
 19 extending from the inner wall of said casing, said vanes contacting said
 20 motor assembly so as to provide a heat conduction relationship with said
 21 motor assembly and to define a plurality of gas passages intermediate said

22 vanes, the longitudinal axes of said vanes being substantially parallel to the
 23 axis of said casing;
 24 a shaft disposed within and coaxial with the axis of said casing, said shaft being
 25 rotatably engaged with said motor assembly;
 26 a first rotor disposed within said compression portion and attached to said shaft
 27 so as to provide a first centrifugal compression stage, said first compression
 28 stage being gaseously coupled to said gas passages of said inlet portion; and
 29 a second rotor disposed within said compression portion and attached to said
 30 shaft so as to provide a second centrifugal compression stage, said second
 31 centrifugal compression stage being gaseously coupled to said first
 32 centrifugal compression stage, said second centrifugal compression stage
 33 being intermediate said first centrifugal compression stage and said outlet
 34 opening, said second centrifugal compression stage being gaseously coupled
 35 to said outlet opening;
 36 said motor assembly and said plurality of vanes cooperating in effecting a
 37 transfer of the heat dissipated from said motor assembly to the gaseous
 38 refrigerant entering said inlet passage whereby the heat dissipated by said
 39 motor assembly is conductively transferred to said vanes and the heat of said
 40 vanes is convectionally transferred to the gaseous refrigerant flowing
 41 between said vanes so as to cool said motor assembly, evaporate any liquid
 42 in the gaseous refrigerant thereby permitting the evaporator to operate at a
 43 nominal zero superheat level, and prevent gaseous refrigerant containing
 44 liquid molecules from entering said first and second compression stages.

1 25. The multistage centrifugal compressor of claim 24 wherein said gas passages
 2 of said inlet portion and said first compression stage are directly gaseously coupled
 3 to one another at a point inside said casing without the utilization of transfer tubes
 4 external to said casing, and said first and second compression stages are directly
 5 gaseously coupled to one another at a point inside said casing without the utilization
 6 of transfer tubes external to said casing.

1 26. The multistage compressor of claim 24 wherein said gas passages of said inlet
 2 and compression portions are axisymmetrical.

1 27. The multistage compressor of claim 24 further including a pair of bearings,
 2 each of which being couplingly engaged with a corresponding end of said shaft, said

3 bearings being arranged in said casing in a manner such that said rotors and said
4 motor assembly are intermediate said bearings.

1 28. The multistage compressor of claim 24 wherein the direction of the flow of
2 gaseous refrigerant entering said inlet opening and exiting said outlet opening is
3 substantially parallel to the axis of said casing.

