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(54) **Two-stage vapor cycle compressor**

(57) A two-stage vapor cycle compressor (10) includes a first stage impeller (20), a second stage impeller (21) situated adjacent to the first stage impeller, an electric motor (30) running on a pair of foil bearings (18,19), a thrust disk (16) including two foil bearings (17) and being positioned between the second stage impeller and the electric motor, and a compressor housing (40) enclosing the first and second stage impeller and the electric motor. A refrigerant vapor (27) compressed by the first

stage and second stage impeller flows through an internal passageway (26) formed by the compressor housing and cools the foil bearings (17,18,19) and the electric motor (30). The compressor may be a gravity insensitive, small, and lightweight machine that may be easily assembled at low manufacturing costs. The two-stage vapor cycle compressor may be suitable for, but not limited to, applications in vapor compression refrigeration systems, such as air-conditioning systems, for example, in the aircraft and aerospace industries.

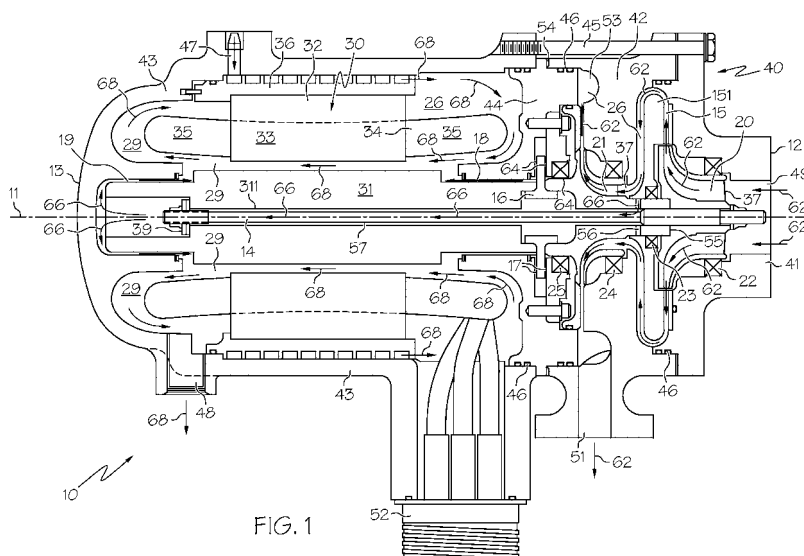


FIG. 1

Description

BACKGROUND OF THE INVENTION

[0001] The present invention generally relates to vapor cycle compressors and, more particularly, to a low cost two-stage vapor cycle compressor and a method for operating an electrically driven two-stage vapor cycle compressor.

[0002] Vapor compression refrigeration is a refrigeration method that is widely used for air-conditioning spaces, for example, public spaces such as private and public buildings, automobiles, and aircraft cabins, or for domestic or commercial refrigerators and other commercial and industrial services. Vapor-compression refrigerant systems typically circulate a liquid refrigerant as a medium that absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Vapor-compression refrigerant systems typically include a compressor, a condenser, a throttle or expansion valve, and an evaporator. The circulating refrigerant enters the compressor in a thermodynamic state known as saturated vapor, which has a low pressure and a low temperature, and is compressed to a higher pressure, resulting in a higher temperature as well. The hot vapor is routed through a condenser where it is cooled and condensed into a liquid. The now liquid refrigerant is routed through the expansion valve to the evaporator. Here the refrigerant absorbs and removes heat from air circulating through the evaporator and goes over into the saturated vapor state. To complete the refrigeration cycle, the refrigerant in vapor form is routed back to the compressor. Consequently, the main purpose of the compressor is to boost the pressure of the refrigerant in vapor form so that the high pressure, high temperature refrigerant in vapor form can be used to do heat transfer. A typical two-stage vapor cycle compressor includes two impellers to realize two stages of compression.

[0003] Industries, and especially the aerospace industry, typically strive for vapor cycle compressors that have a high reliability and long life span, that have a compact size, are easy to assemble, and can be manufactured at a low cost while operating highly efficiently. U.S. Patent 6,564,560, for example, utilizes ceramic roller element bearings to achieve an oil-free liquid chiller. Still the roller element bearings have to be actively lubricated by liquid refrigerant.

[0004] U.S. Patent 5,857,348, for example, utilizes non-lubricated radial bearings, such as magnetic or foil gas bearings cooled with refrigerant in vapor form, as journal bearings. First and second stage impellers are mounted on opposite ends of a drive shaft driven by a high-speed brushless DC (continuous current) permanent magnet motor. This layout may not allow a compact design of the compressor. The arrangement of the compressor components on the drive shaft and the use of return channels and guide vanes may not enable the most efficient cooling method for the air bearings and the

motor but may increase the number of parts used in the assembly of the compressor.

[0005] U.S. Patent 6,997,686, for example, teaches a two-stage compressor including a first impeller and a second impeller connected in series by a transition pipe and using a low-pressure refrigerant, such as R134a. Foil air bearings are used in combination with an induction motor running at high speeds. An encoder disc is included to sense the rotational speed of the rotating assembly of the compressor. The compressor housing includes a separate cooling inlet and outlet for circulating liquid refrigerant in an inner cooling jacket. O-rings are used to seal the cooling jacket within the compressor housing.

[0006] As can be seen, there is a need for a two-stage vapor cycle compressor that has a simple design including a reduced number of parts and interfaces compared to prior art compressors and that can be manufactured at a relatively low cost by taking advantage of modern high volume production techniques. Furthermore, there is a need for a method that optimizes the flow cooling the bearings and the motor to increase the efficiency of the compressor compared to prior art compressors.

SUMMARY OF THE INVENTION

[0007] In one aspect of the present invention, a two-stage vapor cycle compressor comprises a first stage impeller, a second stage impeller situated adjacent to the first stage impeller, an electric motor running on a pair of foil bearings, a thrust disk including two foil bearings, and a compressor housing enclosing the first and second stage impeller and the electric motor. The electric motor drives the first stage and the second stage impeller. The thrust disk is positioned between the second stage impeller and the electric motor. The compressor housing forms an internal passageway. The first stage impeller and the second stage impeller compress a refrigerant vapor. The refrigerant vapor flows through the passageway and cools the electric motor and the foil bearings.

[0008] In another aspect of the present invention, a passageway of a two-stage vapor cycle compressor comprises a compression loop including a first stage impeller and a second stage impeller, a thrust bearing and forward journal bearing cooling loop, and a rotor bore and aft journal bearing cooling loop. The first stage impeller and the second stage impeller compress a refrigerant vapor. A first portion of the refrigerant vapor exits the compression loop proximate to an outlet of the second impeller and flows over the thrust bearings and the forward journal bearing. A second portion of the refrigerant vapor exits the compression loop proximate to an inlet of the second stage impeller and travels axially through the rotor bore and flows over the aft journal bearing. The thrust bearings, the forward journal bearing, and the aft journal bearing are foil bearings.

