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Centrifugal compressor with labyrinth seal

Abstract

A compressor for an HVAC system includes a stator and a rotor. The stator has a stator profile. The rotor has a rotor profile. The rotor is rotatable about a rotational axis. The stator and the rotor are separated from each other by a gap formed between the stator profile and the rotor profile. The gap includes an inlet, an outlet, and at least two cavities connected by a channel. Each cavity includes a first concave portion defined by the stator profile and a second concave portion defined by the rotor profile. The first concave portion is positioned at least partially opposite from the second concave portion. The first concave portion extends in a first direction and the second concave portion extends in a second direction opposite to the first direction. The first direction and the second direction are within about 45 degrees of opposite of each other.

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Background/Summary

BACKGROUND
Field of the Invention
(1) The present invention generally relates to a centrifugal compressor used in a chiller system. More specifically, the present invention relates to a centrifugal compressor having a labyrinth seal.
Background Information
(2) A chiller system is a refrigerating machine or apparatus that removes heat from a medium. Commonly, a liquid, such as water, is used as the medium and the chiller system operates in a vapor-compression refrigeration cycle. This liquid can then be circulated through a heat exchanger

to cool air or equipment as required. As a necessary byproduct, refrigeration creates waste heat that must be exhausted to the ambient surroundings or, for greater efficiency, recovered for heating purposes. A conventional chiller system often utilizes a centrifugal compressor, which is often referred to as a turbo compressor. Thus, such chiller systems can be referred to as turbo chillers. Alternatively, other types of compressors, e.g. a screw compressor, can be utilized.

(3) In a conventional (turbo) chiller, refrigerant is compressed in the centrifugal compressor and sent to a heat exchanger in which heat exchange occurs between the refrigerant and a heat exchange medium (liquid). This heat exchanger is referred to as a condenser because the refrigerant condenses in this heat exchanger. As a result, heat is transferred to the medium (liquid) so that the medium is heated. Refrigerant exiting the condenser is expanded by an expansion valve and sent to another heat exchanger in which heat exchange occurs between the refrigerant and a heat exchange medium (liquid). This heat exchanger is referred to as an evaporator because refrigerant is heated (evaporated) in this heat exchanger. As a result, heat is transferred from the medium (liquid) to the refrigerant, and the liquid is chilled. The refrigerant from the evaporator is then returned to the centrifugal compressor and the cycle is repeated. The liquid utilized is often water.

(4) A conventional centrifugal compressor basically includes a casing (housing), an inlet guide vane, an impeller, a diffuser, a motor, various sensors and a controller. Refrigerant flows in order through the inlet guide vane, the impeller and the diffuser. Thus, the inlet guide vane is coupled to a gas intake port of the centrifugal compressor while the diffuser is coupled to a gas outlet port of the impeller. The inlet guide vane controls the flow rate of refrigerant gas into the impeller. The impeller increases the velocity (kinetic energy) of refrigerant gas. The diffuser works to transform the velocity of refrigerant gas (dynamic pressure) discharged from the impeller into (static) pressure. The motor rotates the impeller. The controller controls the motor, the inlet guide vane and the expansion valve. In this manner, the refrigerant is compressed in a conventional centrifugal compressor. The inlet guide vane is typically adjustable and the motor speed is typically adjustable to adjust the capacity of the system. In addition, the diffuser may be adjustable to further adjust the capacity of the system. In addition to controlling the motor, the inlet guide vane and the expansion valve, the controller can further control any additional controllable elements, such as the diffuser.

(5) Some centrifugal compressors for chillers have multiple compression stages to achieve a higher degree of compression. Some multistage centrifugal compressors have an in-line configuration in which the impellers are disposed adjacently along the axial direction of the centrifugal compressor and the motor is disposed on one side of the compressor housing (e.g., the discharge side). There are also two-stage centrifugal compressors in which the motor is disposed between the two stages of the centrifugal compressors.

SUMMARY

(6) An object of the present invention is to provide a centrifugal compressor with a labyrinth seal to substantially prevent refrigerant leakage around an outside of an impeller.

