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(71) Applicant: **Sumitomo Heavy Industries, Ltd.**
Tokyo 141-6025 (JP)

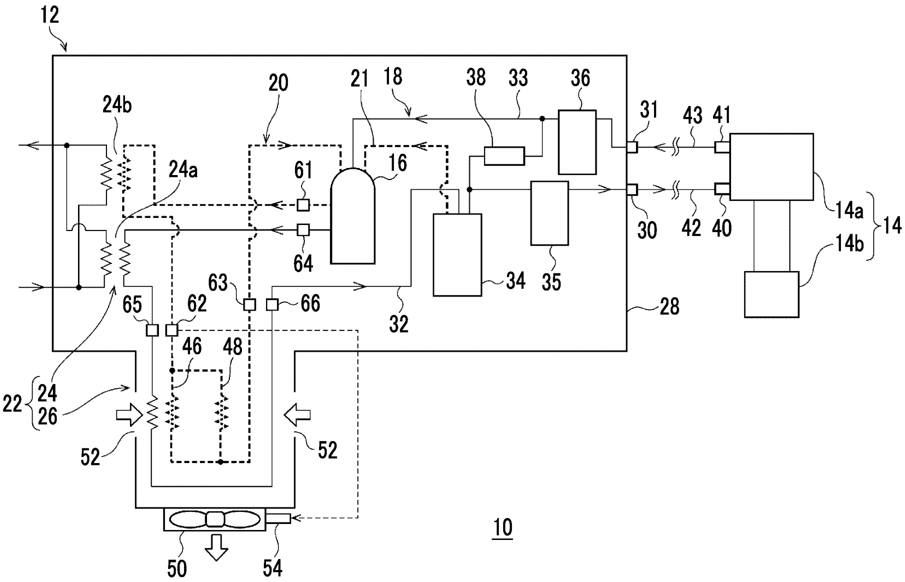
(72) Inventor: **SUZUKI, Sho**
Nishitokyo-shi Tokyo 188-8585 (JP)

(74) Representative: **Louis Pöhlau Lohrentz Patentanwälte**
Postfach 30 55
90014 Nürnberg (DE)

(54) **OIL LUBRICATION-TYPE COMPRESSOR FOR CRYOCOOLER**

(57) A compressor (12) for a cryocooler (10) includes an air-cooled heat exchanger (26) that includes a cooling fan (50) and a first oil line (46) disposed to be forcibly cooled by the cooling fan (50) and a second oil line (48) that bypasses the first oil line (46). The second oil line (48) may be disposed to be forcibly cooled by the cooling fan (50).

FIG. 1



Processed by Luminess, 75001 PARIS (FR)

Description

Technical Field

[0001] The present invention relates to an oil lubrication-type compressor for a cryocooler.

Background Art

[0002] An oil-lubricated helium compressor with a dual aftercooler is proposed (for example, see PTL 1). Two aftercoolers that cool helium and an oil, that is, a water-cooled aftercooler and an air-cooled aftercooler are incorporated in the compressor. The air-cooled aftercooler is disposed in series or in parallel with the water-cooled aftercooler. By operating a fan of the air-cooled aftercooler, redundancy in a case where a cooling water circuit of the water-cooled aftercooler is blocked is provided.

Citation List

Patent Literature

[0003] [PTL 1] Japanese Unexamined Patent Publication No. 2019-505751

Summary of Invention

Technical Problem

[0004] The present inventor has studied the helium compressor described above and has recognized the following problems. Since the two heat exchangers including a water-cooled type and an air-cooled type are mounted on the compressor, the total length of an oil line to be cooled tends to be long, and the pressure loss of an oil flow can increase accordingly. A subsequent decrease in the flow rate of an oil can decrease the cooling capacity and can cause overheating of the compressor or a decrease in the life caused by a high-temperature operation. In particular, in a case where the temperature of cooling water supplied to the water-cooled heat exchanger is too low, the problem is likely to be manifested since oil viscosity can be nonlinearly increased at such a low temperature. As a possible measure, for example, it is conceivable to recover the flow rate of the oil by increasing input energy, such as driving an oil pump at high power. However, this is undesirable because power consumption is increased.

[0005] An exemplary object of one embodiment of the present invention is to reduce a pressure loss of an oil line in an oil lubrication-type compressor for a cryocooler.