[0009] In a further aspect of the present invention, a method for operating an electrically driven two-stage vapor cycle compressor comprises the steps of: compress-

ing a refrigerant vapor in a first stage and in a second stage, extracting a first portion of the refrigerant vapor from the inlet to the second stage, cooling a rotor bore of an electric motor and an aft journal bearing with the first portion of the refrigerant vapor, extracting a second portion of the refrigerant vapor from the discharge of the second stage, and cooling thrust bearings and an forward journal bearing with the second portion of the refrigerant vapor.

[0010] These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figure 1 is a simplified cross-sectional side view of a two-stage vapor cycle compressor according to an embodiment of the present invention;

[0012] Figure 2 is a perspective cut-away view of a shrouded impeller according to an embodiment of the present invention;

[0013] Figure 3 is a simplified block diagram of an internal passageway of a two-stage vapor cycle compressor according to an embodiment of the present invention; and

[0014] Figure 4 is a flow chart representing a method for operating an electrically driven two-stage vapor cycle compressor according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0015] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is best defined by the appended claims.

[0016] Broadly, the present invention provides a two-stage vapor cycle compressor and a method for vapor cooling an electrically driven two-stage vapor cycle compressor. In one embodiment the present invention provides a two-stage vapor cycle compressor that may be a relatively small and lightweight machine. The two-stage vapor cycle compressor as in one embodiment the present invention may be gravity insensitive, and may withstand the environmental conditions of aerospace applications. In one embodiment the present invention provides a two-stage cycle compressor that has a simple layout, that may be relatively easy to assemble, and that has relatively low manufacturing costs. In one embodiment the present invention provides a two-stage cycle compressor that enables compression of a refrigerant, such as a commercial CFC (chlorofluorocarbons)-free refrigerant, for example, R314a, at a relatively high speed with a relatively high efficiency. In one embodiment the present invention provides a method for operating an

electrically driven two-stage vapor cycle compressor that may enable cooling of the motor and the foil bearings efficiently and with exactly the right amount of refrigerant vapor to enable rotation of the impellers of the two-stage vapor cycle compressor at relatively high speed, for example, at about 50,000 rpm (rotations per minute) and above. An embodiment of the present invention provides a two-stage vapor cycle compressor that is suitable for, but not limited to, applications in vapor compression refrigeration systems, such as air-conditioning systems, for example, in the aircraft and aerospace industries.

[0017] In contrast to the prior art, where vapor cycle compressors typically include a relatively high number of parts, the two-stage vapor cycle compressor as in one embodiment of the present invention may include a reduced number of parts by combining parts typically used separately, such as the first stage diffuser and the second stage inlet return channel plate or the second stage diffuser and the discharge scroll housing, and by taking advantage of modern high volume production techniques, such as pressure die-casting, investment casting, or injection molding. The two-stage vapor cycle compressor as in one embodiment of the present invention may include a reduced number of interfaces, for example, by creating a compressor housing that may be formed by only three different housings, the motor housing, the scroll housing, and the inlet housing, which may be held together by a single row of bolts. Furthermore, by using cast aluminum or cast aluminum alloys, the housings of the compressor may be lightweight but may also have the thickness and strength as required for aerospace applications.

[0018] In further contrast to the prior art, where often foil bearings are used only for the journal bearings, the two-stage vapor cycle compressor as in one embodiment of the present invention may include foil bearings for both the journal and the thrust bearings. Utilizing foil bearings for both the journal and the thrust bearings may enable the use of refrigerant vapor for cooling of these bearings and may eliminate water or oil contamination of the refrigerant, which may occur by using prior art oil or water cooled bearings, and may simplify the compressor layout. Furthermore, foil bearings may be high load capacity bearings that may withstand vibrations and shock environments found, for example, in aerospace applications. Also, by eliminating oil as a cooling medium for thrust and journal bearings, the operation of the two-stage vapor cycle compressor as in one embodiment of the present invention may be gravity insensitive.

[0019] In further contrast to the prior art, the present invention as in one embodiment may improve the aerodynamic performance and efficiency of the compressor compared to prior art compressors by utilizing a cast single-piece shrouded impeller for the first and second stage impeller and by applying a shimming concept for better alignment of the first and second impeller with the first and second diffuser, respectively. Using a single-piece shrouded impeller that may be a casting, as in one em-

bodiment of the present invention, may minimize the internal leakage of each compression stage and, consequently, increase the efficiency of each compression stage. Also, casting the shrouded impeller for the first and second compression stage may cost less than fully machining the wheels and shroud contour and then brazing them together, as typically done in the prior art.

[0020] In further contrast to the prior art, where the motor cooling is typically separated from the bearing cooling, the vapor cycle compressor as in one embodiment of the present invention may include a cooling passageway that may enable cooling the forward journal bearing and the thrust bearings with the same cooling loop, where the refrigerant vapor for cooling may be extracted from the discharge of the second stage by bypassing a seal. The cooling passageway as in one embodiment of the present invention may further enable cooling the aft journal bearing and the motor rotor with the same cooling loop, where the refrigerant vapor for cooling may be extracted from the inlet of the second stage compressor and enters the rotor bore through an integrated cooling port instead of using prior art return channels and guide vanes that may add parts to the assembly and that may lower the efficiency of the bearing cooling. The cooling passageway as in one embodiment of the present invention may further include another cooling loop for cooling the electric motor. In contrast to the prior art where the electric motor may be cooled with a combination of liquid coolant and vapor refrigerant, the electric motor as in one embodiment of the present invention may be cooled entirely with a phase changing refrigerant, which may be the same refrigerant as compressed in the vapor cycle compressor and may be supplied from the condenser in liquid form. While the refrigerant enters the motor cooling jacket in liquid form, it may turn to vapor form as it may be heated by the losses in the motor stator. The motor cooling refrigerant vapor may then, discharge into the internal motor cavities and may mix with the two bearing cooling loops before it may discharge from the vapor cycle compressor back to the evaporator. Typically, the cooling medium used for cooling bearings in the known prior art is not mixed with the cooling medium used for cooling the motor.