(7) In view of the state of the known technology, one aspect of the present disclosure is to provide a compressor for an HVAC system. The compressor includes a stator and a rotor. The stator has a stator profile. The rotor has a rotor profile. The rotor is rotatable about a rotational axis. The stator and the rotor are separated from each other by a gap formed between the stator profile and the rotor profile. The gap includes an inlet, an outlet, and at least two cavities connected by a channel. Each cavity includes a first concave portion defined by the stator profile and a second concave portion defined by the rotor profile. The first concave portion is positioned at least partially opposite from the second concave portion. The first concave portion extends in a first direction and the second concave portion extends in a second direction opposite to the first direction. The first direction and the second direction are within about 45 degrees of opposite of each other.

(8) Another aspect of the present disclosure is to provide a chiller system including a condenser, an evaporator, and a compressor. The compressor includes an impeller assembly. An input suction line is configured for gas refrigerant movement from the evaporator to the compressor. An output

discharge line is configured for gas refrigerant movement from the compressor to the condenser. A motor assembly is configured to drive the compressor. The impeller assembly includes a stator having a stator profile and a rotor having a rotor profile. The rotor being rotatable about a rotational axis. The stator and the rotor are separated from each other by a gap formed between the stator profile and the rotor profile. The gap includes an inlet, an outlet, and at least two cavities connected by a channel. Each cavity includes a first concave portion defined by the stator profile and a second concave portion defined by the rotor profile. The first concave portion is positioned at least partially opposite from the second concave portion.
(9) Another aspect of the present disclosure is to provide a stepped labyrinth seal for rotatable members in a compressor assembly. The compressor assembly includes a stator having a stator profile, and a rotor having a rotor profile. The rotor is rotatable about a rotational axis. The stator and the rotor are separated from each other by a gap formed between the stator profile and the rotor profile. The gap includes an inlet, an outlet, and at least two cavities connected by a channel. Each cavity includes a first concave portion defined by the stator profile and a second concave portion defined by the rotor profile. The first concave portion is positioned at least partially opposite from the second concave portion. The channel includes a plurality of grooves.
(10) These and other objects, features, aspects and advantages of the present invention will become apparent to those skilled in the art from the following detailed description, which, taken in conjunction with the annexed drawings, discloses preferred embodiments.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) Referring now to the attached drawings which form a part of this original disclosure:
(2) FIG. **1** is a schematic diagram illustrating a two stage chiller system having a centrifugal compressor in accordance with an exemplary embodiment;
(3) FIG. **2** is a perspective view of the centrifugal compressor of the chiller system illustrated in FIG. **1**, with portions broken away and shown in cross-section for the purpose of illustration;
(4) FIG. **3** is a schematic longitudinal cross-sectional view of the impellers, motor and labyrinth seals of the centrifugal compressor illustrated in FIGS. **1** and **2**;
(5) FIG. **4** is an elevational view in cross-section of the labyrinth seal of the centrifugal compressor FIGS. **1**-**3**;
(6) FIG. **5** is an enlarged cross-sectional view of the labyrinth seal of FIG. **4**;
(7) FIG. **6** is an enlarged cross-sectional view of a channel of the labyrinth seal of FIG. **5**;
(8) FIG. **7** is an enlarged cross-sectional view of a labyrinth seal having a groove in accordance with another exemplary embodiment;
(9) FIG. **8** is a perspective view of a seal member of the labyrinth seal of FIG. **7**;
(10) FIG. **9** is a front elevational view of the seal member of FIG. **8**;
(11) FIG. **10** is a schematic diagram illustrating a two stage chiller system having an inline compressor in accordance with another exemplary embodiment;
(12) FIG. **11** is an elevational view in cross-section of a compressor of the chiller system of FIG. **10**; and
(13) FIG. **12** is a schematic diagram illustrating a single stage chiller system having a centrifugal compressor in accordance with another exemplary embodiment.
DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENT
(14) Selected embodiments will now be explained with reference to the drawings. It will be apparent to those skilled in the art from this disclosure that the following descriptions of the embodiments are provided for illustration only and not for the purpose of limiting the invention as defined by the appended claims and their equivalents.