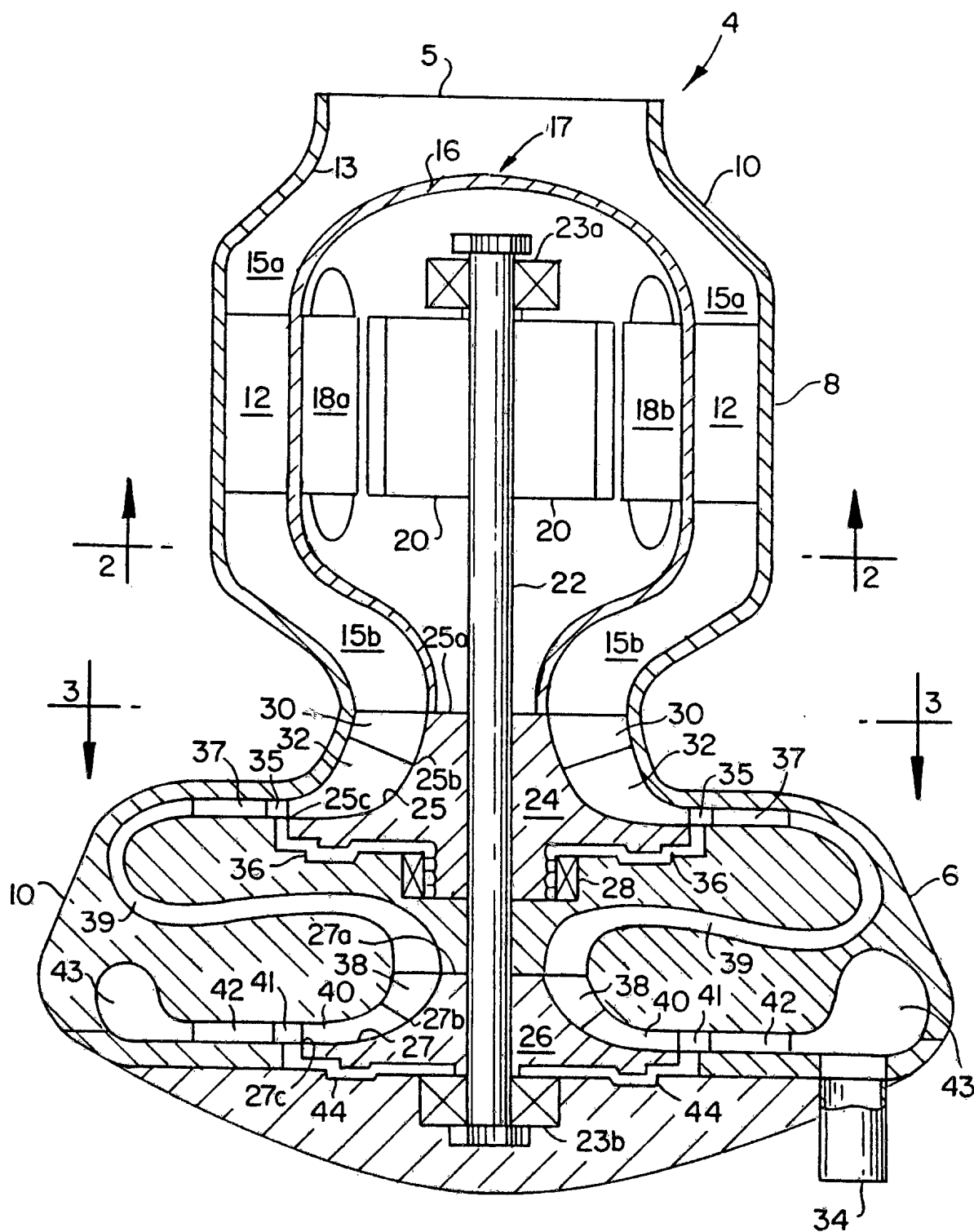
1 29. The multistage centrifugal compressor of claim 24 wherein said casing has a
2 substantially cylindrical shape.

1 30. The multistage compressor of claim 24 wherein the longitudinal axes of said
2 vanes are substantially parallel to the axis of said casing.

1 31. The multistage centrifugal compressor of claim 24 wherein said first and
2 second rotors each have a gas-facing surface.

1 32. The multistage centrifugal compressor of claim 31 wherein said gas facing
2 surface of said first and second rotors define a volute inducer airfoil extending over
3 said gas-facing surface, and an exducer airfoil partially coextensive with said inducer
4 foil, whereby said inducer airfoil of said first rotor suctionally induces the refrigerant
5 gas into said first compression stage and said exducer airfoil of said first rotor outputs
6 the centrifugally compressed gaseous refrigerant into said second compression stage,
7 and said inducer airfoil of said second rotor suctionally induces the centrifugally
8 compressed gaseous refrigerant outputted from said first compression stage into said
9 second compression stage, and said exducer airfoil of said second compression stage
10 outputs the doubly centrifugally compressed gaseous refrigerant into said outlet
11 passage of said compression portion.