[0021] Referring now to Figure 1, a simplified cross-sectional side view of a two-stage vapor cycle compressor 10 is illustrated according to an embodiment of the present invention. The compressor 10 may extend along a central axis 11 from a front end 12 to a back end 13. The compressor 10 may include a tie rod 14, a first stage impeller 20, a second stage impeller 21, a first stage diffuser 15 including a diffuser plate 151, a thrust disk 16, an electric motor 30, and a compressor housing 40. The tie rod 14 may hold the entire rotating assembly of the compressor 10 including a rotor 31 of the electric motor 30, the first stage impeller 20, the second stage impeller 21, and the thrust disk 16 together. The tie rod 14 and, therefore, the first stage impeller 20 and the second stage impeller 21, as well as the thrust disk 16, may be driven

by the electric motor 30, which may be a high power density electric motor, such as a high-speed alternating current multi-pole permanent magnet electric motor. The tie rod 14 may have a washer 39 installed at the circumference at one end proximate to the back end 13 of the compressor 10. The washer 39 may allow a controlled amount of leakage of refrigerant vapor 27 (Figure 3).

[0022] The electric motor 30 may be mounted on the tie rod 14 proximate to the back end 13 of the compressor 10. The electric motor 30 may run on a pair of journal bearings 18 and 19, which may be foil bearings. Journal bearing 18 may be a forward journal bearing, while journal bearing 19 may be an aft journal bearing. Foil bearings 18 and 19 may use a flexible foil surface to maintain a film of vapor between the rotating tie rod 14 and the stationary bearing parts and may enable the electric motor 30 to run at speeds above about 50,000 rpm, for example, at speeds of about 75,000 rpm and above. The electric motor 30 may include a rotor 31 and a stator 32. The rotor 31 may include an axially extending bore 311 at the center for receiving the tie rod 14. The stator 32 may include an iron stack 33 and a winding 34. The winding 34 may include end turns 35. A cooling jacket 36 may be radially piloted on to the iron stack 33 as well as to a motor housing 43. The cooling jacket 36 may be in direct contact with the outer diameter of the iron stack 33 of the stator 32. A variety of layouts may be used for the cooling jacket 36, for example, a cooling jacket including a cooling jacket resistor as disclosed in U.S. Patent Application Serial Number 11/555,645, hereby incorporated by reference. The electric motor 30 may be operated sensorless and, therefore, the speed of the electric motor 30 may not be determined by a speed sensor. Information about the rotational speed and position of the rotor 31 may be obtained from electromagnetic field data.

[0023] The first stage impeller 20 and the second stage impeller 21 may be configured in series and may be mounted on the tie rod 14 proximate to the front end 12, opposite from the electric motor 30 and separated from the electric motor 30 by the thrust disk 17. The first stage impeller 20 and the second stage impeller 21 may be situated adjacent to each other thereby eliminating inter-stages cooling as often done in the prior art. The first stage impeller 20 and the second stage impeller 21 may be mounted on the tie rod 14 proximate to the front end 12 of the compressor 10, at the opposite end from the electric motor 30, and may rotate with the tie rod 14. The tie rod 14 may function as a cantilever, which may be supported both transversely and rotationally at the end proximate to the back end 13 by the electric motor 30 and the journal bearings 18 and 19 and which may be free to rotate at the opposite end where the first stage and second stage impeller 20 and 21, respectively, may be installed. The first stage diffuser 15 may be integrated into the first stage impeller 20 to minimize potential internal leakage. Furthermore, the first stage diffuser plate 151 may also be a second stage inlet return channel plate. The first stage impeller 20, as shown in detail in

Figure 2, and the second stage impeller 21 may have the same layout and size. The first stage impeller 20 and the second stage impeller 21 may have a diameter of about 2 inches. Both the first stage impeller 20 and the second stage impeller 21 may be shrouded for improved aerodynamic efficiency and to eliminate potential tip leakage. By using shrouded impellers 20 and 21, the entire flow 62 (Figure 1) may pass through the blade channels 38 (Figure 2). Both the first stage impeller 20 and the second stage impeller 21 may be single piece castings and may be manufactured from a cast aluminum or cast aluminum alloy during a pressure die-casting, an investment casting, or an injection molding process. Other cast materials suitable for aerospace applications may be used. The airfoil contours of the impellers 20 and 21 may be designed such that a casting tool may be pulled away from the casting after the casting process, allowing the impellers 20 and 21 to be manufactured as a single piece.

[0024] Referring again to Figure 1, the thrust disk 16 may include two thrust bearings 17 positioned at opposite sides of the thrust disk 16. The thrust bearings 17 may control axial movement of the tie rod 14 relative to the compressor housing 40. The thrust bearings 17 may be foil bearings. Also, the position of the thrust disk 16 and the thrust bearings 17 may be chosen such that it may not interfere with the alignment of the impellers 20 and 21 and the diffusers 15 and 53, respectively. As can be seen in Figure 1, the thrust disk 16 may be positioned between the second stage impeller 21 and the electric motor 30. Compressor thrust loads may be additive and may be balanced against the thrust disk 16. Positioning the thrust disk 16 and the thrust bearings 17 between the second stage impeller 21 and the electric motor 30, and therefore, on the compressor side, may minimize axial misalignment due to differential thermal growth of the compressor housing 40 versus the rotor 31 of the electric motor 30 and may support high-speed operation of the compressor 10.

[0025] The compressor housing 40 may enclose the electric motor 30, the first stage impeller 20 and diffuser 15, the second stage impeller 21 and diffuser 53, the tie rod 14, and the thrust disk 16 and may include an inlet housing 41, a scroll housing 42, and a motor housing 43. The compressor housing 40 may be assembled with a single row of bolts 45. The inlet housing 41 may be positioned at the front end 12 of the compressor 10 and may include a compressor inlet 49. The scroll housing 42 may be adjacent to and in direct contact with the inlet housing 41 and may include a compressor outlet 51. A second stage diffuser 53 may be incorporated within the scroll housing 42. The motor housing 43 may be positioned adjacent to the scroll housing 42 and may include an inlet port 47 and an outlet port 48. The inlet port 47 and the outlet port 48 may be positioned across from each other on the circumference of the motor housing 43. The motor housing 43 may house the electric motor 30 and may also accommodate a hermetically sealed connector 52. The electric motor 30 may be installed with-

in the motor housing 43 such that the outer diameter of the cooling jacket 36 may be in direct contact with the inner diameter of the motor housing 43. The inlet port 47 and the outlet port 48 may be in fluid connection with the cooling jacket 36. The inlet port 47 and the outlet port 48 may be positioned relative to the cooling jacket 36 such that a refrigerant may have the longest possible resident time in the compressor 10 to maximize the cooling effect. Shown in Figure 1 are one inlet port 47 and one outlet port 48, but alternate configurations may include, for example, two outlet ports 48 positioned at opposite ends of the cooling jacket 36. It may further be possible to position the inlet port 47 at mid point of the cooling jacket 36 and enable a refrigerant to discharge on either side of the cooling jacket into internal cavities 29 of the electric motor 30. The aft journal bearing 19 may be integrated into the motor housing 43 proximate to the back end 13 of the compressor. The inlet housing 41, the scroll housing 42, and the motor housing 43 may be connected with each other with a single row of bolts 45 and may form an outer housing, the compressor housing 40, of the compressor 10.