(15) Referring initially to FIG. **1**, a chiller, or HVAC, system **10** having a centrifugal compressor, or compressor assembly, **12** in accordance with an exemplary embodiment is illustrated. The centrifugal compressor **12** of FIG. **1** is a two-stage compressor, and thus, the chiller system **10** of FIG. **1** is a two stage chiller system. The two-stage chiller system of FIG. **1** also includes an optional economizer **14**. FIG. **1** merely illustrates an example of a chiller system **10** in which a centrifugal compressor **12** in accordance with the exemplary embodiment can be used.
(16) The chiller systems **10** is conventional, except for the centrifugal compressor **12**, which includes a labyrinth seal **16**, as shown in FIGS. **3-6**. Therefore, the chiller system **10** will not be discussed and/or illustrated in detail herein except as related to the centrifugal compressor **12**, which includes the labyrinth seal **16**. However, it will be apparent to those skilled in the art that the conventional parts of the chiller system **10** can be constructed in a variety of ways without departing from the scope of the present invention. The chiller system **10** is preferably a water chiller that utilizes cooling water and chiller water in a conventional manner.
(17) The chiller system **10** includes a chiller controller **18**, the two-stage centrifugal compressor **12**, a condenser **20**, a first expansion valve or orifice (expansion mechanism) **22**, an economizer **14**, a second expansion valve or orifice (expansion mechanism) **24**, and an evaporator **26** connected together in series to form a loop refrigeration cycle, as shown in FIG. **1**. Refrigerant gas moves from the evaporator **26** to the compressor **12** through an input suction line **62**. Refrigerant gas moves from the compressor **12** to the condenser **20** through an output discharge line **64**. However, the economizer **14** can be removed. In either case, various sensors (not shown) are disposed throughout the circuits of the chiller system **10** to control the chiller system **10** in a conventional manner. A capillary tube can be used for the first and second expansion mechanisms **22** and **24**.
(18) The compressor **12** is a two-stage centrifugal compressor, as shown in FIGS. **1-3**. The compressor **12** illustrated herein includes two impellers. However, the compressor **12** can include three or more impellers (not shown) or may be a single stage compressor as shown in FIG. **12**. The two-stage centrifugal compressor **12** is conventional except that the compressor **12** includes the labyrinth seal **16**, as shown in FIGS. **3-6**.
(19) The centrifugal compressor **12** includes two impellers **28**. In other words, the compressor **12** includes a first stage impeller **28**A and a second stage impeller **28**B. The centrifugal compressor **12** further includes a first stage inlet guide vane **30**A, a first diffuser/volute **32**A, a second stage inlet guide vane **30**B, and a second diffuser/volute **32**B, a compressor motor, or motor assembly, **34**. The motor **34** is configured to drive the compressor **12**. A casing **36** covers the centrifugal compressor **12**. The casing **36** includes an inlet portion **36**A and an outlet portion **36**B for the first stage of the compressor **12**. The casing **36** also includes an inlet portion **36**C and an outlet portion **36**D for the second stage of the compressor **12**.
(20) The chiller controller **18** receives signals from the various sensors and controls the inlet guide vanes **30**A and **30**B, and the compressor motor **34** in a conventional manner, as explained in more detail below. Refrigerant flows in order through the first stage inlet guide vane **30**A, the first stage impeller **28**A, the second stage inlet guide vane **30**B, and the second stage impeller **28**B. The inlet guide vanes **30**A and **30**B control the flow rate of refrigerant gas into the impellers **28**A and **28**B, respectively, in a conventional manner. The impellers **28**A and **28**B increase the velocity of refrigerant gas, generally without changing pressure. The motor speed determines the amount of increase of the velocity of refrigerant gas. The diffusers/volutes **32**A and **32**B increase the refrigerant pressure. The diffusers/volutes **32**A and **32**B are non-movably fixed relative to the casing **36**. The compressor motor **34** rotates the impellers **28**A and **28**B via a shaft **42**. The shaft **42** of the centrifugal compressor **12** can be supported on a magnetic bearing assembly **68** that is fixedly supported to the casing **36**. The magnetic bearing assembly **68** includes a first radial magnetic bearing **68**A, a second radial magnetic bearing **68**B, and an axial magnetic bearing **68**C. In this manner, the refrigerant is compressed in the centrifugal compressor **12**.
(21) In operation of the chiller system **10**, the first stage impeller **28**A and the second stage impeller

