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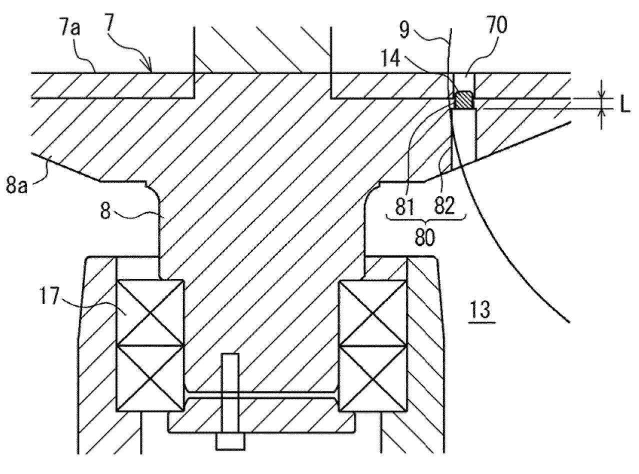
(54) SINGLE-SCREW COMPRESSOR AND REFRIGERATION/AIR-CONDITIONING DEVICE EQUIPPED WITH SAME

(57) A single-screw compressor includes: a casing which forms an outer periphery thereof; a screw including spiral tooth grooves formed in its outer peripheral surface; a gate rotor which defines along with the casing and the screw a compression chamber, and which includes gate-rotor teeth formed to fit in the tooth grooves; and a gate-rotor support which supports the gate rotor, and includes gate-rotor support teeth provided to face the gate-rotor teeth. A gate-rotor hole is formed in at least one of the gate-rotor teeth to extend therethrough in a thickness direction thereof. A support hole is formed in the gate-rotor support teeth to extend through at least one of the gate-rotor support teeth in a thickness direction thereof, and has ends one of which communicates with the gate-rotor hole and the other of which communicates with a low-pressure space provided in the casing. A pin is provided in the support hole in such a way as to be press-fitted therein. The pin comes off the support hole when an internal pressure of the compression chamber is raised to a level, thereby causing the compression chamber to communicate with the low-pressure space.

FIG. 7



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Description

Technical Field

[0001] The present invention relates to a single-screw compressor and a refrigerating and air-conditioning apparatus provided with the single-screw compressor.

Background Art

[0002] A single-screw compressor is known as a type of displacement compressor, and used, for example, as a component of a refrigerant circuit incorporated in a refrigerating and air-conditioning apparatus. In the single-screw compressor, a screw having spiral tooth grooves and a gate rotor having plural gate-rotor teeth which fit in the tooth grooves of the screw are provided in a casing which forms an outer periphery of the compressor. In the single-screw compressor, the tooth grooves of the screw and the teeth of the gate rotor are meshed and engaged with each other, forming a compression chamber.

[0003] In the single-screw compressor, when liquid refrigerant is sucked into the compression chamber, liquid compression occurs, thereby suddenly raising the internal pressure of the compression chamber. In the compression chamber, when liquid refrigerant, which is higher in density than vaporized refrigerant, is sucked into the chamber, the internal pressure thereof rises to a level to which it cannot be raised by gas compression. In the single-screw compressor, generally, the casing and the screw are made, for example, of metal materials such as iron materials, and the gate rotor is made of a synthetic resin material, to thereby avoid metal-to-metal contact between the screw and the gate rotor. Therefore, in the single-screw compressor, the gate rotor of the synthetic resin material having a low material strength can be broken, as a result of which the compressor becomes unable to perform its compression operation, and its operation is stopped.

[0004] Next, it will be briefly described what work is done for restoration of the single-screw compressor in the case where the gate rotor is broken and the operation of the single-screw compressor is thus stopped. First, for a refrigerant circuit which is formed as a closed loop circuit, an operator fully closes stop valves on a high-pressure side and low-pressure side of the single-screw compressor, thereby cutting off the single-screw compressor from the refrigerant circuit, and recovers refrigerant from the single-screw compressor. Next, the operator recovers refrigerating machine oil from the single-screw compressor, detaches the single-screw compressor from a pipe system of the refrigerant circuit, and carries the single-screw compressor to a workshop where maintenance service can be performed safely and efficiently. In the workshop, the operator completely disassembles the single-screw compressor and removes fracture fragments of the gate rotor in the casing. After removing the fracture fragments and reassembling the single-screw compressor, the operator re-sets the single-screw compressor in the refrigerant circuit. The above series of recovery operations require a great deal of time, for which the user is unable to use the refrigerating and air-conditioning apparatus, and further incurs costs as well. This is a big problem for the user.

[0005] Thus, in a screw compressor disclosed in, for example, Patent Literature 1, the internal pressure of the compression chamber is detected using a dedicated detector, it is determined that liquid compression occurs when the detected pressure exceeds a predetermined value, and the position of a slide valve is controlled such that a discharge timing is made earlier, thereby reducing raising of the inner pressure of the compressor.

Citation List

Patent Literature

[0006] Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2010-255595

Summary of Invention

Technical Problem

[0007] In the screw compressor disclosed in Patent Literature 1, in order to reduce the internal pressure of the compression chamber based on a detected value obtained by the dedicated detector, it is necessary to set a sampling frequency of the internal pressure of the compression chamber at a high level for the following reason: The detected value of the internal pressure of the compression chamber, which changes with the passage of time, is compared with a predetermined value, and it is determined that liquid compression occurs when the detected value is greater than the predetermined value. Thus, if the sampling frequency is low, determination of liquid compression is delayed, as a result of which the internal pressure of the compression chamber rises, thus breaking the gate rotor. Therefore, the screw compressor needs a dedicated detector which detects the internal pressure of the compression chamber, and also needs a pressure sensor capable of outputting an electric signal or a control unit which receives the electric signal, and makes a determination. Inevitably, the manufacturing cost of the screw compressor is higher.

[0008] Also, in the screw compressor disclosed in Patent Literature 1, when the detected value exceeds the predetermined value, and it is determined that liquid compression occurs, the position of the slide valve is mechanically adjusted by a dedicated controller. That is, in this screw compressor, from time at time liquid compression occurs and the internal pressure of the compression chamber rises, it takes some time to move the slide valve to a target position. Therefore, after the compressor is in the stopped state for a long time, in the case where sudden liquid compression occurs as in a dormant start, it is hard to reduce raising of the internal pressure of the compression chamber before the gate rotor will be broken.

[0009] The present invention has been made to solve the above problem, and an object of the invention is to provide a single-screw compressor which can reduce raising of the internal pressure of a compression chamber which is caused by liquid compression, and prevent breakage of a gate rotor, and also provide a refrigerating and air-conditioning apparatus provided with the single-screw compressor.

Solution to Problem

[0010] A single-screw compressor according to an embodiment of the present invention includes: a casing which forms an outer periphery of the compressor; a screw including spiral tooth grooves formed in its outer peripheral surface; a gate rotor which defines along with the casing and screw a compression chamber, and which includes a plurality of gate-rotor teeth formed to fit in the tooth grooves; and a gate-rotor support which supports the gate rotor, and includes a plurality of gate-rotor support teeth provided to face the plurality of gate-rotor teeth. In the single-screw compressor, a gate-rotor hole is formed in at least one of the gate-rotor teeth to extend therethrough in a thickness direction thereof; a gate-rotor support hole is formed in at least one of the gate-rotor support teeth to extend therethrough in a thickness direction thereof, and has ends one of which communicates with the gate-rotor hole and the other of which communicates with a low-pressure space provided in the casing; a pin is provided in the gate-rotor support hole in such a way as to be press-fitted therein; and the pin comes off the gate-rotor support hole when an internal pressure of the compression chamber is raised to a level, thereby causing the compression chamber to communicate with the low-pressure space.

Advantageous Effects of Invention

[0011] In the single-screw compressor according to an embodiment of the present invention and a refrigerating and air-conditioning apparatus provided with the single-screw compressor, the pin comes off the gate-rotor support hole when the internal pressure of the compression chamber is raised to a level, thereby causing the compression chamber to communicate with the low-pressure space through the gate-rotor hole and gate-rotor support hole. Therefore, even if the internal pressure of the compression chamber is raised by liquid compression, it is possible to reduce the raising of the internal pressure of the compression chamber and thereby prevent breakage of the gate rotor.

Brief Description of Drawings

[0012]

Fig. 1 is a refrigerant circuit diagram of a refrigerating and air-conditioning apparatus provided with a single-screw compressor according to embodiment 1 of the present invention.

Fig. 2 is a sectional view illustrating an internal structure of the single-screw compressor according to embodiment 1 of the present invention.

Fig. 3 is an enlarged sectional view taken along line A-A in FIG. 2 as seen in the direction indicated by arrows A therein.

Fig. 4 is a plan view illustrating a gate rotor of the single-screw compressor according to embodiment 1 of the present invention.