[0026] The compressor 10 may further include a bearing housing 44, which may be axially positioned between the second stage impeller 21 and the electric motor 30 and may be sandwiched between the scroll housing 42 and the motor housing 43. The bearing housing 44 may extend vertically to be in direct contact with motor housing 43 and the scroll housing 42. The bearing housing 44 may have the forward journal bearing 18 integrated and may accommodate the thrust disk 16. The bearing housing 44 may position the thrust disk 16 between a rotor 31 of the electric motor 30 and the second stage impeller 21.

[0027] Each housing, the inlet housing 41, the scroll housing 42, the motor housing 43, and the bearing housing 44, may be manufactured from cast aluminum and cast aluminum alloys during a pressure die-casting, investment casting, or injection molding process. Each housing, the inlet housing 41, the scroll housing 42, the motor housing 43, and the bearing housing 44, may be a single piece casting. Other cast materials suitable for aerospace applications may be used.

[0028] Double "o"-rings 46 may be installed at the interface between the bearing housing 44 and the motor housing 43. Double "o"-rings 46 may also be installed at the interface between the bearing housing 44 and the scroll housing 42. Furthermore, double "o"-rings 46 may be installed at the interface between the inlet housing 41 and the scroll housing 42. The double "o"-rings 46 may not be limited to two "o" rings and may be multiple "o"-rings, where more than two "o"-rings may be installed at the mentioned interfaces. The double "o"-rings 46 may prevent leakage of refrigerant vapor 27 (Figure 3) from the inside of the compressor 10 to the outside of the compressor 10. The double "o"-rings 46 may assist in hermetically sealing the compressor 10.

[0029] Shimming may be used for better alignment of the first stage impeller 20 and the second stage impeller

with the diffuser 15 and the scroll housing 42 including the second stage diffuser 53, respectively, which may be essential for the aerodynamic performance of the compressor 10. To enable high speed operation of the compressor 10, it may be critical to align the exit of the first stage impeller 20 and the inlet of the first stage diffuser 15 as well as the exit of the second stage impeller 21 and the inlet of the second stage diffuser 53 (incorporated in the scroll housing 42) as perfectly as possible. A shim 54 may be applied between the scroll housing 42 and the bearing housing 44 to meet dimensional requirements between the scroll housing 42 and the second stage impeller 21. A shim 55 may be applied between the first stage impeller 20 and the first stage diffuser 15. A shim may be a piece of a corrective material that may be applied as needed to meet dimensional requirements between the impellers 20 and 21 and the diffusers 15 and 53, respectively.

[0030] Four radial seals, seal 22, seal 23, seal 24, and seal 25 as shown in Figure 1, may be installed within the compressor 10 to reduce internal leakages and improve the efficiency of the compressor 10. The seals 22, 23, 24, and 25 may be floating carbon ring seals or labyrinth seals. Seal 22 may be positioned proximate to the inlet 37 of the first stage impeller 20, seal 23 may be positioned proximate to an outlet of the first stage impeller 20, seal 24 may be positioned proximate to the inlet 37 of the second stage impeller 21, and seal 25 may be positioned proximate to an outlet of the second stage impeller 21. The seal 25, positioned proximate to the outlet of the second stage impeller 21, may be a segmented seal and may accommodate a controlled amount of leakage of refrigerant vapor 27 (Figure 3) and may be used as a cooling flow regulation point. Therefore, the seal 25 may be used to supply the thrust bearings 17 and the forward journal bearing 18 with a controlled flow of pressurized refrigerant vapor 27.

[0031] Referring now to Figure 3, a simplified block diagram of an internal passageway 26 of a two-stage vapor cycle compressor 10 is illustrated according to an embodiment of the present invention. The inlet housing 41, the scroll housing 42, the motor housing 43, and the bearing housing 44 may define an internal passageway 26 of the compressor 10. The passageway 26 may be formed by open cavities inside the inlet housing 41, the scroll housing 42, the motor housing 43, and the bearing housing 44. At the same time, excess internal cavities or pockets where the refrigerant 26 may potential accumulate may be minimized by manufacturing the inlet housing 41, the scroll housing 42, the motor housing 43, and the bearing housing 44 as castings. Furthermore, the electric motor 30 may not employ a bore seal or any other kind of barrier between the rotor 31 and the stator 32. Therefore, internal motor cavities 29 may exist within the rotor 31 and stator 32 assembly of the electric motor 30, such as a wide gap between the rotor 31 and the stator 32. The internal motor cavities 29 may be part of the passageway 26 and may enable cooling the rotor 31 and the

stator 32 efficiently.

[0032] A refrigerant in vapor form, refrigerant vapor 27, may travel within the passageway 26 through the interior of the compressor 10. The same refrigerant in liquid form, liquid refrigerant 28, may enter the cooling jacket 36 of the electric motor 30 through the inlet port 47. The refrigerant, in vapor form 27 and in liquid form 28, may be, for example, a commercial CFC (chlorofluorocarbons)-free refrigerant, such as R314a. The refrigerant, in vapor form 27 and in liquid form 28, may be the only refrigerant that may be used throughout the compressor 10 for the two-stage compression and the cooling of the electric motor 30, the journal bearings 18 and 19, and the thrust bearings 17. The passageway 26 may facilitate four different but interconnected refrigerant flow loops, a compression loop 61, a thrust bearing 17 and forward journal bearing 18 cooling loop 63, a rotor bore 311 and aft journal bearing 19 cooling loop 65, and an electric motor 30 cooling loop 67. The refrigerant vapor 27 may flow within the compression loop 61 in the direction of the arrows 62. The refrigerant vapor 27 may flow within the thrust bearing 17 and forward journal bearing 18 cooling loop 63 in the direction of the arrows 64. The refrigerant vapor 27 may flow within the rotor bore 311 and aft journal bearing 19 cooling loop 65 in the direction of the arrows 66. The liquid refrigerant 28 at first and then the refrigerant vapor 27 may flow within the electric motor 30 cooling loop 67 in the direction of the arrows 68. The passageway 26 and the arrows 62, 64, 66, and 68 indicating the flow direction within the loops 61, 63, 65, and 67, respectively, are also shown in Figure 1.