Solution to Problem

[0006] According to an aspect of the present invention, there is provided an oil lubrication-type compressor for a cryocooler. The compressor for a cryocooler includes an air-cooled heat exchanger that includes a cooling fan and a first oil line disposed to be forcibly cooled by the cooling fan and a second oil line that bypasses the first oil line.

Advantageous Effects of Invention

[0007] With the present invention, the pressure loss of the oil line in the oil lubrication-type compressor for a cryocooler can be reduced.

Brief Description of Drawings

[0008]

Fig. 1 is a diagram schematically showing a cryocooler according to an embodiment.
Fig. 2 is a diagram schematically showing an example of an oil circulation line of a compressor according to the embodiment.
Fig. 3 is a diagram schematically showing another example of the oil circulation line of the compressor according to the embodiment.

Description of Embodiments

[0009] Hereinafter, an embodiment for carrying out the present invention will be described in detail with reference to the drawings. In the description and drawings, the same or equivalent components, members, and processing will be assigned with the same reference symbols, and redundant description thereof will be omitted as appropriate. The scales and shapes of shown parts are set for convenience in order to make the description easy to understand and are not to be understood as limiting unless stated otherwise. The embodiment is merely an example and does not limit the scope of the present invention. All characteristics and combinations to be described in the embodiment are not necessarily essential to the invention.

[0010] Fig. 1 is a diagram schematically showing a cryocooler according to an embodiment.

[0011] A cryocooler 10 includes an oil lubrication-type compressor for a cryocooler (hereinafter, also simply referred to as a compressor) 12 and a cold head 14. The compressor 12 is configured to collect a refrigerant gas of the cryocooler 10 from the cold head 14, to pressurize the collected refrigerant gas, and to supply the refrigerant gas to the cold head 14 again. The compressor 12 is also referred to as a compressor unit. The cold head 14 is also referred to as an expander and includes a room temperature section 14a and a low-temperature section 14b which is also referred to as a cooling stage. The compressor 12 and the cold head 14 configure a refrigeration cycle of the cryocooler 10, and thereby the low-temperature section 14b is cooled to a desired cryogenic temperature. The refrigerant gas is also referred to as a working gas, and other suitable gases may be used although a helium gas is typically used.

[0012] Although the cryocooler 10 is, for example, a single-stage or two-stage Gifford-McMahon (GM) cryocooler, the cryocooler 10 may be a pulse tube cryocooler, a Stirling cryocooler, or other types of cryocoolers.

[0013] Although the cold head 14 has a different configuration depending on the type of the cryocooler 10, the compressor 12 can use the configuration to be described below regardless of the type of the cryocooler 10.

[0014] In general, both a pressure of a refrigerant gas supplied from the compressor 12 to the cold head 14 and a pressure of a refrigerant gas collected from the cold head 14 to the compressor 12 are considerably higher than the atmospheric pressure and can be called a first high pressure and a second high pressure, respectively. For convenience of description, the first high pressure and the second high pressure are also simply called a high pressure and a low pressure, respectively. Typically, the high pressure is, for example, 2 to 3 MPa. The low pressure is, for example, 0.5 to 1.5 MPa and is, for example, approximately 0.8 MPa.

[0015] The compressor 12 includes a compressor main body 16, a refrigerant gas line 18, an oil circulation line 20, and a compressor cooling system 22. In Fig. 1, in order to facilitate understanding, the refrigerant gas line 18 is shown by a solid line, and the oil circulation line 20 is shown by a broken line. Although details will be described later, the compressor cooling system 22 is configured to include a liquid-cooled heat exchanger 24 and an air-cooled heat exchanger 26 and to cool the refrigerant gas line 18 and the oil circulation line 20. In addition, the compressor 12 includes a compressor casing 28 that accommodates each of components of the compressor 12, such as the compressor main body 16, the refrigerant gas line 18, the oil circulation line 20, and the compressor cooling system 22.

[0016] The compressor main body 16 is configured to internally compress a refrigerant gas sucked from a suction port thereof and to discharge the refrigerant gas from a discharge port. An oil is used in the compressor main body 16 for the sake of cooling and lubrication, and the sucked refrigerant gas is directly exposed to the oil in the compressor main body 16. Accordingly, the refrigerant gas is delivered from the discharge port in a state where the oil is slightly mixed.