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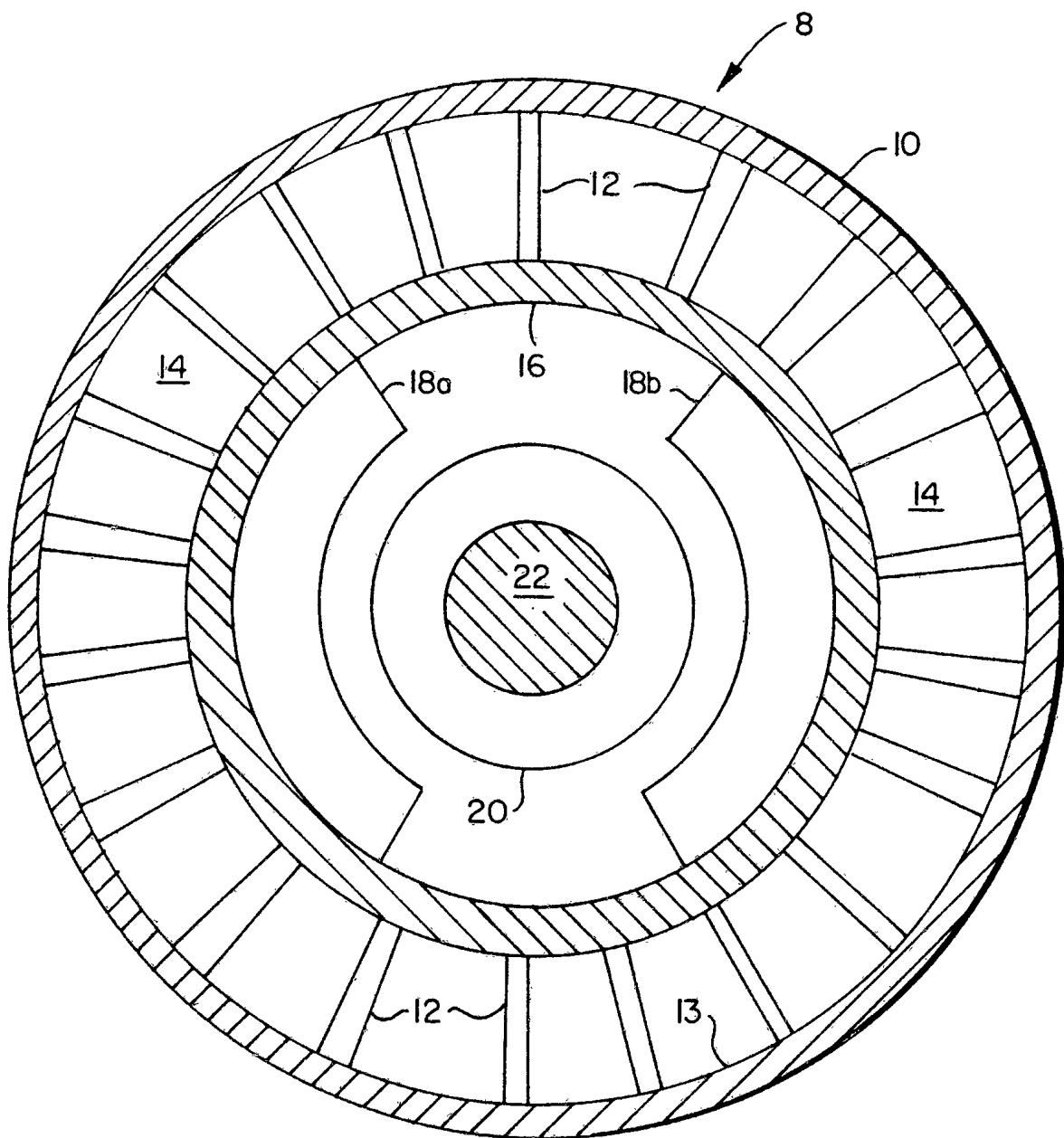