Fig. 5 is a sectional view taken along line B-B in FIG. 4 as seen in directions indicated by arrows B therein.

Fig. 6 is a sectional view of the gate rotor and a gate-rotor support of the single-screw compressor according to embodiment 1 of the present invention.

Fig. 7 is a sectional view of the gate rotor and gate-rotor support of the single-screw compressor according to embodiment 1 of the present invention with a pin press-fitted in a gate-rotor support hole.

Fig. 8 is a sectional view of a gate rotor and gate-rotor support of a single-screw compressor according to embodiment 2 of the present invention.

Fig. 9 is a sectional view of a gate rotor and gate-rotor support of a single-screw compressor according to embodiment 3 of the present invention.

Fig. 10 is a plan view illustrating a gate rotor of a single-screw compressor according to embodiment 4 of the present invention.

Description of embodiments

[0013] Embodiments of the present invention will be described with reference to the accompanying drawings. It should be noted that in each of the figures, components which are the same as or equivalent to those illustrated in a previous figure or figures are denoted by the same reference signs, and their descriptions will thus be omitted or simplified as appropriate. Also, with respect to the configurations of the elements illustrated in the figures, shapes, sizes, arrangement, etc., can be changed as appropriate within the scope of the present invention.

Embodiment 1

[0014] Fig. 1 is a refrigerant circuit diagram of a refrigerating and air-conditioning apparatus provided with a single-screw compressor according to embodiment 1 of the present invention. The single-screw compressor 1 according to embodiment 1 is used as a component of a refrigerant circuit 200 incorporated in a refrigerating and air-conditioning apparatus 100 as illustrated in Fig. 1. As illustrated in Fig. 1, the refrigerant circuit 200 is configured such that a single-screw compressor 1, a condenser 20, a liquid receiver (not illustrated), an expansion valve 21, an evaporator 22, etc., are sequentially connected by refrigerant pipes, and are provided as a closed loop circuit. The single-screw compressor 1 compresses and discharges refrigerant; the condenser 20 condenses refrigerant; the liquid receiver separates liquid refrigerant and gas refrigerant from each other; the expansion valve 21 decompresses the refrigerant; and the evaporator 22 evaporates the refrigerant. Furthermore, the refrigerating and air-conditioning apparatus 100 includes an inverter not illustrated and a control unit 23 which can communicate with the inverter to receive or send a signal from or to the inverter. The refrigerating and air-conditioning apparatus 100 uses R410 refrigerant, R32 refrigerant, or carbon dioxide refrigerant as refrigerant to be made to flow through the refrigerant circuit 200.

[0015] Fig. 2 is a sectional view illustrating an internal configuration of the single-screw compressor according to embodiment 1 of the present invention. Fig. 3 is an enlarged sectional view taken along line A-A in Fig. 2 as seen in the direction indicated by arrows A. Fig. 4 is a plan view illustrating a gate rotor of the single-screw compressor according to embodiment 1 of the present invention. Fig. 5 is a sectional view taken along line B-B in Fig. 4 as seen in the directions indicated by arrows B. Fig. 6 is a sectional view of the gate rotor and a gate-rotor support of the single-screw compressor according to embodiment 1 of the present invention. Fig. 7 is a sectional view of the gate rotor and gate-rotor support of the single-screw compressor according to embodiment 1 of the present invention with a pin press-fitted in a gate-rotor support hole.

[0016] The single-screw compressor 1 according to embodiment 1 will be described by referring to by way of example a single-stage single-screw compressor; however, it is not limited to the single-stage single-screw compressor, and may be applied as a two-stage single-screw compressor. As illustrated in Figs. 2 and 3, the single-screw compressor 1 according to embodiment 1 includes a cylindrical casing 2 which forms an outer periphery thereof, a compression unit 3 and a drive unit 4 which are provided in the casing 2. In the casing 2, a low-pressure space 13 is provided as space into which low-pressure gas refrigerant flows from the evaporator 22 of the refrigerant circuit 200, and in which low-pressure gas is guided to the compression unit 3.

[0017] As illustrated in Figs. 2 and 3, the compression unit 3 includes a screw 5, a rotation shaft 6, a pair of gate rotors 7 and gate-rotor supports 8. The screw 5 includes a plurality of spiral tooth grooves (screw grooves) formed in a surface of a cylindrical body. The rotation shaft 6 supports the screw 5, and one of shaft end portions of the rotation shaft 6 is roratably supported by a bearing 50 and the other is coupled to the drive unit 4. As illustrated in Fig. 4, the gate rotors 7 each have a plurality of gate-rotor teeth 7a which are formed at an outer periphery thereof to fit in the tooth grooves of the screw 5, and are located to sandwich the screw 5 in a radial direction as illustrated in Figs. 2 and 3. The gate-rotor supports 8 each include a plurality of gate-rotor support teeth 8a which are located to face the plural gate-rotor teeth 7a, and support the gate rotors 7.

[0018] In the compression unit 3, the tooth grooves of the screw 5 and the gate-rotor teeth 7a of the gate rotors 7 are meshed and engaged with each other, thereby forming compression chambers 9. In the single-screw compressor 1, two gate rotors 7 are provided on opposite sides with respect to the single screw 5 at positions separated from each other by 180 degrees in a rotation direction. Thus, two compression chambers 9 are provided on an upper side and lower side of the rotation shaft 6 at positions separated from each other through 180 degrees in the rotation direction.

[0019] As illustrated in Figs. 4 and 5, each of the gate rotors 7 is formed in the shape of a star having eleven gate-rotor teeth 7a. Therefore, each of the gate-rotor supports 8 is also formed in the shape of a star having eleven gate-rotor support teeth 8a, as well as each gate rotor 7. The gate rotor 7 is formed of a synthetic resin material to avoid metal-to-metal contact with the screw 5 formed of a metallic material. The material of the gate rotor 7 is thus lower in material strength than metallic materials. Therefore, in order that the gate rotor 7 be reinforced, the gate rotor 7 is fixed to top surfaces of the gate-rotor support teeth 8a of the gate-rotor support 8 made of a metallic material. Needless to say, the gate-rotor support 8 is provided in such a manner as to avoid metal-to-metal contact between the gate-rotor support teeth 8a and the tooth grooves of the screw 5. It should be noted that as illustrated in Fig. 3, the gate-rotor support 8 includes a shaft portion both ends of which are supported by bearings 16 and 17.

[0020] As illustrated in Figs. 2 and 3, in the single-screw compressor 1, two variable valves 11 are provided in the respective compression chambers 9, and the volume ratios of the variable valves 11 can be varied in order to adjust the discharge timing of refrigerant. As illustrated in Fig. 3, each of the variable valves 11 is rod-shaped to have a section formed in the shape of a crescent, and is slidably provided in space which is shaped by part of the casing 2 that is protruded in the radial direction. Each variable valve 11 has an end face fixed a rod 12, and can be moved parallel to the rotation shaft 6 by moving the rod 12 in an axial direction thereof. The discharge timing of refrigerant sucked into the compression chambers 9 can be adjusted by movement of the variable valves 11 in parallel with the rotation shaft 6. That is, positions of the variable valves 11 are controlled by the control unit 23 for the purpose of adjusting the discharge timing in such a way as to increase an energy efficiency.

[0021] The drive unit 4 includes an electric motor 10. The electric motor 10 is fixed in such a way as to be inscribed in the casing 2, and includes a stator 10a having space in the radial direction and a motor rotor 10b rotatably provided in the stator 10a. The motor rotor 10b is connected to a shaft end of the rotation shaft 6, and is provided coaxially with the screw 5. In the single-screw compressor 1, the electric motor 10 is driven to rotate the rotation shaft 6, thereby rotating the screw 5. It should be noted that the electric motor 10 is driven at a rotation speed which is variable by an inverter not illustrated, to thereby increase or decrease the rotation speed of the rotation shaft 6.

[0022] Next, an operation of the single-screw compressor 1 according to embodiment 1 will be described. When electricity is supplied to the single-screw compressor 1 from the inverter, the electric motor 10 is started. In the single-screw compressor 1, when the electric motor 10 is started, refrigerants having substantially the same mass are sucked into the respective compression chambers 9, and the suction of the refrigerants thereinto is completed at the same timing. In each of the compression chambers 9, after the suction of refrigerant is completed, the volume of each compression chamber 9 is reduced, thus raising the internal pressure thereof. In the single-screw compressor 1, when the volume of each compression chamber 9 is reduced to a set value, the compression chamber 9 is made to communicate with a discharge port by an associated one of the variable valves 11, thus discharging discharge gas. Timings at which the compression chambers 9 are made to discharge the respective refrigerants are adjusted by controlling the respective variable valves 11.