[0017] The compressor main body 16 may be, for example, a scroll type pump, a rotary type pump, or other pumps that pressurize a refrigerant gas. The compressor main body 16 may be configured to discharge the refrigerant gas at a fixed and constant flow rate. Alternatively, the compressor main body 16 may be configured to have a variable flow rate of the refrigerant gas to be discharged. The compressor main body 16 is called a compression capsule in some cases.

[0018] The refrigerant gas line 18 includes a discharge port 30, a suction port 31, a discharge flow path 32, and a suction flow path 33. The discharge port 30 is an outlet of a refrigerant gas that is provided in the compressor casing 28 in order to deliver the refrigerant gas, which is pressurized to a high pressure by the compressor main body 16, from the compressor 12, and the suction port 31 is an inlet of the refrigerant gas that is provided in the compressor casing 28 in order for the compressor 12 to receive the low-pressure refrigerant gas. The compressor casing 28 accommodates the discharge flow path 32 and the suction flow path 33.

[0019] The discharge port of the compressor main body 16 is connected to the discharge port 30 by the discharge flow path 32, and the suction port 31 is connected to the suction port of the compressor main body 16 by the suction flow path 33.

[0020] The liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 that configure the compressor cooling system 22 are provided at the discharge flow path 32. In addition, an oil separator 34 and an adsorber 35 are provided downstream of the compressor cooling system 22 at the discharge flow path 32.

[0021] The oil separator 34 is provided in order to separate an oil, which is mixed in a refrigerant gas as passing through the compressor main body 16, out from the refrigerant gas. The adsorber 35 is provided in order to remove, for example, a vaporized oil and other contaminants remaining in the refrigerant gas from the refrigerant gas through adsorption. The oil separator 34 and the adsorber 35 are connected in series. In the discharge flow path 32, the oil separator 34 is disposed on a compressor main body 16 side, and the adsorber 35 is disposed on a discharge port 30 side.

[0022] An oil return line 21 that connects the oil separator 34 to the compressor main body 16 is provided. An oil collected by the oil separator 34 can return to the compressor main body 16 through the oil return line 21. In the middle of the oil return line 21, a filter that removes dust included in the oil separated out by the oil separator 34 and an orifice that controls the amount of the oil returning to the compressor main body 16 may be provided.

[0023] On the other hand, a storage tank 36 is provided at the suction flow path 33. The storage tank 36 is provided as a volume for removing pulsation included in a low-pressure refrigerant gas returning from the cold head 14 to the compressor 12.

[0024] In addition, a bypass valve 38 that connects the discharge flow path 32 to the suction flow path 33 to bypass the compressor main body 16 is provided at the refrigerant gas line 18. For example, the bypass valve 38 branches off from the discharge flow path 32 between the oil separator 34 and the adsorber 35 and is connected to the suction flow path 33 between the compressor main body 16 and the storage tank 36. The bypass valve 38 is provided in order to control a flow rate of a refrigerant gas and/or in order to equalize the discharge flow path 32 and the suction flow path 33 when the compressor 12 is stopped.

[0025] The refrigerant gas line 18 of the compressor 12 is connected to the cold head 14.

[0026] A high-pressure port 40 and a low-pressure port 41 are provided in the room temperature section 14a of the cold head 14. The high-pressure port 40 is connected to the discharge port 30 by a high-pressure pipe 42, and the low-pressure port 41 is connected to the suction port 31 by a low-pressure pipe 43.

[0027] The oil circulation line 20 connects an oil outlet to an oil inlet of the compressor main body 16 via the compressor cooling system 22 (that is, the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26). Accordingly, an oil flowing out from the compressor main body 16 can be cooled by the compressor cooling system 22 and flow into the compressor main body 16 again.

[0028] In the embodiment, the oil circulation line 20 branches into a plurality of (two in the example) oil flow paths at the compressor cooling system 22 as will be described later. The branched oil flow paths merge between the compressor cooling system 22 and the oil inlet of the compressor main body 16 again.

[0029] An orifice that controls a flow rate of an oil flowing inside may be provided at the oil circulation line 20. In addition, a filter that removes dust included in the oil may be provided at the oil circulation line 20. Such an orifice and such a filter may be provided, for example, on a downstream side of the oil circulation line 20, that is, between the compressor cooling system 22 and the oil inlet of the compressor main body 16.