[0033] Referring now to Figures 1 and 3, the refrigerant vapor 27 may enter the compression loop 61 and the compressor 10 at the compressor inlet 49 positioned at the front end 12 of the compressor 10 and integrated in the inlet housing 41. The refrigerant vapor 27 may axially enter the compressor inlet 49. At this point the refrigerant vapor 27 may have a relatively low pressure and a relatively low temperature and may come from an evaporator 58. The refrigerant vapor 27 may axially enter the first stage impeller 20 at an inlet 37 (shown in Figure 2). The refrigerant vapor 27 may flow entirely through the blade channels 38 (Figure 2) of the first stage impeller 20. The refrigerant vapor 27 may exit the first stage impeller 20 radially and may travel within the passageway 26 formed between the first stage diffuser blade 151 and the inlet housing 41 and then the scroll housing 42. The refrigerant vapor 27 may travel in the direction of the arrows 62 up and over the diffuser blade 151 and may then come down towards the inlet of the second stage impeller 21. The refrigerant vapor 27 may axially enter the second stage impeller 21. The refrigerant vapor 27 may flow entirely through the blade channels 38 (Figure 2) of the second stage impeller 21. The refrigerant vapor 27 may exit the second stage impeller 21 radially and may travel within the passageway 26 through the second stage diffuser 53 incorporated within the scroll housing 42. The refrigerant vapor 27, which may now have a relatively high pressure

and a relatively high temperature, may exit the compressor 10 through the compressor outlet 51 and may travel toward a condenser 59.

[0034] Proximate to the inlet 37 (Figure 2) of the second stage impeller 21, a portion of the refrigerant vapor 27 flowing in the compression loop 61 may be extracted and may enter the rotor bore 311 and aft journal bearing 19 cooling loop 65 by flowing in the direction of the arrows 66. The refrigerant vapor 27 may flow through a cooling port 56, which may be a relatively small opening positioned proximate to the inlet 37 (Figure 2) of the second stage impeller 21, and may enter a space 57 between the tie rod 14 and the circumference of the bore 311 of the rotor 31. The cooling port 56 and the space 57 may be part of the passageway 26. The refrigerant vapor 27 may travel axially in the direction of the arrows 66 within the space 57 toward the back end 13 of the compressor and may cool the bore 311 of the rotor 31. The refrigerant vapor 27 may exit the space 57 through the washer 39 and may flow over the aft journal bearing 19 as indicated by arrows 66, thereby cooling the journal bearing 19 before mixing in with the refrigerant vapor 27 traveling within the electric motor 30 cooling loop 67.

[0035] After exiting the second stage impeller 21, a portion of the refrigerant vapor 27 flowing in the compression loop 61 may be extracted from the discharge of the second stage impeller 21, may bypass the segmented seal 25 positioned at an outlet of the second stage impeller 21, and may enter the thrust bearing 17 and forward journal bearing 18 cooling loop 63 by flowing in the direction of the arrows 64. The refrigerant vapor 27 may first flow over the two thrust bearings 17 and then over the forward journal bearing 18 in the direction of the arrows 64, thereby cooling the thrust bearings 17 and the journal bearing 18. After passing the journal bearing 18, the refrigerant vapor 27 flowing in the cooling loop 63 may mix in with the refrigerant vapor flowing in the electric motor 30 cooling loop 67.

[0036] Liquid refrigerant 28, which may be extracted from the condenser 59, may enter the electric motor 30 cooling loop 67 and the cooling jacket 36 through the inlet port 47. The liquid refrigerant 28 may heat up by the losses in the stator 32 while moving along the cooling jacket 36 and may take on vapor form. The refrigerant vapor 27 may continue to travel through the cooling jacket 36 thereby cooling the iron stack 33 and partially cooling the winding 34 of the stator, but may also discharge to internal motor cavities 29. By flowing along the passageway 26, which may lead through the internal motor cavities 29, in the direction of the arrows 68, the refrigerant vapor 27 may cool the end turns 35 of the winding 34 and the rotor 31. The refrigerant vapor 27 flowing in the electric motor 30 cooling loop 67 may mix with the refrigerant vapor 27 flowing in the thrust bearing 17 and forward journal bearing 18 cooling loop 63 just before flowing over the rotor 31. The refrigerant vapor 27 flowing in the electric motor 30 cooling loop 67 may mix with the refrigerant vapor 27 flowing in the rotor bore 311 and aft

journal bearing 19 cooling loop 65 just after flowing over the rotor 31. The combined refrigerant vapor 27 may continue to flow in the passageway 26 through the cooling jacket 36 and through the internal motor cavities 29 in the direction of the arrows 68 further cooling the iron stack 33, the winding 34, and the end turns 35 of the stator 32 as well as the rotor 31. The combined refrigerant vapor 27 may exit the electric motor 30 cooling loop 67 and the compressor 10 through the outlet port 48. The discharged refrigerant vapor 27 may travel back to the evaporator 58.

[0037] Referring now to Figure 4, a flow chart representing a method 70 for operating an electrically driven two-stage vapor cycle compressor 10 is illustrated according to an embodiment of the present invention. The method 70 may involve a step 71 where a refrigerant vapor 27 having a relatively low pressure and a relatively low temperature is supplied from an evaporator 58 to a two-stage vapor cycle compressor 10. A step 72 may involve compressing the refrigerant vapor 27 in two stages by letting the refrigerant vapor 27 flow through a first stage impeller 20 followed by a first stage diffuser 15 and then through a second stage impeller 21 followed by a second stage diffuser 53. In a step 73 the compressed refrigerant vapor 27, now having a relatively high pressure and a relatively high temperature, may be discharged from the compressor 10 to a condenser 59.

[0038] A step 74 may involve extracting a portion of the refrigerant vapor 27 from the refrigerant vapor 27 entering the second stage impeller 21, and therefore from the inlet to the second stage. In a following step 75, the extracted portion of the refrigerant vapor 27 may flow through and cool a bore 311 of a rotor 31. In a following step 76, the extracted portion of the refrigerant vapor 27 may exit the bore 311 through a washer 39 and may flow over and cool an aft journal bearing 19. A step 77 may involve mixing the extracted portion of the refrigerant vapor 27 with the refrigerant vapor 27 cooling the stator 32 and the rotor 31 of the electric motor 30.