28B of the compressor **12** are rotated, and the refrigerant of low pressure in the chiller system **10** is sucked by the first stage impeller **28**A. The flow rate of the refrigerant is adjusted by the inlet guide vane **30**A. The refrigerant sucked by the first stage impeller **28**A is compressed to intermediate pressure, the refrigerant pressure is increased by the first diffuser/volute **32**A, and the refrigerant is then introduced to the second stage impeller **28**B. The flow rate of the refrigerant is adjusted by the inlet guide vane **30**B. The second stage impeller **28**B compresses the refrigerant of intermediate pressure to high pressure, and the refrigerant pressure is increased by the second diffuser/volute **32**B. The high pressure gas refrigerant is then discharged to the chiller system **10**.
(22) The refrigerant used in the chiller system **10**, and other HVAC applications, is a low global warming potential (low GWP) refrigerant to reduce the impact on the environment caused by the release of refrigerants into the atmosphere. GWP is a measure of a greenhouse gas when it is released into the atmosphere and benchmarked against CO.sub.2, which is defined to have a GWP equal to one. Thus, GWP is a measure of the potential for a refrigerant or other gas to behave as a greenhouse gas, which can contribute to global warming. The lower the GWP rating, or “GWP value”, the lower the potential of the refrigerant to behave as a greenhouse gas when released into the atmosphere. Examples of low-GWP refrigerants for HVAC applications include R1233zd, R1234ze and R1234yf. Each of R1233zd, R1234ze and R1234yf has a global warming potential (GWP)<10. In this application, “low-GWP refrigerant” shall be defined as a refrigerant having a GWP value smaller than 10. Alternatively, the refrigerant can be a low pressure refrigerant, such as R1233zd, in which the evaporation pressure is equal to or less than the atmospheric pressure. Preferably, the refrigerant is at least one of a low pressure refrigerant and a low global warming potential refrigerant.
(23) A stepped labyrinth seal **16** is disposed between each impeller **28**A and **28**B and the casing **36**, as shown in FIG. **3**. The labyrinth seals **16** are substantially identically configured, such that the following description refers to the labyrinth seal disposed between the second stage impeller **28**B and the casing **36**, as shown in FIGS. **3-6**.
(24) The second stage impeller **28**B includes a shroud **40** disposed at ends of the impeller blades **41**, as shown in FIG. **4**. The impeller **28**B and the shroud **40** form a rotor **44** having a rotor profile **44**A. The rotor **44** is rotatable about a rotational axis A, as shown in FIG. **4**.
(25) A seal member **46** is connected to an inner surface **36**A of the casing **36**, as shown in FIG. **4**. The casing **36** and the seal member **46** define a stator **48** having a stator profile **48**A.
(26) An impeller assembly **66** includes the stator **48** having the stator profile **48**A and the rotor **44** having the rotor profile **44**A, as shown in FIGS. **4** and **5**.
(27) A gap **50** is defined between the rotor **44** and the stator **48** to facilitate rotation of the rotor **44** within the stator **48**, as shown in FIGS. **3-6**. In other words, the stator **48** and the rotor **44** are separated from each other by the gap **50** formed between the stator profile **48**A and the rotor profile **44**A. The gap **50** includes an inlet **50**A and an outlet **50**B. A plurality of cavities **52** and a plurality of channels **54** fluidly connect the inlet **50**A and the outlet **50**B of the gap **50**. The gap **50** preferably includes at least three cavities **52** and a plurality of channels **54**, as shown in FIG. **5**. Each channel **54** connects two cavities **52** adjacently disposed in a flow direction F through the gap **50**. The gap **50** has an average direction. The average direction of the gap **50** is defined by a line **60** connecting the inlet **50**A to the outlet **50**B. As shown in FIG. **5**, the line **60** is substantially parallel to a slope **40**A of the shroud **40**.
(28) A portion of the channel **54** defined by the stator profile **48**A, as shown in FIGS. **4-6**, is connected to a portion of the cavity **52** defined by the stator profile **48**A. A portion of the channel **54** defined by the rotor profile **44**A is connected to a portion of the cavity **52** defined by the rotor profile **44**A.
(29) As shown in FIGS. **4-6**, at least two of the cavities **52** are connected by one of the plurality of channels **54**. A first cavity **52**A and a second cavity **52**B are connected by the channel **54**A.
(30) Each cavity **52** includes a first concave portion **56** defined by the stator profile **48**A and a