FIG. 2

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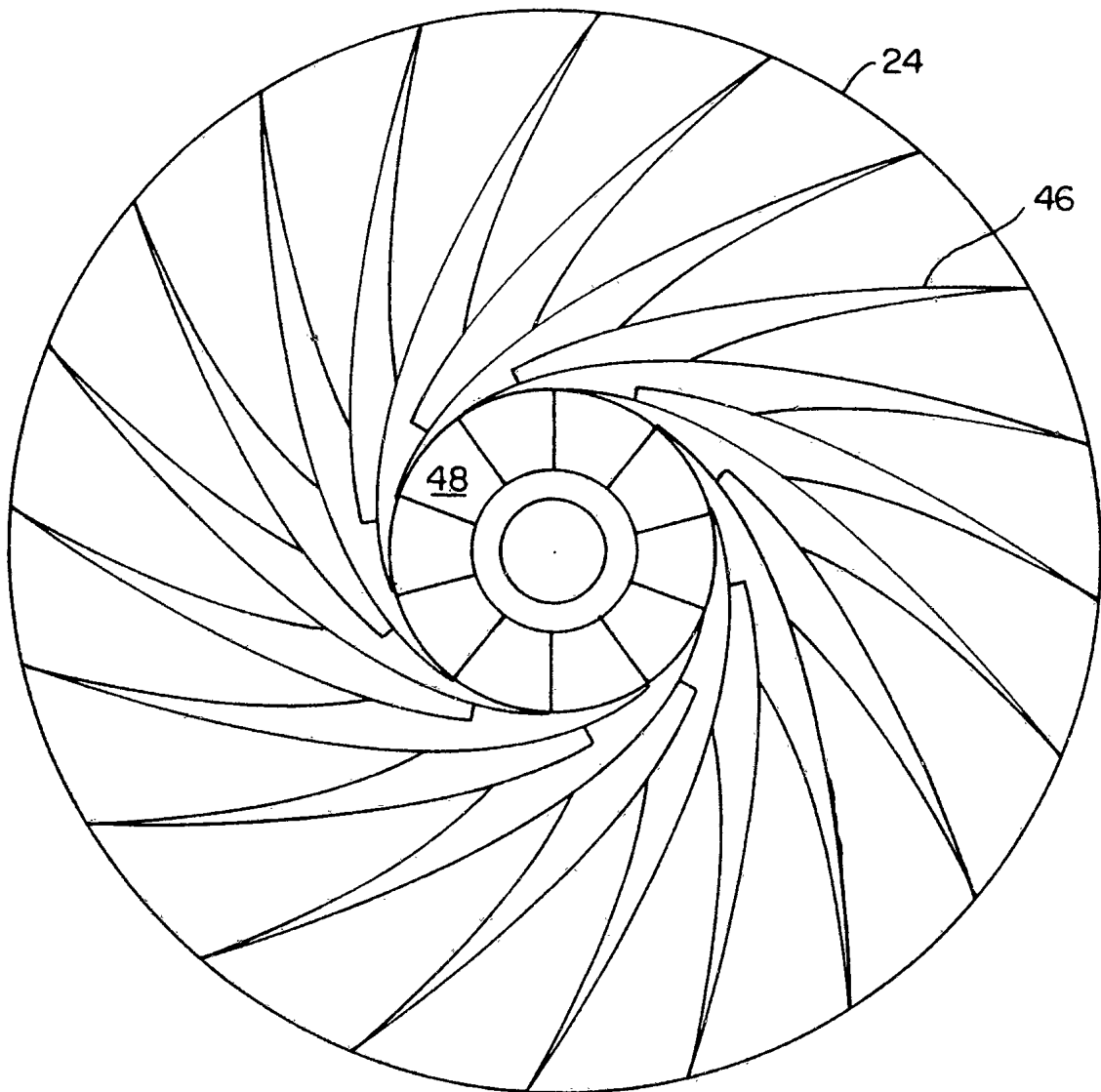