[0039] A step 78 may involve extracting a portion of the refrigerant vapor 27 from the refrigerant vapor 27 exiting the second stage impeller 21, and therefore from the second stage discharge. In a following step 79, the extracted portion of the refrigerant vapor 27 may flow over and cool thrust bearings 17. In a following step 81, the extracted portion of the refrigerant vapor 27 may flow over and cool a forward journal bearing 18. A step 82 may involve mixing the extracted portion of the refrigerant vapor 27 with the refrigerant vapor 27 cooling the stator 32 and the rotor 31 of the electric motor 30.

[0040] A step 83 may involve supplying a liquid refrigerant 28 from the condenser 59 to a cooling jacket 36 of an electric motor 30 that rotates the first stage and second stage impeller 20 and 21, respectively. In a step 84, the liquid refrigerant 28 may heat up from the heat developed by the electric motor 30 while cooling the iron stack 33 and partially cooling the winding 34 of a stator 32 and may change phase taking on vapor form. In a step 85, the refrigerant vapor 27 may continue to flow in the cool-

ing jacket 36 and to cool the stator 32 but may also enter internal motor cavities 29 and may cool the end turns 35 of the winding 34 and the rotor 31. A step 86 may involve mixing the refrigerant vapor 27 cooling the rotor 31 and stator 32 of the electric motor 30 with the extracted portions of the refrigerant vapor 27 coming from the forward journal bearing 18 and from the aft journal bearing 19. In a step 87 the combined refrigerant vapor 27 may continue to cool the stator 32 and the rotor 31. A step 87 may involve discharging the combined refrigerant vapor 27 from the compressor 10 to the evaporator 58.

[0041] Application of method 70 may enable compression of a refrigerant, such as a commercial CFC (chlorofluorocarbons)-free refrigerant, for example, R314a, at a relatively high speed. Method 70 may facilitate cooling the electric motor 30 and the foil bearings 17, 18, and 19 efficiently and with just the right amount of refrigerant vapor 27 to enable rotation of the impellers 20 and 21 of the two-stage vapor cycle compressor 10 at relatively high speed, for example, at about 50,000 rpm and above.

[0042] It should be understood, of course, that the foregoing relates to exemplary embodiments of the invention and that modifications may be made without departing from the spirit and scope of the invention as set forth in the following claims.

Claims

1. A two-stage vapor cycle compressor (10), comprising:

a first stage impeller (20);
 a second stage impeller (21) situated adjacent to said first stage impeller (20);
 an electric motor (30) running on a pair of foil bearings (18, 19), wherein said electric motor (30) drives said first stage (20) and said second stage impeller (21);
 a thrust disk (16) including two foil bearings (17), wherein said thrust disk (16) is positioned between said second stage impeller (21) and said electric motor (30); and
 a compressor housing (40) enclosing said first (20) and second stage impeller (21) and said electric motor (30), wherein said compressor housing (40) forms an internal passageway (26);

wherein said first stage impeller (20) and said second stage impeller (21) compress a refrigerant vapor (27); and
 wherein said refrigerant vapor (27) flows through said passageway (26) and cools said electric motor (30) and said foil bearings (17, 18, 19).

2. The two-stage vapor cycle compressor (10) of claim 1, further including a first stage diffuser (15) integrated into said first stage impeller (20) and a second

stage diffuser (53) integrated into said compressor housing (40), wherein said first stage diffuser (15) includes a diffuser plate (151), and wherein said diffuser plate (151) is also a second stage inlet return channel plate.

3. The two-stage vapor cycle compressor (10) of any one or more claims 1-2, wherein said first stage impeller (20) is a single piece casting, is shrouded, and has a diameter of about two inches, and wherein said second stage impeller (21) is a single piece casting, is shrouded, and has a diameter of about two inches.

4. The two-stage vapor cycle compressor (10) of any one or more claims 1-3, wherein said compressor housing (40) includes:

an inlet housing (41) including a compressor inlet (49);

a scroll housing (42) having a second stage diffuser (53) incorporated within and including a compressor outlet (51), wherein said scroll housing (42) is positioned adjacent to and in direct contact with said inlet housing (41); and
 a motor housing (43) including an inlet port (47) and an outlet port (48), wherein said motor housing (43) is positioned adjacent to said scroll housing (42), and wherein one of said journal bearings (19) is integrated within said motor housing (40);

wherein a single row of bolts (45) connects said inlet housing (41), said scroll housing (42), and said motor housing (43) with each other; and
 wherein each of said inlet housing (41), said scroll housing (42), and said motor housing (43) is a single piece casting.

5. The two-stage vapor cycle compressor (10) of any one or more claims 1-4, further including:

a first stage diffuser (15) and a second stage diffuser (53), wherein said second stage diffuser (53) is incorporated in a scroll housing (42); and
 a first shim (55) and a second shim (54);
 wherein said first shim (55) aligns an exit of said first stage impeller (20) with an inlet of said first stage diffuser (15); and
 wherein said second shim (54) aligns an exit of said second stage impeller (21) with an inlet of said second stage diffuser (53).

6. The two-stage vapor cycle compressor (10) of any one or more claims 1-5, further including four radial seals (22, 23, 24, 25) positioned proximate to an inlet and an outlet of said first stage impeller (20) and said second stage impeller, wherein said radial seal (25)

proximate to said outlet of said second stage impeller (21) is a segmented seal, and wherein said segmented seal supplies said foil bearings (17) included in said thrust disk (16) and a first of said foil bearings (18) said electric motor (30) is running on with a controlled flow (64) of said refrigerant vapor (27). 5

7. The two-stage vapor cycle compressor (10) of any one or more claims 1-6, further including a cooling port (56), wherein said cooling port (56) is positioned proximate to an inlet of said second stage impeller (21), and wherein said cooling port (56) supplies a rotor bore (311) of said electric motor (30) and a second of said foil bearings (19) said electric motor (30) is running on with a controlled flow (66) of said refrigerant vapor (27). 10 15

8. The two-stage vapor cycle compressor (10) of any one or more claims 1-7, further including a plurality of multiple "o"-rings (46), wherein said multiple "o"-rings (46) prevent leakage of said refrigerant vapor (27) from an inside of said compressor (10) an outside of said compressor (10). 20