second concave portion **58** defined by the rotor profile **44**A, as shown in FIGS. **4-6**. The first concave portion **56** is positioned at least partially opposite from the second concave portion **58**. The first concave portion **56** extends in a first direction D**1**, as shown in FIG. **6**. The second concave portion extends in a second direction D**2** opposite to the first direction D**1**. The first direction D**1** and the second direction D**2** are within about 45 degrees of opposite of each other. In other words, an angle formed between the first direction D**1** and the second direction D**2** is between approximately 135 degrees and approximately 225 degrees. The first direction D**1** and the second direction D**2** are preferably between approximately 40 degrees and approximately 90 degrees from the rotational axis A. In other words, an angle formed between the first direction D**1** and the rotational axis A is between approximately 40 degrees and approximately 90 degrees, and an angle formed between the second direction D**2** and the rotational axis A is approximately 40 degrees and approximately 90 degrees.

(31) As shown in FIG. **5**, a first channel **54**A extends between a first cavity **52**A and a second cavity **52**B. A second channel **54**B extends between the second cavity **52**B and a third cavity **52**C. The first and second channels **54**A and **54**B are non-collinear. As shown in FIG. **6**, the first channel **54**A is a first distance X**1** from the rotational axis A, and the second channel **54**B is a second distance X**2** from the rotational axis A. The first distance X**1** and the second distance X**2** are different from one another, such that the plurality of channels **54** form a stepped configuration between the inlet **50**A and the outlet **50**B of the gap **50**.

(32) Each channel **54** has a first end **54**C and a second end **54**D, as shown in FIG. **6**. Each cavity **52** has an inlet end **52**D and an outlet end **52**E. A first distance L**1** between the inlet end **52**D and the outlet end **52**E of each cavity **52** is at least ⅕ of a second distance L**2** between the first end **54**C and the second end **54**D of each channel **54**. More preferably, the first distance L**1** between the inlet end **52**D and the outlet end **52**E of each cavity **52** is at least ¼ of the second distance L**2** between the first end **54**C and the second end **54**D of each channel **54**. Still more preferably, the first distance L**1** between the inlet end **52**D and the outlet end **52**E of each cavity **52** is at least ⅓ of the second distance L**2** between the first end **54**C and the second end **54**D of each channel **54**. The distance L**1** can be any suitable length, such as approximately 1.023 inches or 2.60 cm.

(33) The stepped labyrinth seal **16**, as shown in FIGS. **3-6**, minimizes refrigerant leakage around the outside of the impeller **28**. In other words, the labyrinth seal **16** minimizes refrigerant leakage between the rotor **44** and the stator **48**. The stepped configuration of the labyrinth seal **16** slows the flow of the leaked refrigerant, thereby increasing the flow of refrigerant through the impeller **28**.

(34) The seal member **46** is connected to the casing **36** by a plurality of fasteners **72**, as shown in FIG. **4**. The seal member **46** has a flange **74** disposed at a first end **46**A, as shown in FIGS. **7** and **8**. A plurality of fastener openings **74**A formed in the outer periphery of the flange are configured to receive the plurality of fasteners **72**. An opening **46**C extends through the seal member **46** from the first end **46**A to a second end **46**B The inner surface **46**D of the seal member **46** forms the stator profile **48**A. The seal member **46** can be formed of any suitable material, such as a thermoplastic.