[0030] As described above, the compressor cooling system 22 includes the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26. The liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 are connected in series, and the liquid-cooled heat exchanger 24 is provided upstream of the air-cooled heat exchanger 26. Accordingly, an oil heated by compression heat generated with compression of a refrigerant gas in the compressor main body 16 and a high-pressure refrigerant gas initially flow from the compressor main body 16 into the liquid-cooled heat exchanger 24 to be cooled and then flow into the air-cooled heat exchanger 26.

[0031] In the embodiment, the liquid-cooled heat exchanger 24 is mounted on the compressor 12 as a main cooling device of the compressor 12, and the air-cooled heat exchanger 26 is mounted on the compressor 12 as a backup cooling device of the compressor 12. Accordingly, the liquid-cooled heat exchanger 24 operates at all times during an operation of the compressor 12, and the air-cooled heat exchanger 26 does not operate when the liquid-cooled heat exchanger 24 operates normally, but may operate when the liquid-cooled heat exchanger 24 does not operate due to a failure or the like when a cooling capacity thereof has decreased. Thus, as will be described later, the air-cooled heat exchanger 26 may be configured to switch on or off based on an output of a sensor provided at the compressor 12, such as a temperature sensor for an oil or a refrigerant gas.

[0032] The liquid-cooled heat exchanger 24 includes a first portion 24a that cools a refrigerant gas through heat exchange between the refrigerant gas and a coolant and a second portion 24b that cools an oil through heat exchange between the oil and the coolant. The first portion 24a is disposed between the compressor main body 16 and the oil separator 34 at the discharge flow path 32, more specifically, between the discharge port of the compressor main body 16 and the air-cooled heat exchanger 26 and cools the refrigerant gas flowing in the discharge flow path 32. The second portion 24b is disposed between the oil outlet of the compressor main body 16 and the air-cooled heat exchanger 26 at the oil circulation line 20 and cools the oil flowing in the oil circulation line 20.

[0033] Although water (for example, tap water, industrial water, and the like) is typically used as a coolant, other suitable coolants may be used. The coolant is supplied to the compressor 12 from the outside and is exhausted to the outside of the compressor 12 via the first portion 24a and the second portion 24b of the liquid-cooled heat exchanger 24. In this manner, compression heat generated by the compressor main body 16 is removed to the outside of the compressor 12 together with the coolant. The coolant may be cooled by, for example, a coolant circulation device (not shown) such as a known water chiller and may be supplied to the compressor 12 again.

[0034] The air-cooled heat exchanger 26 includes a cooling fan 50, a first oil line 46 that is disposed to be forcibly cooled by the cooling fan 50, and a second oil line 48 that bypasses the first oil line 46 and that is disposed to be forcibly cooled by the cooling fan 50.

[0035] The first oil line 46 and the second oil line 48 are a portion of the oil circulation line 20 disposed in the air-cooled heat exchanger 26. The second oil line 48 branches off from the oil circulation line 20 upstream of the air-cooled heat exchanger 26, that is, between the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 and merges with the first oil line 46 again downstream of the air-cooled heat exchanger 26, that is, between the air-cooled heat exchanger 26 and the oil inlet of the compressor main body 16.

[0036] As an exemplary configuration, the cooling fan 50 is provided in the compressor casing 28 to exhaust air from the air-cooled heat exchanger 26 to the outside as the cooling fan 50 operates.

[0037] Two air intakes 52 are provided at a portion of the compressor casing 28 surrounding the air-cooled heat exchanger 26, and air is taken into the air-cooled heat exchanger 26 through the air intakes 52 from the outside as the cooling fan 50 operates. One airflow that blows from one air intake 52 into the air-cooled heat exchanger 26 is used in forced cooling of the refrigerant gas line 18 and the first oil line 46, and another airflow that blows from the other air intake 52 into the air-cooled heat exchanger 26 is used in forced cooling of the second oil line 48. In Fig. 1, for the sake of understanding, the airflows are schematically shown by thick arrows.

[0038] As will be described later, the cooling fan 50 may operate based on an oil temperature measured by an oil temperature sensor. Alternatively, the cooling fan 50 may operate based on a refrigerant gas temperature measured by a refrigerant gas temperature sensor.