[0023] In the single-screw compressor 1, normally, only refrigerant gas, which is gaseous, is sucked into each compression chamber 9. However, in the single-screw compressor 1, there is a case where two-phase gas-liquid refrigerant returns from the evaporator 22, and liquid refrigerant flows into the single-screw compressor 1. In the single-screw compressor 1, in the case where liquid refrigerant is sucked into the compression chamber 9, liquid compression occurs, thus steeply raising the internal pressure of the compression chamber 9. In the compression chamber 9, the density of the liquid refrigerant sucked therein is higher than that of vaporized refrigerant, and the internal pressure of the chamber is thus raised to a level to which it cannot be raised by gas compression. In the single-screw compressor 1 having the above configuration, the gate rotors 7 made of a synthetic resin which has the lowest material strength among the components of each compression chamber 9 may be broken, and become unable to be operated.

[0024] Next, it will be described how a restoration operation is performed if the gate rotor 7 is broken. In the single-screw compressor 1, there is a case where the gate rotor 7 is broken in the casing 2, and broken fragments of the gate rotor 7 scatter terribly. In this case, it is conceivable that broken fragments of the gate rotor 7 enter the refrigerant circuit 200. It is therefore necessary to wash the pipes in the refrigerant circuit 200. Thus, in order to wash the pipes, another compressor is set. Also, to remove the broken fragments of the gate rotor which are scattered in the single-screw compressor, it is necessary to completely disassemble the single-screw compressor once. Disassembled parts thereof are washed and then reassembled. The assembled single-screw compressor is installed in the washed refrigerant circuit, and a test run of the single-screw compressor is made. In such a manner, in the single-screw compressor, in the case where the gate rotor 7 is broken, it takes long time and much trouble to perform the restoration operation, and the restoration operation incurs a considerably high cost.

[0025] In view of the above, in the single-screw compressor 1 according to embodiment 1, as illustrated in Figs. 4 and 5, a gate-rotor hole 70 is provided to extend through a gate-rotor tooth 7a of the gate-rotor teeth 7a in a thickness direction thereof. Also, as illustrated in Fig. 6, a gate-rotor support hole 80 is provided to extend through a gate-rotor support tooth 8a of the gate-rotor support 8 in a thickness direction of the gate-rotor support tooth 8a, such that one of ends of the gate-rotor support hole 80 communicates with the gate-rotor hole 70, and the other communicates with a low-pressure space 13 provided in the casing 2. The gate-rotor hole 70 and the gate-rotor support hole 80 have circular cross sections, and are located coaxial with each other. However, the gate-rotor hole 70 and gate-rotor support hole 80 are not limited to circular holes, and may be, for example, square holes.

[0026] As illustrated in Fig. 6, the gate-rotor support hole 80 in the gate-rotor support 8 includes a first gate-rotor support hole 81 which communicates with the gate-rotor hole 70 and a second gate-rotor support hole 82 having ends one of which communicates with the first gate-rotor support hole 81 and the other of which communicates with the low-pressure space 13. The first gate-rotor support hole 81 is smaller in diameter than the gate-rotor hole 70. The second gate-rotor support hole 82 is larger in diameter than the first gate-rotor support hole 81. However, the diameters of the first gate-rotor support hole 81 and second gate-rotor support hole 82 are not limited to such diameters as described above.

[0027] As illustrated in Fig. 7, a pin 14 is press-fitted in the first gate-rotor support hole 81. The pin 14 is inserted through the gate-rotor hole 70 in the gate rotor 7, located in such a way as to extend between the gate-rotor hole 70 and the first gate-rotor support hole 81, and press-fitted in the first gate-rotor support hole 81. Therefore, the pin 14 is sized such that an outside diameter of the pin 14 is smaller than an inside diameter of the gate-rotor hole 70, and greater than an inside diameter of the first gate-rotor support hole 81. Because of this configuration, a gap is provided between the pin 14 and the gate-rotor hole 70 to prevent the pin 14, which is formed of a material different from that of the gate rotor 7, from being press-fitted in the gate rotor 7. Also, in addition to the above purpose, for the purpose of minimizing a dead volume space in which a liquid is liable to stay, the pin 14 is provided to extend between the gate-rotor hole 70 and first gate-rotor support hole 81, since the gate-rotor hole 70 provided in the gate rotor 7 becomes such a dead volume space.

[0028] It should be noted that the pin 14 and the gate-rotor support 8 are made of metallic materials having substantially the same coefficient of linear expansion. This is because if the pin 14 and the gate-rotor support 8 have different coefficients of linear expansion, the rates of expansion of the pin 14 and the gate-rotor support 8 are also made to differ from each other under the influence of heat, and a press-fitted state of the pin 14 is lost regardless of the internal pressure of the compression chamber 9, thereby causing the pin 14 to fall off the first gate-rotor support hole 81.

[0029] In the single-screw compressor 1 according to embodiment 1, a contact pressure on an outer peripheral surface of the pin 14, the outside diameter of the pin 14 and a contact width of the pin 14 which is a width of part of the pin 14 that contacts the first gate-rotor support hole 81 are set such that the pin 14 press-fitted in the gate-rotor support 8 will fall off the first gate-rotor support hole 81 vertically downwards because of a target pressure difference in the case where liquid compression occurs and the internal pressure of the compression chamber 9 thus rises.

[0030] Next, a relationship between the outside diameter and height of the pin 14 which is cylindrical and a press-fitting force acts which the pin 14 is press-fitted into the gate-rotor support 8 will be described. Where 2r (mm) is the outside diameter of the pin 14, L (mm) is the contact width of the pin 14, that is, a width of a contact area between an outer periphery of the pin 14 and an inner periphery of the first gate-rotor support hole 81 as illustrated in Fig. 7, and P (MPa) is the contact pressure which is applied onto the outer peripheral surface of the pin 14 when the pin 14 is press-fitted into the first gate-rotor support hole 81, a force F acting on the outer peripheral surface of the pin 14 is expressed by the following equality (1).

[Equality 1]

$$F = P \times 2\pi rL \qquad (1)$$

[0031] Also, where μ is a coefficient of static friction, a static frictional force F' of the pin 14 is expressed by the following equality (2).

[Equality 2]

$$F' = \mu \times F \qquad (2)$$

[0032] Also, where P' (MPa) is the internal pressure of the compression chamber 9 during liquid compression, and Ps (MPa) is a pressure in the low-pressure space 13, a force F" acting on the pin 14 during liquid compression is expressed by the following equality (3).

[Equality 3]

$$F'' = (P' - Ps) \times \pi r^2 \qquad (3)$$

[0033] The condition under which the pin 14 falls off the first gate-rotor support hole 81 during liquid compression is F" > F'. When equalities (1) to (3) are substituted into this inequality and the inequality is rearranged, the following inequality (4) is satisfied.

[Inequality 4]

$$L/r < (P' - Ps)/2\mu P \qquad (4)$$

[0034] Thus, when the radius r (mm) of the pin 14 and the contact width L (mm) are set using inequality (4), the pin 14 falls off the first gate-rotor support hole 81 when the internal pressure of the compression chamber 9 becomes higher than or equal to a target value. That is, in the single-screw compressor 1 according to embodiment 1, the gate rotor 7 and gate-rotor support 8 are processed in such a way as to satisfy inequality (4).

[0035] Also, the refrigerating and air-conditioning apparatus 100 provided with the single-screw compressor 1 according to embodiment 1 as illustrated in Fig. 1 includes a rotation-speed detection unit 24 which detects a rotation speed of the single-screw compressor 1, an opening-degree detection unit 25 which detects an opening degree of the expansion valve 21 and a notification unit 26 which indicates that the pin 14 is located out of the first gate-rotor support holes 81. When the rotation-speed detection unit 24 determines that the above rotation speed reaches a predetermined maximum rotation speed, the control unit 23 determines a difference between an opening degree detected by the opening-degree detection unit 25 at the time when the rotation speed reaches the predetermined maximum rotation speed and a predetermined target opening degree, and determines whether the difference is greater than a target value or not. When determining that the difference is greater than the target value, the control unit 23 determines that the pin 14 is located out of the first gate-rotor support hole 81 and causes the notification unit 26 to make a notification indicating such a fact.

[0036] It should be noted that the control unit 23 incorporates a table of target numbers of pluses of the expansion valve 21 which are determined with respect to the case where the single-screw compressor 1 is operated at a maximum rotation speed, based on condensing temperatures and evaporating temperatures of the refrigerant circuit 200. The control unit 23 incorporates a control program which causes, upon reception of a signal indicating the condensing temperature and evaporating temperature of the refrigerant circuit and the actual number of pulses of the expansion valve 21, which are obtained when the compressor 1 is actually operated at the maximum rotation speed, the control unit 23 to compare the actual number of pulses with a target number of pulses, determine an instruction based on the result of the comparison, and issue a signal.