FIG. 3

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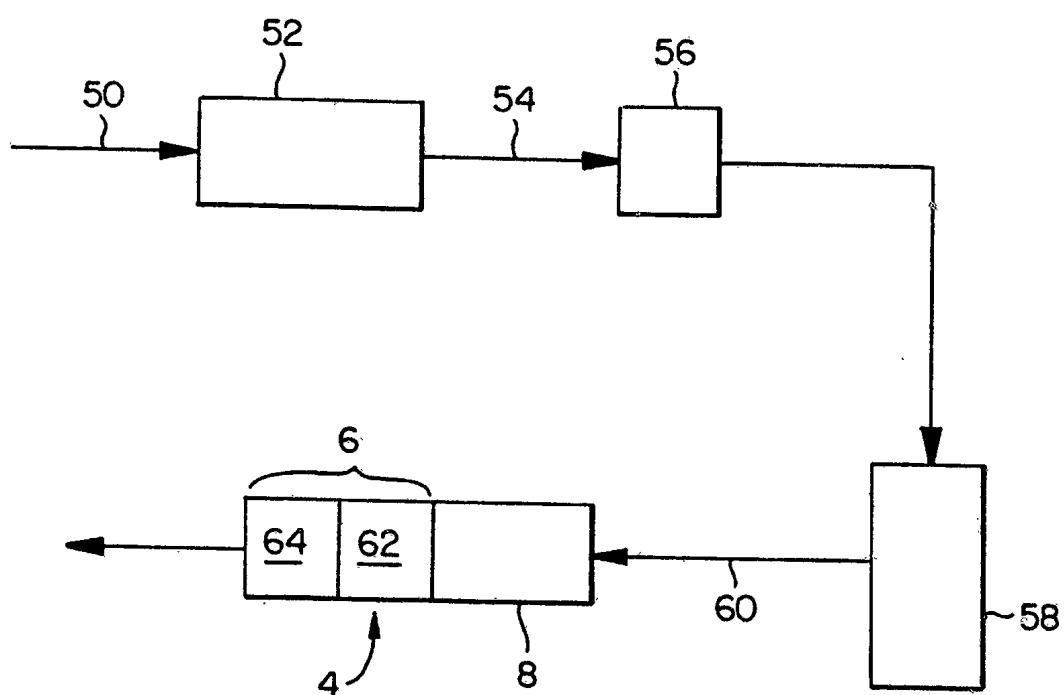


FIG. 4

INTERNATIONAL SEARCH REPORT

 International application No.
 PCT/US94/04801

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : Please See Extra Sheet.

US CL : 62/83, 498, 505, 510; 417/366, 371, 423.8

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 62/83, 498, 505, 510; 417/366, 371, 423.8

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US, A, 2,458,730 (PONOMAREFF) 11 January 1949, see fig. 1 and col. 3, lines 10-31, and col. 4, line 73-col. 5, line 14.	12-15 ----- 1-11, 16-32
Y	US, A, 3,106,334 (FOGLEMAN ET AL.) 08 October 1963, col.1, lines 18-22.	1-11, 16-32
Y	DT, A, 1,914,798 (LENZ) 24 September 1971, see the fig.	7-9, 16-17, 26, and 28
A	US, A, 4,537,046 (FUJIYAMA ET AL.) 27 August 1985.	1-32
A	US, A, 3,894,815 (BEETON) 15 July 1975.	1-32
A	US, A, 3,859,815 (KASAHARA) 14 January 1975.	1-32

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

03 AUGUST 1994

Date of mailing of the international search report

AUG 25 1994

 Name and mailing address of the ISA/US
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/04801

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
A	US, A, 3,825,366 (HERRICK) 23 July 1974.	1-32
A	US, A, 3,479,837 (MINER) 25 November 1969.	1-32
A	US, A, 3,171,589 (CRAMER ET AL.) 02 March 1965.	1-32
A	US, A, 2,888,193 (GREENWALD) 26 May 1959.	1-32
A	NL, A, 69,291 (HUBER) 15 January 1952.	1-32
A	JP, A, 4-112990 (NAKATANI) 14 April 1992.	1-32
A	GB, A, 381,561 (BROWN) 03 October 1932.	1-32

INTERNATIONAL SEARCH REPORT

In ternational application No.
PCT/US94/04801

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (5):

F25B 43/00, 01/00, 01/10, 31/00; F04B 17/00, 35/00, 39/02, 39/06