[0039] During an operation of the cryocooler 10, a refrigerant gas collected from the cold head 14 to the compressor 12 flows from the low-pressure port 41 into the suction port 31 of the compressor 12 through the low-pressure pipe 43. The refrigerant gas is collected to the suction port of the compressor main body 16 via the storage tank 36 on the suction flow path 33. The refrigerant gas is compressed and pressurized by the compressor main body 16. The refrigerant gas delivered from the discharge port of the compressor main body 16 is cooled by the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 and exits the compressor 12 from the discharge port 30 via the oil separator 34 and the adsorber 35. The refrigerant gas is supplied into the cold head 14 via the high-pressure pipe 42 and the high-pressure port 40.

[0040] An oil flowing out from the oil outlet of the compressor main body 16 flows into the liquid-cooled heat exchanger 24 through the oil circulation line 20 and is cooled through heat exchange between the oil and a coolant at the liquid-cooled heat exchanger 24. The cooled oil flows from the liquid-cooled heat exchanger 24 into the air-cooled heat exchanger 26. The oil branches off and flows to the first oil line 46 and the second oil line 48 in the air-cooled heat exchanger 26. In a case where the cooling fan 50 operates, the oil is cooled with air when flowing in the first oil line 46 and the second oil line 48. The oil flowing out from the air-cooled heat exchanger 26 returns to the oil inlet of the compressor main body 16 through the oil circulation line 20.

[0041] The compressor 12 may be provided with various types of sensors. For example, the compressor 12 may include at least one oil temperature sensor (61 to 63) that measures the temperature of an oil. The first sensor 61 is provided upstream of the liquid-cooled heat exchanger 24 on the oil circulation line 20 and measures the temperature of the oil flowing from the compressor main body 16 into the liquid-cooled heat exchanger 24. The second sensor 62 is provided downstream of the liquid-cooled heat exchanger 24 on the oil circulation line 20, specifically, between the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 and measures the temperature of the oil flowing from the liquid-cooled heat exchanger 24 into the air-cooled heat exchanger 26. The third sensor 63 is provided downstream of the air-cooled heat exchanger 26 on the oil circulation line 20 and measures the temperature of the oil flowing from the air-cooled heat exchanger 26 into the compressor main body 16. The temperature sensor may be, for example, a thermistor.

[0042] The compressor 12 may include at least one refrigerant gas sensor (64 to 66) that measures the temperature of a refrigerant gas. A fourth sensor 64 is provided upstream of the liquid-cooled heat exchanger 24 on the discharge flow path 32 of the refrigerant gas line 18 and measures the temperature of the refrigerant gas flowing from the compressor main body 16 into the liquid-cooled heat exchanger 24. A fifth sensor 65 is provided downstream of the liquid-cooled heat exchanger 24 on the refrigerant gas line 18, specifically, between the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 and measures the temperature of the refrigerant gas flowing from the liquid-cooled heat exchanger 24 into the air-cooled heat exchanger 26. A sixth sensor 66 is provided downstream of the air-cooled heat exchanger 26 on the refrigerant gas line 18 and measures the temperature of the refrigerant gas flowing from the air-cooled heat exchanger 26 into the oil separator 34.

[0043] The air-cooled heat exchanger 26 may be provided with a fan controller 54 that turns the cooling fan 50 on and off. The fan controller 54 is configured to receive, from at least one sensor, a sensor signal indicating a measurement result of the sensor and to operate the cooling fan 50 based on the measurement result. For example, Fig. 1 shows a case where a sensor signal of the second sensor 62 is input to the fan controller 54.

[0044] The fan controller 54 is realized by an element or a circuit including a CPU and a memory of a computer as a hardware configuration and is realized by a computer program as a software configuration, but is shown in the drawings as a functional block realized in cooperation therewith as appropriate. It is clear for those skilled in the art that the functional blocks can be realized in various manners in combination with hardware and software.

[0045] For example, the fan controller 54 may operate the cooling fan 50 based on an oil temperature measured by at least one of the oil temperature sensors (61 to 63). In this case, the fan controller 54 receives a sensor signal indicating a measured temperature of an oil from the first sensor 61, the second sensor 62, or the third sensor 63 and compares the measured temperature with a temperature threshold value. The temperature threshold value is set to a value at which it is evaluated that the oil is insufficiently cooled in a case where the oil temperature is higher than the threshold value.