[0037] In the single-screw compressor 1, when liquid refrigerant is sucked into the compression chamber 9, liquid compression occurs, as a result of which the internal pressure of the compression chamber 9 rises suddenly. In the compression chamber 9, because the density of the liquid refrigerant sucked therein is higher than that of vaporized refrigerant, the internal pressure of the chamber rises to a level to which it cannot be raised by gas compression.

[0038] At this time, because the pressure of the compression chamber 9 acts on an upper end of the pin 14 and that of the low-pressure space 13 acts on a lower end of the pin 14, a force depending on the difference between the pressures of the compression chamber 9 and the low-pressure space 13 acts on the pin in the axial direction thereof. In the single-screw compressor 1 according to embodiment 1, the contact pressure on the outer peripheral surface of the pin, the outside diameter of the pin and the contact width L thereof are set such that the pin 14 press-fitted in the first gate-rotor support hole 81 of each gate-rotor support 8 falls off vertically downwards because of the target pressure difference when the internal pressure of the compression chamber 9 is raised by liquid compression. Thus, since refrigerant is sucked evenly into the two compression chambers 9, when the internal pressure of each of the compression chambers 9 is made to exceeds the target differential pressure by liquid compression, each of the pin 14 in each of the compression chambers 9 falls off.

[0039] Therefore, in the single-screw compressor 1 according to embodiment 1, when the pin 14 falls off, the refrigerant in the compression chamber 9 passes through the gate-rotor hole 70 provided in the gate rotor 7, and flows into the low-pressure space 13 through the gate-rotor support hole 80 in the gate-rotor support 8. Thus, when the internal pressure of the compression chamber 9 is raised by liquid compression, the pin 14 is made to come off the first gate-rotor support hole 81 by a stress smaller than the destruction strength of the gate rotor 7, thus causing the compression chamber 9 to communicate with the low-pressure space 13 and thereby distributing the internal pressure of the compression chamber 9 to the low-pressure space 13, as a result of which the internal pressure of the compression chambers 9 is reduced. Accordingly, it is possible to prevent raising of the internal pressure of the compression chamber 9 and thus prevent breakage of the gate rotor 7.

[0040] In the single-screw compressor 1 according to embodiment 1, when the pin 14 is located out of the first gate-rotor support hole 81, the compression chamber 9 continuously communicates with the low-pressure space 13 through the gate-rotor support 8. Thus, in the single-screw compressor 1, the refrigerant sucked into the compression chamber 9 continuously leaks therefrom a low-pressure side, and a refrigeration capacity is reduced lower than before the pin 14 comes off, under the same condition in which the single-screw compressor 1 is operated at the same high/low pressure or at the same rotation speed.

[0041] In the single-screw compressor 1, as described above, when the pin 14 comes off, the compression chamber 9 and the low-pressure space 13 communicate with each other, as a result of which the refrigerant in the compression chamber 9 leaks therefrom to the low-pressure space 13. In the single-screw compressor 1, because a circulation rate of discharged refrigerant is reduced, the control unit 23 transmits to the inverter a signal instructing the inverter to increase the speed thereof, in order to make up for an insufficient refrigeration capacity. The single-screw compressor 1 gradually increases the rotation speed thereof, and then if it is repeatedly determined in the control program that the refrigeration capacity is insufficient, the rotation speed is eventually increased to the maximum rotation speed. When the rotation speed of the single-screw compressor 1 is set to the maximum rotation speed, the control unit 23 receives the actual number of pulses of the expansion valve 21 at the time when the rotation speed is set to the maximum rotation speed, and compares the actual number of pulses with the target number of pulses. When determining that the difference between the actual number of pulses and the target number of pulses is greater than a target value, the control unit 23 determines that the pin 14 comes off, and causes the notification unit 26 to issue an alarm. Upon reception of the alarm from the notification unit 26, the operator can recognize that the single-screw compressor 1 needs to be inspected.

[0042] If receiving the alarm, the operator causes the operation of the single-screw compressor 1 to be stopped once. Next, the operator fully closes a discharge-side stop valve 27 and suction-side stop valve 28 of the single-screw compressor 1, thereby dividing the refrigerant circuit 200, which is provided as the closed loop circuit, into two. The operator recovers only the refrigerant in the single-screw compressor 1, and removes oil from the refrigerant. Then, the operator removes assemblies of the gate rotor 7 and gate-rotor support 8 from the single-screw compressor 1, and replaces the assemblies with new ones.

[0043] It should be noted that the refrigerating and air-conditioning apparatus 100 provided with the single-screw compressor of embodiment 1 may be configured to stop driving of the single-screw compressor 1 when the pins14 comes off the first gate-rotor support hole 81, and thereby prevent reduction of the refrigeration capacity. Specifically, when the rotation-speed detection unit 24 determines that the rotation speed reaches the predetermined maximum rotation speed, the control unit 23 determines the difference between the opening degree detected by the opening-degree detection unit 25 and the predetermined target opening degree, and determines whether the difference is greater than the target value or not. When determining that the difference is greater than the target value, the control unit 23 determines that the pin 14 comes off the first gate-rotor support hole 81, and causes driving of the single-screw compressor 1 to be stopped.

[0044] In such a manner, in the single-screw compressor 1 according to embodiment 1, the pin 14 comes off the first gate-rotor support hole 81 when the internal pressure of the compression chambers 9 is raised to a level, thereby causing the gate-rotor hole 70 to communicate with a flow-passage hole 83. Thus, even if sudden liquid compression occurs as in a dormant start, and the internal pressure of the compression chambers 9 thus rises to a level to which it cannot be raised by normal gas compression, the compression chamber 9 and the low-pressure space 13 can be made to communicate with each other through the gate-rotor hole 70 and gate-rotor support hole 80. Thus, in the single-screw compressor 1, since the gate-rotor hole 70 and gate-rotor support hole 80 function as bypass holes, it is possible to prevent raising of the internal pressure of the compression chamber 9, and thus prevent breakage of the gate rotor 7, and cause the compression operation to be satisfactorily performed.

[0045] Also, the single-screw compressor 1 according to embodiment 1 is more advantageous in the case where R410 refrigerant, R32 refrigerant, or carbon dioxide refrigerant, which tends to cause, especially, the internal pressure of the compression chambers 9 to be raised, are used as refrigerant for use in the refrigerant circuit.

[0046] Also, in the single-screw compressor 1 of embodiment 1, since the pin 14 and gate-rotor support 8 are made of materials having substantially the same coefficient of linear expansion, it is possible to prevent the press-fitted state of the pin 14 from being lost by the influence of heat, and thus prevent the pin 14 from falling off the first gate-rotor support hole 81.

[0047] Also, in the refrigerating and air-conditioning apparatus 100 provided with the single-screw compressor 1 according to embodiment 1, when the rotation-speed detection unit 24 determines that the rotation speed reaches the predetermined maximum rotation speed, the control unit 23 determines the difference between the opening degree detected by the opening-degree detection unit 25 and the predetermined opening degree. When determining that the difference is greater than the target value, the control unit 23 determines that the pin 14 is located out of the first gate-rotor support hole 81 and causes the notification unit 26 to give an alarm. Thus, upon reception of the alarm from the notification unit 26, the operator can recognize that the single-screw compressor 1 needs to be inspected, and request maintenance services to restore the single-screw compressor 1.

[0048] Also, in the refrigerating and air-conditioning apparatus 100 provided with the single-screw compressor 1 according to embodiment 1, when the rotation-speed detection unit 24 determines that the rotation speeds reaches the predetermined maximum rotation speed, the control unit 23 determines the difference between the opening degree detected by the opening-degree detection unit 25 and the predetermined target opening degree. When determining that the difference is greater than the target value, the control unit 23 determines that the pin 14 is located out of the first gate-rotor support holes 81, and stops driving of the single-screw compressor 1. Then, the operator can request maintenance services to restore the single-screw compressor 1.

[0049] It should be noted that the single-screw compressor 1 according to embodiment 1c can also be put to practical use as a single-gate-rotor type of compressor in which a single gate rotor 7 is provided for a single screw 5, though a detailed illustration of such a type of compressor is omitted. The present invention can achieve the same operations and the same advantages as stated above, even in the case where it is applied to a single-gate-rotor type of single-screw compressor.

Embodiment 2

[0050] Next, a single-screw compressor according to embodiment 2 of the present invention will be described with reference to Fig. 8. Fig. 8 is a sectional view of a gate rotor and a gate-rotor support of the single-screw compressor according to embodiment 2 of the present invention. It should be noted that components which are the same as those of the single-screw compressor 1 according to embodiment 1 will be denoted by the same reference signs, and their descriptions will thus be omitted as appropriate.

[0051] As illustrated in Fig. 8, in addition to the components of embodiment 1 as described above, the single-screw compressor 1 according to embodiment 2 has the following configuration: a flow-passage hole 83 which causes the low-pressure space 13 and the second gate-rotor support hole 82 to communicate with each other is formed in the gate-rotor support tooth 8a. Furthermore, a plug 15 is fitted in the second gate-rotor support hole 82 to close it.