(35) During operation of the compressor **12**, leaked gas refrigerant enters the gap between the rotor **44** and the stator **48** through the gap inlet **50**A, as shown in FIGS. **4** and **5**. The leaked refrigerant flows through the first channel **54**A into a first cavity **52**A. The leaked refrigerant flows from the first cavity **52**A through the second channel **54**B to the second cavity **52**B. The leaked refrigerant flows from the second cavity **52**B through the third channel **54**C to the third cavity **52**C. The leaked refrigerant flows downstream through a plurality of channels **54** and cavities **52** to the gap outlet **50**B. A swirl **76** is generated as the leaked refrigerant enters each cavity **52**, thereby reducing the flow rate of the leaked refrigerant, as shown in FIGS. **5** and **6**. The leaked refrigerant is discharged through the gap outlet **50**B to join the refrigerant discharged from the impeller **28**. The stepped labyrinth seal **16** in accordance with the exemplary embodiment improves the efficiency and performance of the compressor **12** by minimizing refrigerant leakage around the outside of the impeller **28** to increase the flow of refrigerant through the impeller **28**.

(36) As shown in FIG. **9**, a stepped labyrinth seal **116** in accordance with another illustrated exemplary embodiment of the present invention is substantially similar to the stepped labyrinth seal **16** illustrated in FIGS. **1-6** except for the differences described below. Similar parts are identified with similar reference numerals, except increased by 100 (i.e., 1xx, accordingly).
(37) The stepped labyrinth seal **116** illustrated in FIG. **9** includes a gap **150** formed between the stator **148** and the rotor **144**. The gap **150** includes an inlet **150**A and an outlet **150**B through which leaked refrigerant flows
(38) Each channel **154** has a plurality of grooves **170**, as shown in FIG. **9**. The plurality of grooves **170** can have any suitable configuration, such as a plurality of horizontally extending grooves extending between adjacent cavities **152**, or a plurality of concentric grooves as shown in FIG. **7**.
(39) A first channel **154**A has a first plurality of grooves **170**A. The second channel **154**B has a second plurality of grooves **170**B. The plurality of grooves **170**A are formed in the stator **148**. The plurality of grooves **170** increase the surface area of the gap **150** through which the leaked refrigerant flows, thereby reducing the flow rate of the leaked refrigerant through the gap **150**.
(40) As shown in FIGS. **10** and **11**, a chiller system **210** in accordance with another illustrated exemplary embodiment of the present invention is substantially similar to the chiller system illustrated in FIG. **1** except for the differences described below. Similar parts are identified with similar reference numerals, except increased by 200 (i.e., 2xx, accordingly).
(41) The chiller system **210** basically includes a centrifugal compressor **212**, a chiller controller **218**, a condenser **220**, an economizer **214**, expansion valves **220** and **224**, and an evaporator **226** connected together in series to form a loop refrigeration cycle. In addition, various sensors S and T may be disposed throughout the circuit of the chiller system **210**. The chiller system **210** may include orifices instead of the expansion valves **220** and **224**. The centrifugal compressor **212** is a two-stage in-line centrifugal compressor, as shown in FIGS. **10** and **11**.
(42) The chiller system **210** is conventional, except for the compressor **212**, which includes labyrinth seals **216**. The compressor **212** includes a stepped labyrinth seal in association with each of the impellers **228**A and **228**B, similarly to the stepped labyrinth seal illustrated in FIGS. **3-6**. The labyrinth seal **216** is formed between the stator, such as the casing **236**, and a rotor, such as the impellers **228**A and **228**B, as shown in FIG. **11**.
(43) As shown in FIG. **12**, a chiller system **310** in accordance with another illustrated exemplary embodiment of the present invention is substantially similar to the chiller system illustrated in FIG. **1** except for the differences described below. Similar parts are identified with similar reference numerals, except increased by 300 (i.e., 3xx, accordingly).
(44) The chiller system illustrated in FIG. **12** basically includes basically includes a chiller controller **318**, a compressor **312**, a condenser **320**, an expansion valve or orifice (expansion mechanism) **322**, and an evaporator **326** connected together in series to form a loop refrigeration cycle. The chiller systems **310** can further include an expansion valve (expansion mechanism) configured to supply refrigerant gas to a magnetic bearing backup system of the compressor **212**.
(45) The centrifugal compressor **312** of FIG. **12** is a single stage compressor, and thus, the chiller system **310** of FIG. **12** is a single stage chiller system. The chiller system **310** is conventional, except for the compressor **312**, which includes labyrinth seals. The compressor **312** includes a stepped labyrinth seal in association with the impeller **328**, similarly to the stepped labyrinth seal illustrated in FIGS. **3-6**.