[0046] As one cause that an oil temperature measured by the oil temperature sensor exceeds the temperature threshold value, for example, a case where the temperature of a coolant supplied to the liquid-cooled heat exchanger 24 is too high (that is, defective cooling or a failure of a chiller that cools the coolant) or a defect of the liquid-cooled heat exchanger 24 itself (clogging or damage of the heat exchanger) is assumed.

[0047] Therefore, the fan controller 54 operates the air-cooled heat exchanger 26 in a case where a measured temperature exceeds the temperature threshold value. That is, the fan controller 54 switches the cooling fan 50 from off to on to activate the air-cooled heat exchanger 26. On the other hand, in a case where the measured temperature does not exceed the temperature threshold value, the fan controller 54 does not activate the air-cooled heat exchanger 26 (keeps the cooling fan 50 off). In this manner, as the air-cooled heat exchanger 26, which is the backup cooling device of the compressor 12, is operated, a defective operation of the liquid-cooled heat exchanger 24, which is the main cooling device of the compressor 12, can be dealt with.

[0048] Alternatively, the fan controller 54 may operate the cooling fan 50 based on a refrigerant gas temperature measured by the refrigerant gas temperature sensor. For example, the fan controller 54 may receive a sensor signal indicating a measured temperature of a refrigerant gas from the fourth sensor 64 or the fifth sensor 65 and compare the measured temperature with the temperature threshold value. The fan controller 54 operates the air-cooled heat exchanger 26 in a case where the measured temperature exceeds the temperature threshold value but does not activate the air-cooled heat exchanger 26 in a case where the measured temperature does not exceed the temperature threshold value. Even in this manner, it is possible to deal with the defective operation of the liquid-cooled heat exchanger 24 using the air-cooled heat exchanger 26.

[0049] Meanwhile, one of main applications of the cryocooler 10 is to cool a superconducting magnet. Typically, the superconducting magnet is cooled by being immersed in a large amount of liquid helium, and the cryocooler 10 is used in cooling and recondensing the liquid helium. In such a device of the related art, even when the cryocooler 10 is stopped, the cooling of the superconducting magnet can be maintained for a while with a large amount of liquid helium. On the other hand, in recent years, research and development of a superconducting magnet that greatly reduces the amount of liquid helium used has been advanced against a backdrop of a surge in helium prices. In such a helium-saving type superconducting device, the stop of the operation of the cryocooler 10 is likely to lead to the loss of the cooling of the superconducting magnet.

[0050] According to the embodiment, since the compressor cooling system 22 includes the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26, redundancy related to the cooling of the compressor 12 is secured. Even when a defective operation occurs in the liquid-cooled heat exchanger 24, a cooling function of the compressor 12 can be complemented or replaced by the air-cooled heat exchanger 26. Accordingly, a risk of an excessive temperature rise of the compressor 12 and the subsequent stop of the operation of the cryocooler 10 is reduced. Therefore, the cryocooler 10 according to the embodiment is useful for improving continuity of the operation of a so-called helium-saving type superconducting device.

[0051] However, in the embodiment, since two heat exchangers of the liquid-cooled type and the air-cooled type are mounted on the compressor cooling system 22 (in particular, the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 are connected in series), the total length of the oil circulation line 20 to be cooled tends to be long, and the pressure loss of an oil flow can increase accordingly. A subsequent decrease in the flow rate of an oil of the oil circulation line 20 can decrease the cooling capacity of the compressor cooling system 22 and can cause overheating of the compressor 12 or a decrease in the life caused by a high-temperature operation. In particular, in a case where the temperature of a coolant supplied to the liquid-cooled heat exchanger 24 is too low, the problem is likely to be manifested since oil viscosity can be nonlinearly increased at such a low temperature. As a possible measure, for example, it is conceivable to recover the flow rate of the oil of the oil circulation line 20 by increasing input energy, such as driving an oil pump at high power. However, this is undesirable because power consumption is increased.