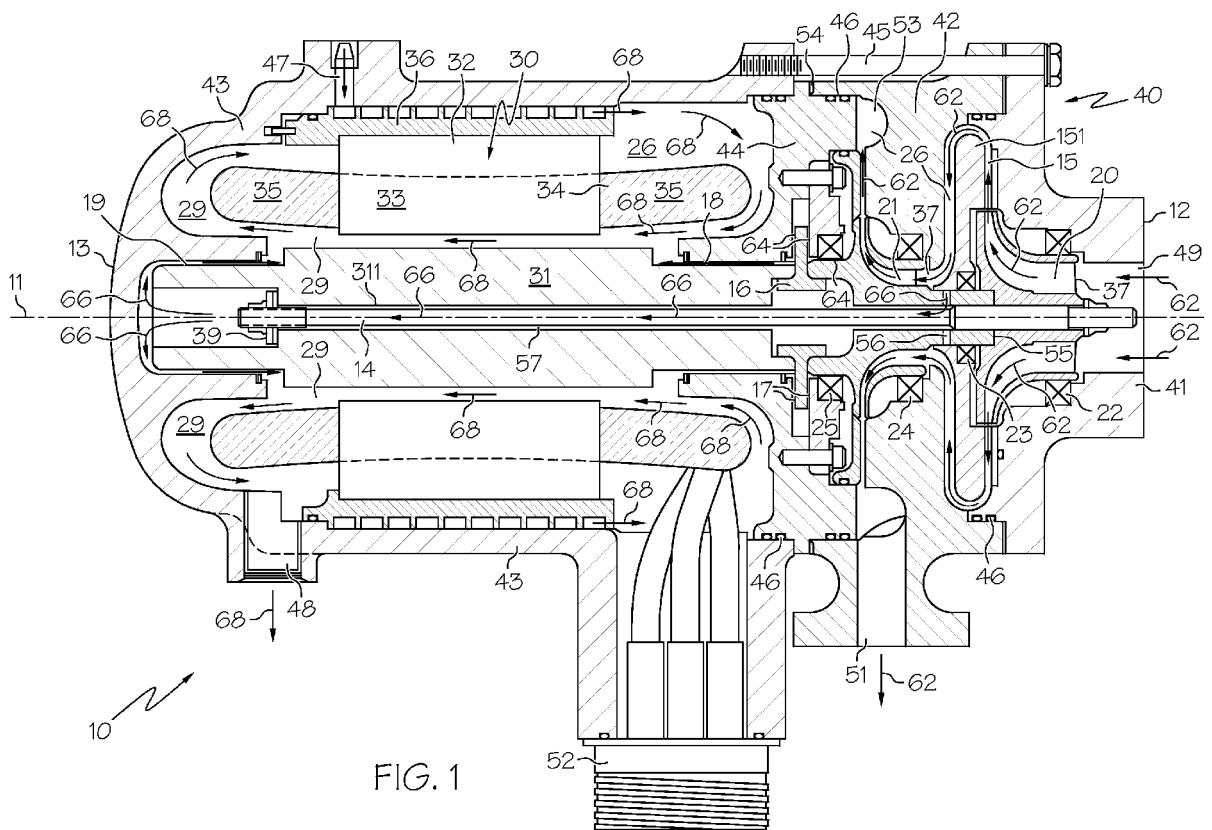
9. The two-stage vapor cycle compressor (10) of any one or more claims 1-8, wherein said electric motor (30) is an alternating current multi-pole permanent magnet electric motor running at speeds above about 50,000 rotations per minute, wherein said electric motor (30) operates sensorless, and wherein electromagnetic field data provide information about the rotational speed and position of said electric motor (30). 25 30

10. The two-stage vapor cycle compressor (10) of any one or more claims 1-9, wherein said compressor (10) is a small and lightweight machine that is gravity insensitive and that withstands environmental conditions of aerospace applications. 35 40

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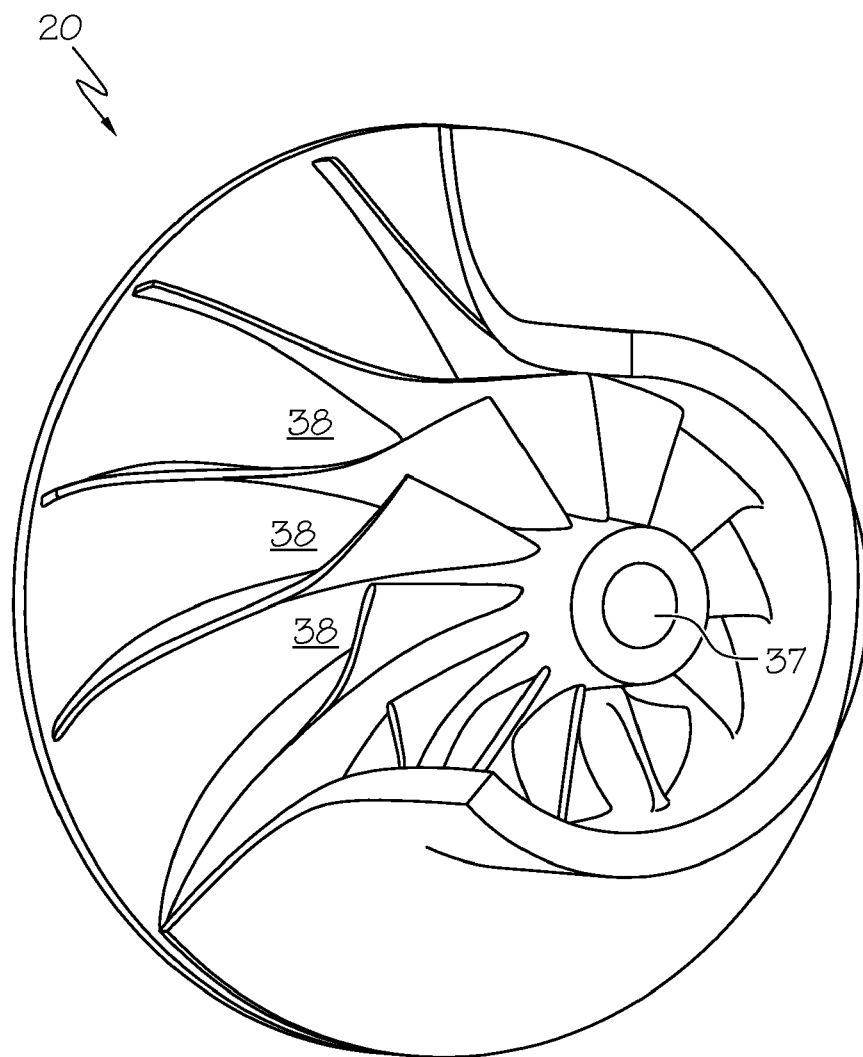