[0052] The flow-passage hole 83 is formed to extend from a side face of the gate-rotor support tooth 8a and intersect the second gate-rotor support hole 82. Preferably, a cross-sectional inside diameter of the flow-passage hole 83 should be set slightly smaller than the inside diameter of the first gate-rotor support hole 81. This is because if the pin 14 falls off the first gate-rotor support hole 81, it can be caught by the flow-passage hole 83 and held in the gate-rotor support 8 to prevent the pin 14 from jumping out of the gate-rotor support 8. The pin 14 that has come off is recovered later.

[0053] The plug 15 is provided to hold the pin 14 in the gate-rotor support 8 in order to prevent the pin 14 which has come off because of the internal pressure of the compression chamber 9 from being falling out of the gate-rotor support 8 and jumping out vertically downwards. The plug 15 is fixed to the inside of the second gate-rotor support hole 82 by press fitting, shrink fitting, welding or the like. Also, the plug 15 may be provided with a screwed outer peripheral surface such that it can be screwed into a screw groove formed in an inner peripheral surface of the second gate-rotor support hole 82. It should be noted that the plug 15 does not need to be provided in the case where there is provided another structure for preventing the pin 14 from coming off the gate-rotor support 8, such as a structure for holding the pin 14 using the flow-passage hole 83 as described above.

[0054] In the single-screw compressor 1 according to embodiment 2, when the pin 14 comes off the first gate-rotor support hole 81, the refrigerant in the compression chamber 9 flows through the gate-rotor hole 70 provided in the gate rotor 7 into the gate-rotor support hole 80 in the gate-rotor support 8, flows into the flow-passage hole 83 from the gate-rotor support hole 80, and then flows into the low-pressure space 13. Thus, when the internal pressure of the compression chambers 9 is raised by liquid compression, the pin 14 is made to come off the first gate-rotor support hole 81 by a stress acting thereon that is smaller than a destruction strength of the gate rotor 7, thus causing the compression chamber 9 to communicate with the low-pressure space 13. It is therefore possible to reduce the internal pressure of the compression chambers 9 since it is distributed to the low-pressure space 13, and prevent raising of the internal pressure of the compression chamber 9 and thereby prevent breakage of the gate rotor 7.

[0055] Furthermore, in the single-screw compressor 1 according to embodiment 2, since the plug 15 is fitted in the second gate-rotor support hole 82 to close it, the pin 14 which has coming off the first gate-rotor support hole 81 can be prevented from jumping out of the gate-rotor support 8. The pin 14 having come off the first gate-rotor support hole 81 can be recovered later.

Embodiment 3

[0056] A single-screw compressor according to embodiment 3 of the present invention will be described with reference to Fig. 9. Fig. 9 is a sectional view of a gate rotor and a gate-rotor support of the single-screw compressor according to embodiment 3 of the present invention. It should be noted that although the single-screw compressor according to embodiment 3 as illustrated in Fig. 9 is based on the configuration of the single-screw compressor described in embodiment 2, this is not restrictive, and the single-screw compressor according to embodiment 3 is also applicable to the single-screw compressor 1 according to embodiment 1. It should be noted that components which are the same as those of the single-screw compressors according to embodiments 1 and 2 will be denoted by the same reference numerals, and their descriptions will thus be omitted as appropriate.

[0057] In the single-screw compressor according to embodiment 3, as illustrated in Fig. 9, the gate-rotor hole 70 includes a first gate-rotor hole 71 and a second gate-rotor hole 72. The first gate-rotor hole 71 is formed in part of the gate rotor 7 that is located close to the compression chamber 9; and the second gate-rotor hole 72 has a greater diameter than that of the first rotor hole 71, and one of ends of the second gate-rotor hole 72 communicates with the first gate-rotor hole 71 and the other communicates with the gate-rotor support hole 80.

[0058] In single-screw compressors, since part of the gate-rotor hole 70 which is close to the compression chamber 9 becomes a dead volume in which a liquid is liable to stay, an energy efficiency is slightly reduced. Thus, in the single-screw compressor according to embodiment 3, the gate-rotor hole 70 is formed to include the first gate-rotor hole 71 and the second gate-rotor hole 72, and the first gate-rotor hole 71 is made smaller in diameter than the second gate-rotor hole 72, whereby the dead volume can be reduced.

Embodiment 4

[0059] Next, a single-screw compressor according to embodiment 4 of the present invention will be described with reference to Fig. 10. Fig. 10 is a plan view illustrating a gate rotor of the single-screw compressor according to embodiment 4 of the present invention. It should be noted that components which are same as those of the single-screw compressors according to embodiments 1 to 3 will be denoted by the same reference numerals, and their descriptions will thus be omitted as appropriate.

[0060] As illustrated in Fig. 10, in the single-screw compressor according to embodiment 4, all the gate-rotor teeth 7a include respective rotor holes 70 which extend therethrough in the thickness direction of the teeth, and all the gate-rotor support teeth 8a include respective gate-rotor support holes 80 which extend therethough in the thickness direction of the teeth to communication with the gate-rotor holes 70. As illustrated in Fig. 10, in the case where each of the gate-rotor supports 8 has eleven teeth, pins 14 are press-fitted in first gate-rotor support holes 81 of each gate-rotor support 8.

[0061] Therefore, in the single-screw compressor according to embodiment 4, the area of the flow passage which extends from the compressor 9 to the low-pressure space 13 can be set greater than those of the single-screw compressors according to embodiments 1 to 3. Therefore, even if liquid compression occurs, and the internal pressure of the compression chambers 9 is raised thereby, the raising of the compression chambers 9 can be further reduced. Thus, the single-screw compressor according to embodiment 4 can further effectively prevent breakage of the gate rotor 7.

[0062] The present invention is described above by referring to the above embodiments, but the present invention is not limited to the above configurations of the embodiments. For example, the refrigerant circuit 200 as illustrated in Fig. 1 may be formed to include other components. Furthermore, although it is preferable that R410 refrigerant, R32 refrigerant, or carbon dioxide refrigerant be used as refrigerant to be made to flow through the refrigerant circuit 200, another refrigerant may be used. That is, it should be noted, just for the record, that various changes, applications and usage, which are made by a person with ordinary skill in the art as appropriate, fall within the scope (technical scope) of the present invention.

Reference Signs List

[0063]

1 single-screw compressor 2 casing 3 compression unit 4 drive unit 5 screw 6 rotation shaft 7 gate rotor 7a gate-rotor tooth 8 gate-rotor support 8a gate-rotor support tooth 9 compression chamber
10 electric motor 10a stator 10b motor rotor 11 variable valve 12 rod 13 low-pressure space 14 pin 15 plug 16, 17 bearing 20 condenser 21 expansion valve 22 evaporator 23 control unit 24 rotation-speed detection unit 25 opening-degree detection unit 26 notification unit 27 discharge-side stop valve 28 suction-side stop valve 50 bearing 70 gate-rotor hole 71 first gate-rotor hole
72 second gate-rotor hole 80 gate-rotor support hole 81 first gate-rotor support hole 82 second gate-rotor support hole 83 flow-passage hole
100 refrigerating and air-conditioning apparatus 200 refrigerant circuit

Claims

1. A single-screw compressor comprising:

a casing forming an outer periphery of the single-screw compressor;
a screw including a plurality of spiral tooth grooves formed in an outer peripheral surface of the screw;
a gate rotor including a plurality of gate-rotor teeth formed to fit in the tooth grooves, the gate rotor defining along with the casing and the screw a compression chamber; and
a gate-rotor support configured to support the gate rotor, the gate-rotor support including a plurality of gate-rotor support teeth provided to face the plurality of gate-rotor teeth,
wherein a gate-rotor hole is formed in at least one of the gate-rotor teeth to extend through the at least one of the gate-rotor teeth in a thickness direction thereof,
a gate-rotor support hole is formed in at least one of the gate-rotor support teeth to extend through the at least one of the gate-rotor support teeth in a thickness direction thereof, the gate-rotor support hole having ends one of which communicates with the gate-rotor hole, and another one of which communicates with a low-pressure space provided in the casing,
a pin is press-fitted in the gate-rotor support hole, and
the pin is set to come off the gate-rotor support hole when an internal pressure of the compression chamber is raised to a level, thereby causing the compression chamber to communicate with the low-pressure space.

2. The single-screw compressor of claim 1, wherein: the gate-rotor support hole includes:

a first gate-rotor support hole having a smaller diameter than that of the gate-rotor hole and communicating with the gate-rotor hole, and
a second gate-rotor support hole having a greater diameter than that of the first gate-rotor support hole, and having ends one of which communicates with the first gate-rotor support hole and another one of which communicates with the low-pressure space; and
the pin is press-fitted in the first gate-rotor support hole.