GENERAL INTERPRETATION OF TERMS

(46) In understanding the scope of the present invention, the term “comprising” and its derivatives, as used herein, are intended to be open ended terms that specify the presence of the stated features, elements, components, groups, integers, and/or steps, but do not exclude the presence of other unstated features, elements, components, groups, integers and/or steps. The foregoing also applies to words having similar meanings such as the terms, “including”, “having” and their derivatives. Also, the terms “part,” “section,” “portion,” “member” or “element” when used in the singular can

have the dual meaning of a single part or a plurality of parts.
(47) The term "configured" as used herein to describe a component, section or part of a device includes hardware and/or software that is constructed and/or programmed to carry out the desired function.
(48) The terms of degree such as "substantially", "about" and "approximately" as used herein mean a reasonable amount of deviation of the modified term such that the end result is not significantly changed.
(49) Additionally, the term "low global warming potential (GWP) refrigerant" used herein refers to any refrigerant or blend of refrigerants that is suitable for use in the refrigeration circuit of a chiller system and has a low potential for contributing to global warming as benchmarked against CO.sub.2 gas. The refrigerants R1233zd, R1234ze, and R1234fy are cited in this application as examples of low-GWP refrigerants. However, a person of ordinary skill in the refrigeration field will recognize that the present invention is not limited to these refrigerants.
(50) While only selected embodiments have been chosen to illustrate the present invention, it will be apparent to those skilled in the art from this disclosure that various changes and modifications can be made herein without departing from the scope of the invention as defined in the appended claims. For example, the size, shape, location or orientation of the various components can be changed as needed and/or desired. Components that are shown directly connected or contacting each other can have intermediate structures disposed between them. The functions of one element can be performed by two, and vice versa. The structures and functions of one embodiment can be adopted in another embodiment. It is not necessary for all advantages to be present in a particular embodiment at the same time. Every feature which is unique from the prior art, alone or in combination with other features, also should be considered a separate description of further inventions by the applicant, including the structural and/or functional concepts embodied by such feature(s). Thus, the foregoing descriptions of the embodiments according to the present invention are provided for illustration only, and not for the purpose of limiting the invention as defined by the appended claims and their equivalents.

Claims

1. A chiller system comprising: a condenser; an evaporator; a compressor including an impeller assembly; an input suction line for gas refrigerant movement from the evaporator to the compressor; an output discharge line for gas refrigerant movement from the compressor to the condenser; and a motor assembly configured to drive the compressor; the impeller assembly including a stator having a stator profile; and a rotor having a rotor profile, the rotor being rotatable about a rotational axis, the stator and the rotor being separated from each other by a gap formed between the stator profile and the rotor profile; the gap including an inlet, an outlet, and at least two cavities connected by a channel, each cavity including a first concave portion defined by the stator profile and a second concave portion defined by the rotor profile, the first concave portion being positioned at least partially opposite from the second concave portion, an upstream channel and a downstream channel are connected to a first cavity of the at least two cavities, the upstream channel being connected to the first cavity at a first position in a direction orthogonal to the rotational axis, the downstream channel being connected to the first cavity at a second position in the direction orthogonal to the rotational axis, and the first position being closer to the rotational axis than the second position.
2. The chiller system according to claim 1, wherein the gap includes at least three cavities and a plurality of channels, each channel of the plurality of channels connecting two cavities adjacently disposed in a flow direction through the gap.
3. The chiller system according to claim 2, wherein a first channel extends between a first cavity and a second cavity, and a second channel extends between the second cavity and a third cavity, the

first and second channels being non-collinear.