FIG. 2

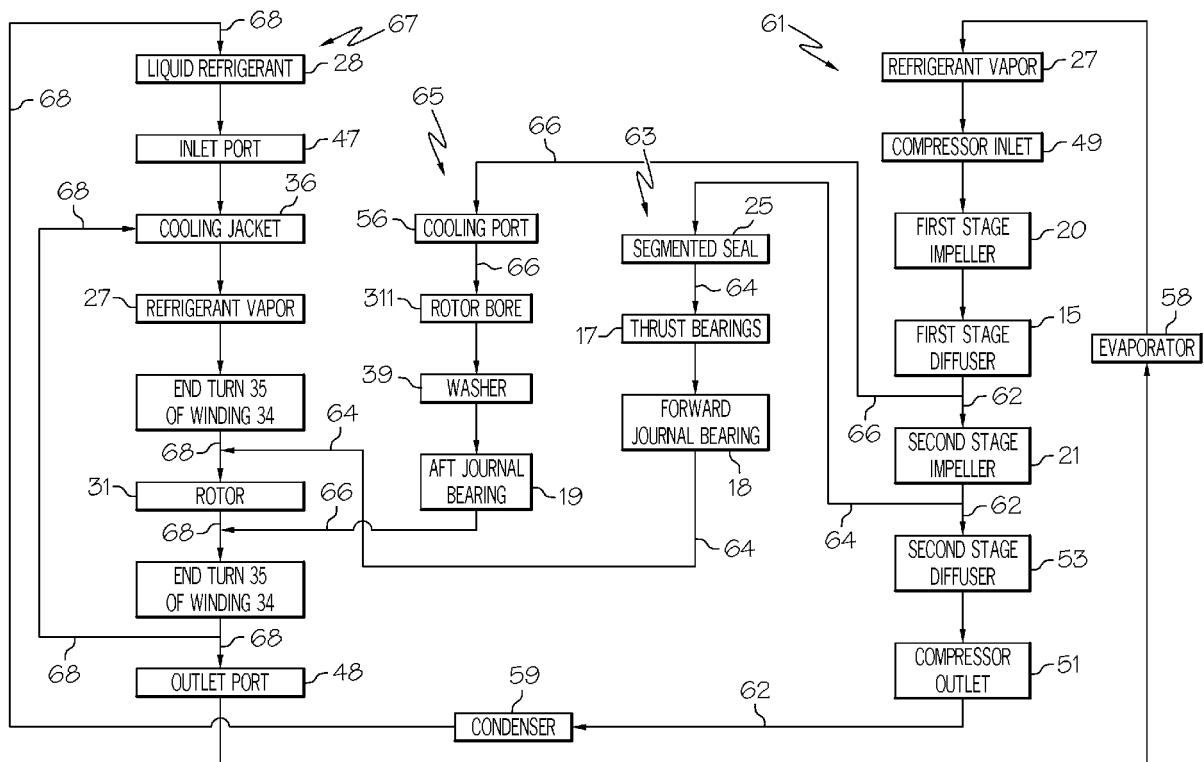


FIG. 3

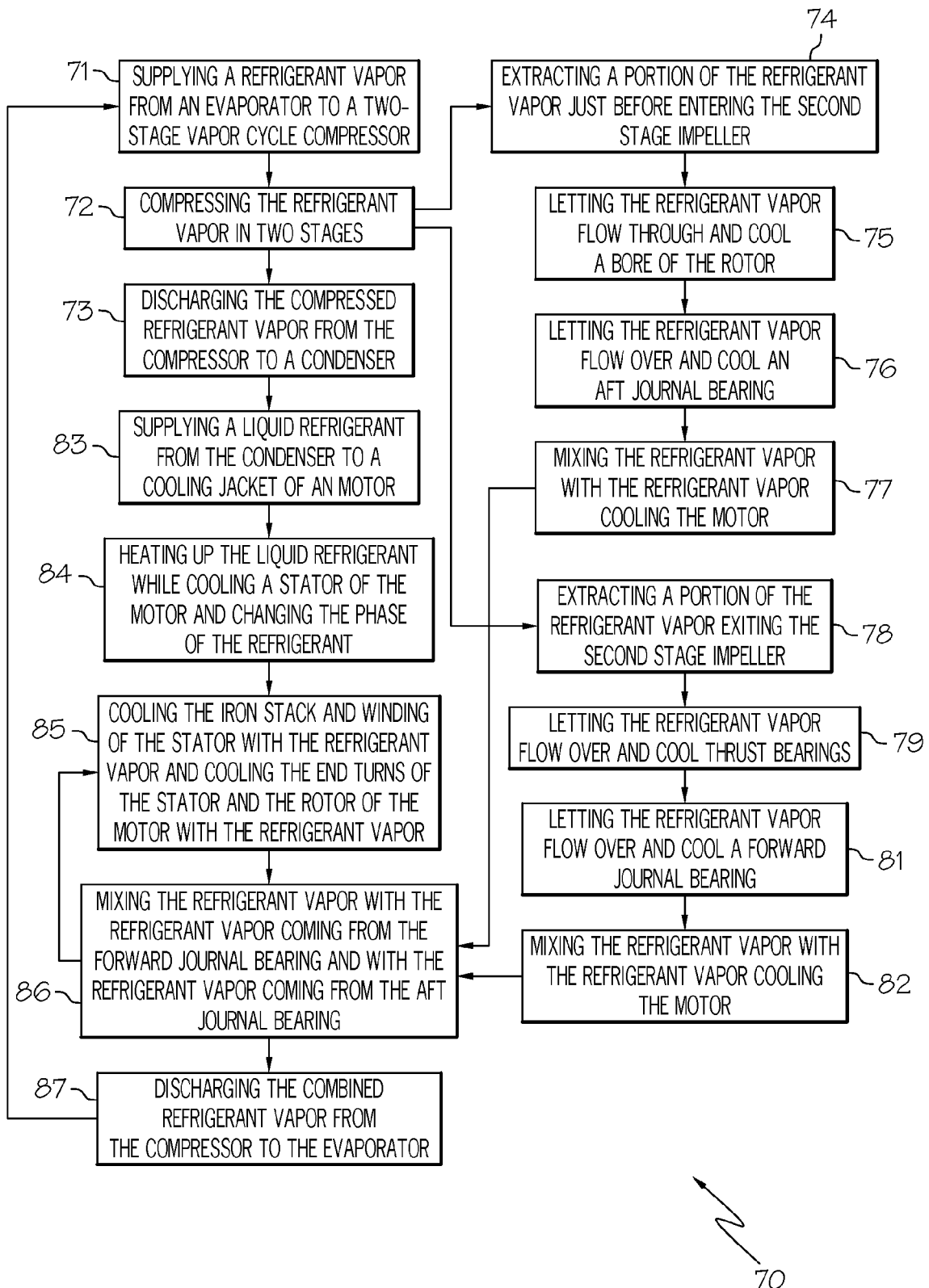


FIG. 4

REFERENCES CITED IN THE DESCRIPTION

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