3. The single-screw compressor of claim 2, wherein a flow-passage hole is provided in at least one of the gate-rotor support teeth to cause the low-pressure space and the second gate-rotor support hole to communicate with each other through the flow-passage hole.

4. The single-screw compressor of claim 3, wherein:

a plug is fitted in the second gate-rotor support hole to close the second gate-rotor support hole; and
the flow-passage hole is provided to cause part of the second gate-rotor support hole which is located between the pin and the plug to communicate with the low-pressure space.

5. The single-screw compressor of any one of claims 1 to 4, wherein the pin and the gate-rotor support are formed of metallic materials having a same coefficient of linear expansion.

6. The single-screw compressor of any one of claims 1 to 5, wherein the gate-rotor hole includes:

a first gate-rotor hole formed in part of the gate rotor which is located close to the compression chamber; and
a second gate-rotor hole having a greater diameter than that of the first gate-rotor hole, and having ends one of which communicates with the first gate-rotor hole and another end of which communicates with the gate-rotor support hole.

7. A refrigerating and air-conditioning apparatus comprising:

a refrigerant circuit in which the single-screw

compressor of any one of claims 1 to 6, a condenser, an expansion valve and an evaporator are sequentially connected by refrigerant pipes; and
a control unit configured to control driving of the single-screw compressor.

8. The refrigerating and air-conditioning apparatus of claim 7, further comprising:

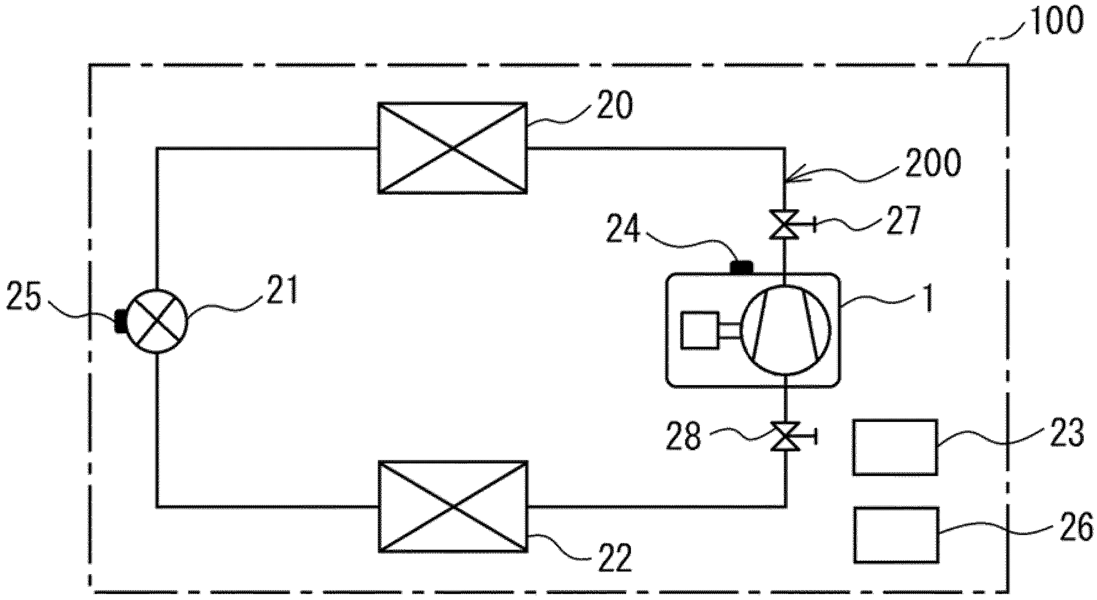
a rotation-speed detection unit configured to detect a rotation speed of the single-screw compressor;
an opening-degree detection unit configured to detect an opening degree of the expansion valve; and
a notification unit configured to make a notification indicating that the pin is located out of the gate-rotor support hole,
wherein when the rotation-speed detection unit determines that the rotation speed reaches a predetermined maximum rotation speed, the control unit determines a difference between the opening degree detected by the opening-degree detection unit and a predetermined target opening degree, and when determining that the difference greater than a target value, the control unit determines that the pin is located out of the gate-rotor support hole, and causes the notification unit to make the notification.

9. The refrigerating and air-conditioning apparatus of claim 7, further comprising:

a rotation-speed detection unit configured to detect a rotation speed of the single-screw compressor; and
an opening-degree detection unit configured to detect an opening degree of the expansion valve,
wherein when the rotation-speed detection unit determines that the rotation speed reaches a predetermined maximum rotation speed, the control unit determines a difference between the opening degree detected by the opening-degree detection unit and a predetermined target opening degree, and when determining that the difference is greater than a target value, the control unit determines that the pin is located out of the gate-rotor support hole, and causes driving of the single-screw compressor to be stopped.

10. The refrigerating and air-conditioning apparatus of any one of claims 7 to 9, wherein R410 refrigerant, R32 refrigerant or carbon dioxide refrigerant is used as refrigerant to be made to flow in the refrigerant circuit.

FIG. 1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200
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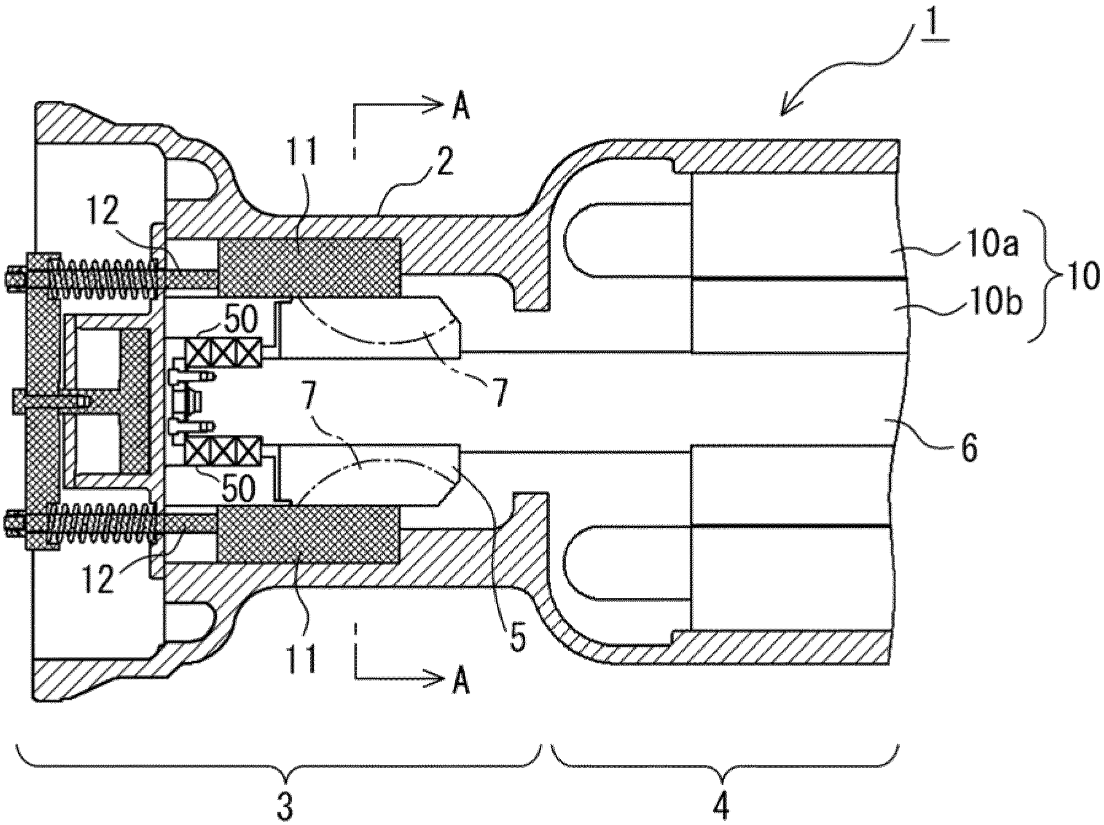
28
23
22
26