4. The chiller system according to claim 1, wherein each channel has a first end and a second end, each cavity has an inlet end and an outlet end, a first distance between the inlet end and the outlet end of each cavity being at least ⅕ of a second distance between the first end and the second end of each channel.

5. The chiller system according to claim 1, wherein the gap has an average direction, the average direction of the gap being defined by a line connecting the inlet to the outlet.

6. The chiller system according to claim 1, wherein the first concave portion extends in a first direction and the second concave portion extends in a second direction, the first direction and the second direction being between approximately forty degrees and approximately 90 degrees from the rotational axis.

7. The chiller system according to claim 1, wherein the refrigerant is a low global warming potential refrigerant.

8. The chiller system according to claim 7, wherein the refrigerant is a low pressure refrigerant.

9. A chiller system comprising: a condenser; an evaporator; a compressor including an impeller assembly; an input suction line for gas refrigerant movement from the evaporator to the compressor; an output discharge line for gas refrigerant movement from the compressor to the condenser; and a motor assembly configured to drive the compressor; the impeller assembly including a stator having a stator profile; and a rotor having a rotor profile, the rotor being rotatable about a rotational axis, the stator and the rotor being separated from each other by a gap formed between the stator profile and the rotor profile; the gap including an inlet, an outlet, and at least three cavities and a plurality of channels, each channel of the plurality of channels connecting two cavities adjacently disposed in a flow direction through the gap, each cavity including a first concave portion defined by the stator profile and a second concave portion defined by the rotor profile, the first concave portion being positioned at least partially opposite from the second concave portion, a first channel extending between a first cavity and a second cavity, and a second channel extending between the second cavity and a third cavity, the first and second channels being non-collinear, the second concave portion of the second cavity being at least partially disposed on a first imaginary line extending along the first channel, and the first concave portion of the second cavity being at least partially disposed on a second imaginary line extending along the second channel.

10. A chiller system comprising: a condenser; an evaporator; a compressor including an impeller assembly; an input suction line for gas refrigerant movement from the evaporator to the compressor; an output discharge line for gas refrigerant movement from the compressor to the condenser; and a motor assembly configured to drive the compressor; the impeller assembly including a stator having a stator profile; and a rotor having a rotor profile, the rotor being rotatable about a rotational axis, the stator and the rotor being separated from each other by a gap formed between the stator profile and the rotor profile; the gap including an inlet, an outlet, and at least two cavities connected by a channel, each cavity including a first concave portion defined by the stator profile and a second concave portion defined by the rotor profile, the first concave portion being positioned at least partially opposite from the second concave portion, in a direction along the rotational axis, a first distance from a center of a first cavity which is disposed upstream of the channel to an upstream end of the channel being smaller than a second distance from the center of the first cavity to a mid-portion of the second concave portion of the first cavity, the mid-portion of the second concave portion of the first cavity being disposed at a mid-point of the second concave portion of the first cavity in a direction perpendicular to the direction along the rotational axis.

11. A chiller system comprising: a condenser; an evaporator; a compressor including an impeller assembly; an input suction line for gas refrigerant movement from the evaporator to the compressor; an output discharge line for gas refrigerant movement from the compressor to the condenser; and a motor assembly configured to drive the compressor; the impeller assembly

including a stator having a stator profile; and a rotor having a rotor profile, the rotor being rotatable about a rotational axis, the stator and the rotor being separated from each other by a gap formed between the stator profile and the rotor profile; the gap including an inlet, an outlet, and at least two cavities connected by a channel, each cavity including a first concave portion defined by the stator profile and a second concave portion defined by the rotor profile, the first concave portion being positioned at least partially opposite from the second concave portion, the channel having a substantially constant distance from a rotor side of the channel to the rotational axis, each of the at least two cavities provided in the gap having a substantially similar shape.