FIG. 2


1
A
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2
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10b
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7
7
6
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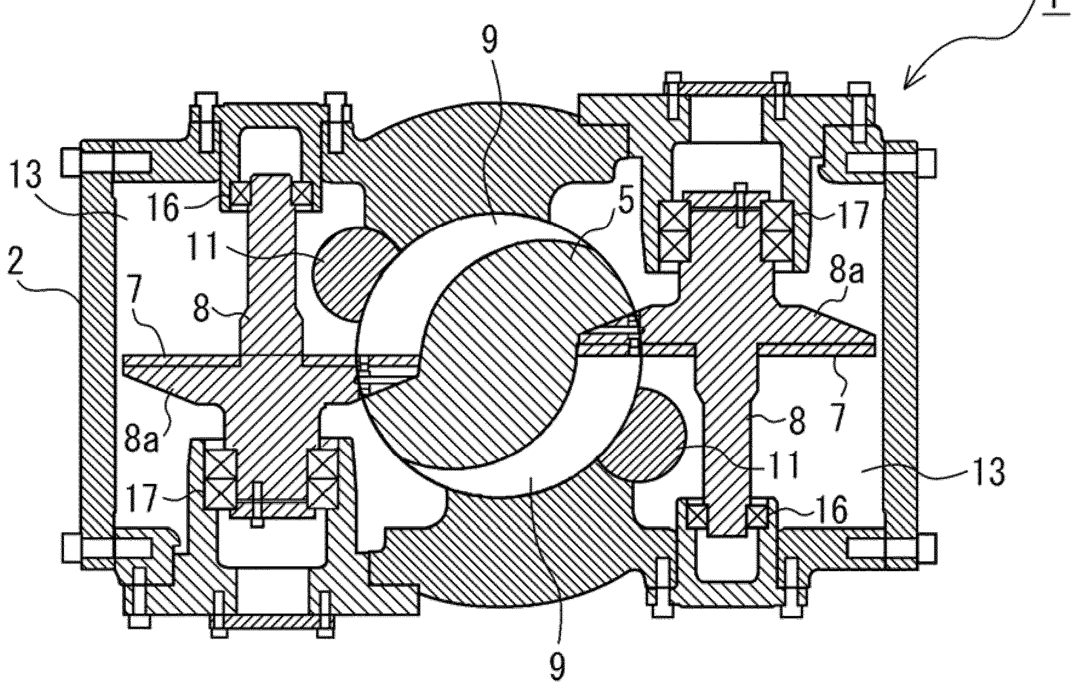
5
A
3
4

FIG. 3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8a
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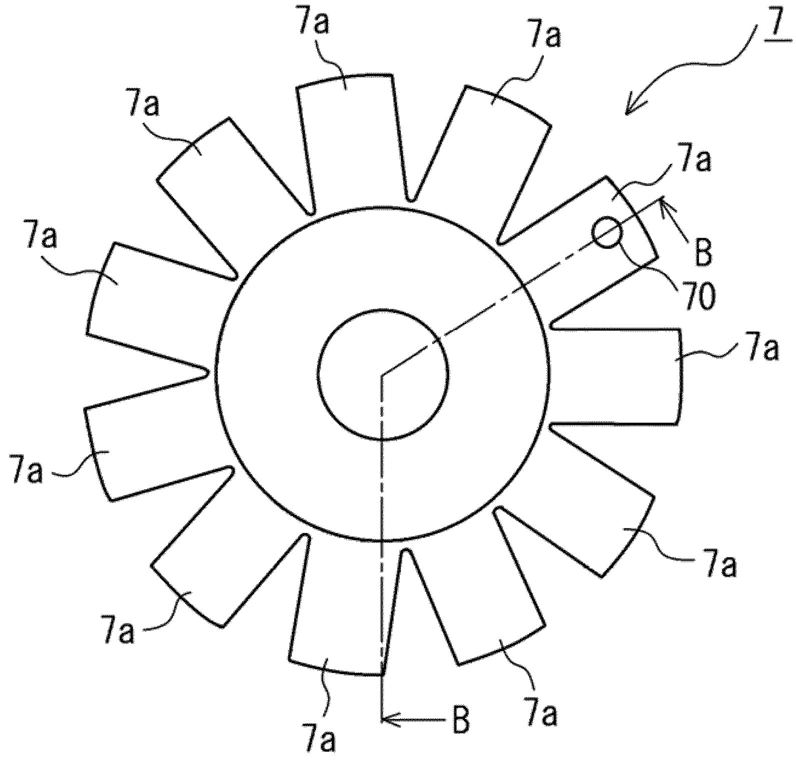
9

FIG. 4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7a
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B

FIG. 5

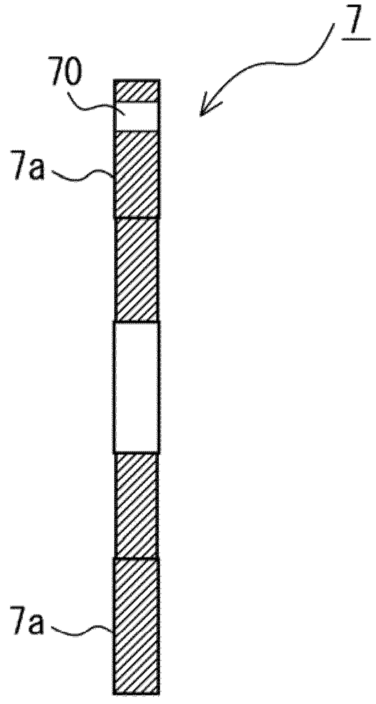


FIG. 6

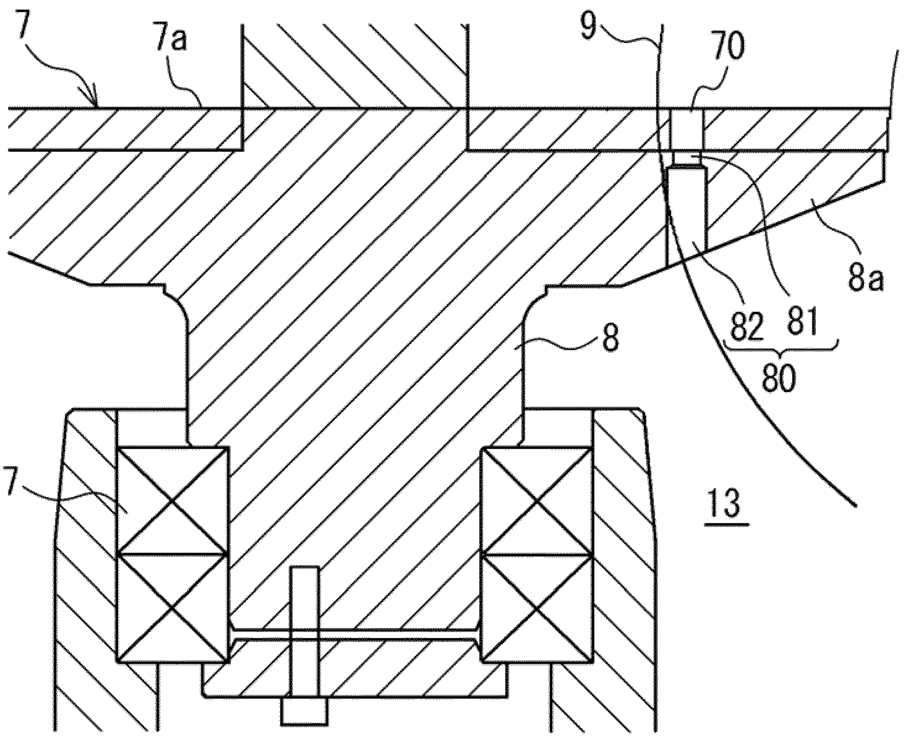


FIG. 7

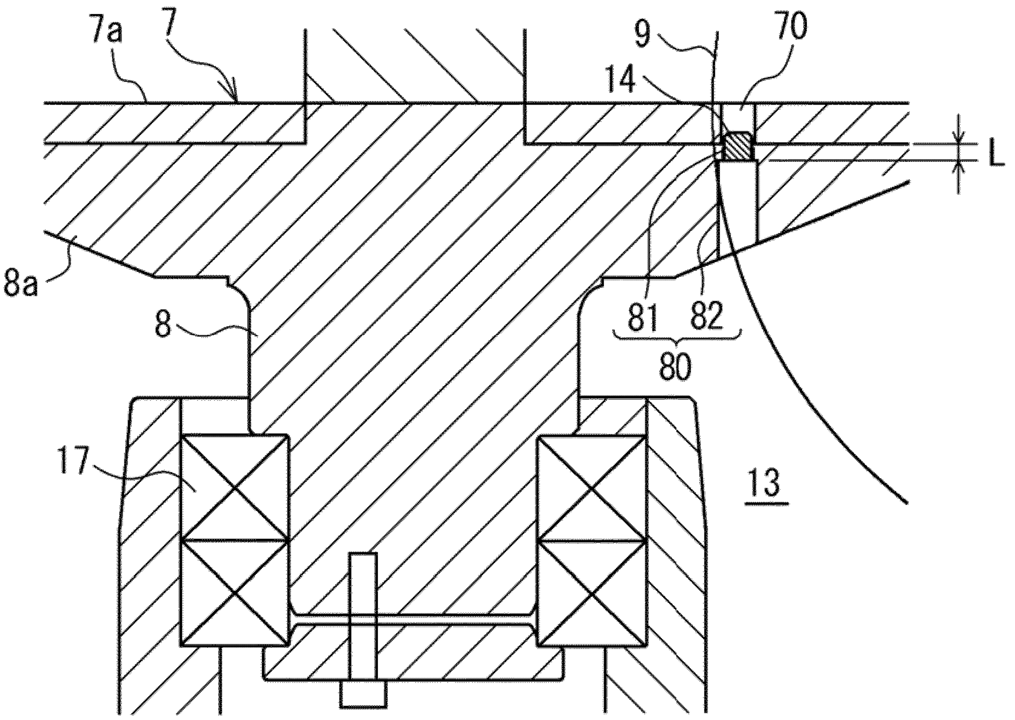


FIG. 8

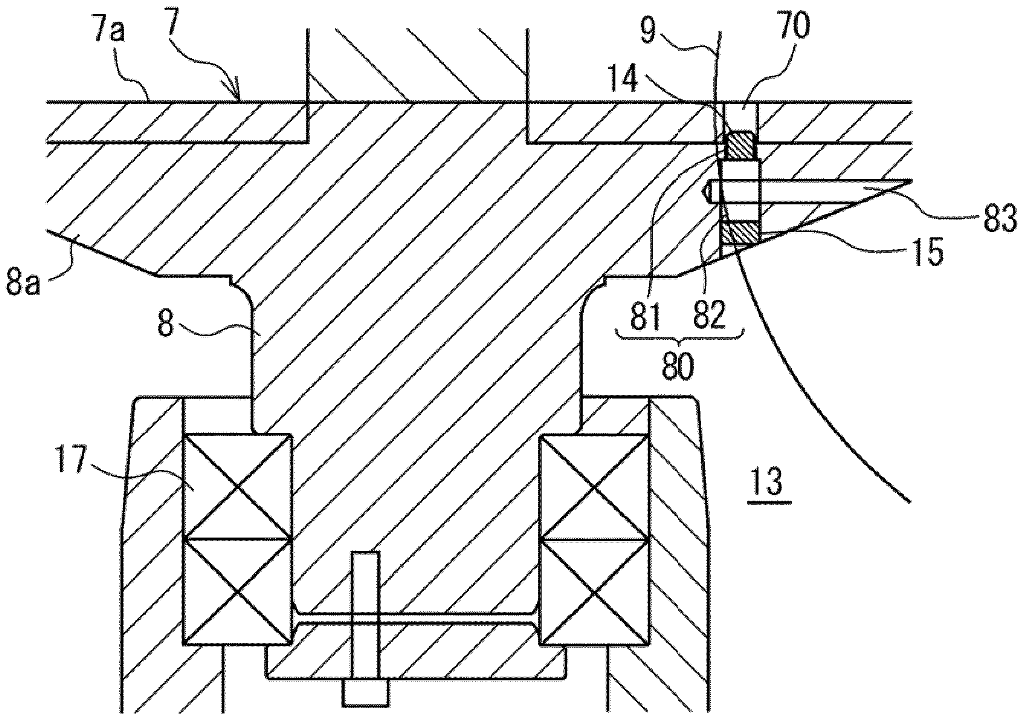


FIG. 9

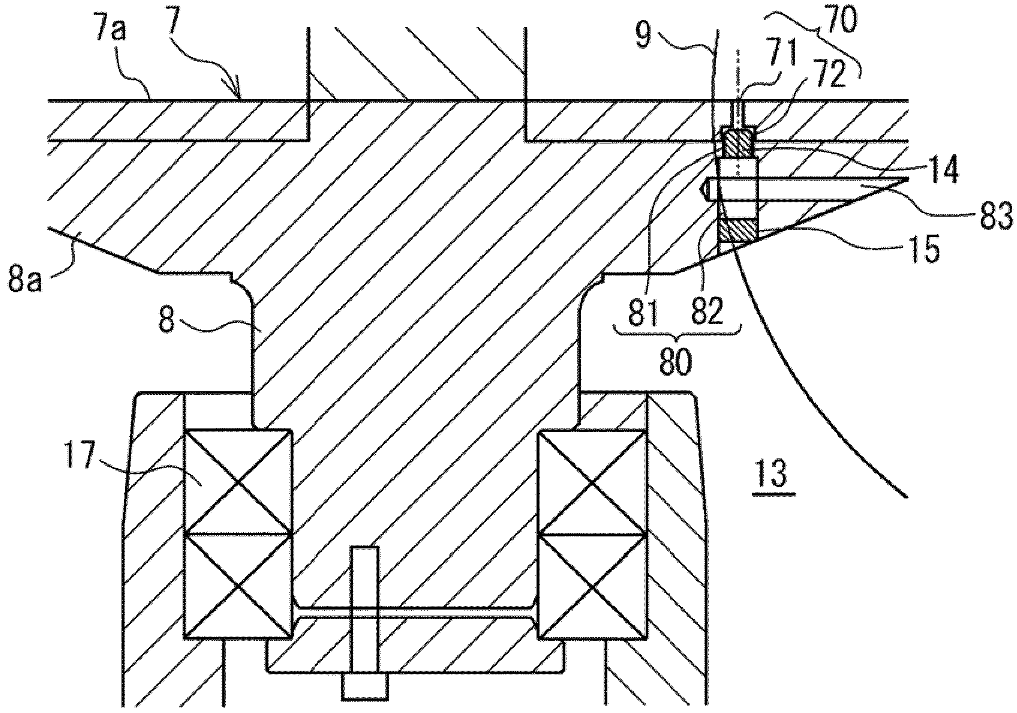
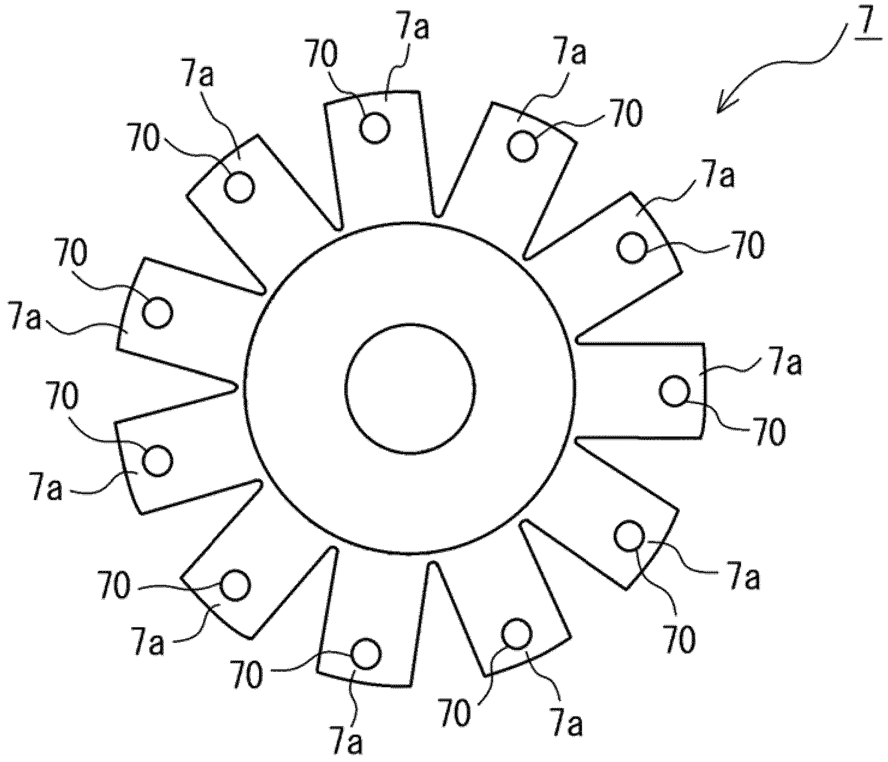


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2016/087743

A. CLASSIFICATION OF SUBJECT MATTER
F04C18/52(2006.01)i

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)
F04C18/52

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2017
Kokai Jitsuyo Shinan Koho	1971-2017	Toroku Jitsuyo Shinan Koho	1994-2017

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.
A	JP 2009-174520 A (Daikin Industries, Ltd.), 06 August 2009 (06.08.2009), paragraphs [0047] to [0068]; fig. 1, 7 & US 2011/0165009 A1 paragraphs [0107] to [0128]; fig. 1, 7 & WO 2009/081962 A1 & EP 2236832 A1 & CN 101918716 A	1-10
A	JP 2016-17438 A (Daikin Industries, Ltd.), 01 February 2016 (01.02.2016), paragraphs [0051] to [0059]; fig. 3 to 5 (Family: none)	1-10

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

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"&" document member of the same patent family

Date of the actual completion of the international search 22 February 2017 (22.02.17)	Date of mailing of the international search report 07 March 2017 (07.03.17)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/087743

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 62-214293 A (Ebara Corp.), 21 September 1987 (21.09.1987), page 2, upper right column, line 17 to lower left column, line 20; fig. 1 to 2 (Family: none)	1-10

Form PCT/ISA/210 (continuation of second sheet) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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