[0052] In order to deal with this, in the embodiment, the air-cooled heat exchanger 26 further includes the second oil line 48 that bypasses the first oil line 46, instead of including only the first oil line 46. In this manner, as a plurality of oil flow paths are provided in parallel at the air-cooled heat exchanger 26, the flow path sectional area of the oil circulation line 20 can be increased, and the pressure loss can be reduced. Even when an oil is cooled to a low temperature by the liquid-cooled heat exchanger 24 and the viscosity of the oil exiting from the liquid-cooled heat exchanger 24 is increased, a decrease in the flow rate of the oil flowing in the air-cooled heat exchanger 26 can be suppressed. It is possible to prevent insufficiency of the flow rate of the oil circulating in the oil circulation line 20 and to avoid defective cooling of the compressor 12.

[0053] Fig. 2 is a diagram schematically showing an example of the oil circulation line 20 of the compressor 12 according to the embodiment. Also in the example of Fig. 2, the compressor 12 includes the compressor main body 16, the compressor cooling system 22, and the oil circulation line 20 connecting the compressor main body 16 and the compressor cooling system 22, as in the embodiment described with reference to Fig. 1. The compressor cooling system 22 includes the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 and is configured to cool the oil circulation line 20. The liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 are connected in series, and the liquid-cooled heat exchanger 24 is provided upstream of the air-cooled heat exchanger 26.

[0054] The oil circulation line 20 branches into the first oil line 46 and the second oil line 48 upstream of the air-cooled heat exchanger 26, that is, between the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26. The air-cooled heat exchanger 26 includes the cooling fan 50, and the first oil line 46 and the second oil line 48 are forcibly cooled by an airflow generated in the air-cooled heat exchanger 26 when the cooling fan 50 operates. The first oil line 46 and the second oil line 48 merge again downstream of the air-cooled heat exchanger 26, that is, between the air-cooled heat exchanger 26 and the oil inlet of the compressor main body 16.

[0055] The air-cooled heat exchanger 26 may include an orifice 56 provided at at least one of the first oil line 46 and the second oil line 48 so that a difference between the flow rate of an oil of the first oil line 46 and the flow rate of an oil of the second oil line 48 is reduced. In the example of Fig. 2, the flow rate of the oil of the second oil line 48 in a case where the orifice 56 does not exist is greater than that of the first oil line 46.

[0056] Therefore, by providing the orifice 56 at the second oil line 48, the flow rate of the oil of the second oil line 48 can be reduced, and the flow rates of the oils of the first oil line 46 and the second oil line 48 can be made uniform. The imbalance of the flow rates of the oils of the first oil line 46 and the second oil line 48 can be eliminated, and efficiency of heat exchange of the air-cooled heat exchanger 26 can be improved.

[0057] According to the study of the inventor, an aperture diameter R [m] of the orifice 56 may be selected from a range of 1.0×10^{-4}(m) $\leq R \leq 5.0 \times 10^{-2}$(m). Herein, the aperture diameter R can be calculated by the following equation.

$$R = 4.54d \left(\frac{L_2}{(L_1 + L_2)}\right)^{1/2} \left(\frac{Q}{\pi \mu (L_1 - L_2)}\right)^{1/4}$$

[0058] Herein, μ denotes the viscosity [Pa·s] of an oil flowing into the air-cooled heat exchanger, L_1 and L_2 denote lengths [m] of the first oil line 46 and the second oil line 48, which are the air-cooled heat exchangers, respectively, d denotes a pipe diameter [m] of the first oil line 46 and the second oil line 48, and Q denotes the flow rate [m^3/s] of an oil of the oil circulation line 20.

[0059] Fig. 3 is a diagram schematically showing another example of the oil circulation line 20 of the compressor 12 according to the embodiment. Also in the example of Fig. 3, the compressor 12 includes the compressor main body 16, the compressor cooling system 22, and the oil circulation line 20 connecting the compressor main body 16 and the compressor cooling system 22, as in the embodiment described with reference to Fig. 1. The compressor cooling system 22 includes the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 and is configured to cool the oil circulation line 20. The liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 are connected in series, and the liquid-cooled heat exchanger 24 is provided upstream of the air-cooled heat exchanger 26.

[0060] The oil circulation line 20 branches into the first oil line 46 and the second oil line 48 upstream of the air-cooled heat exchanger 26, that is, between the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26. The air-cooled heat exchanger 26 includes the cooling fan 50, and the first oil line 46 is forcibly cooled by an airflow generated in the air-cooled heat exchanger 26 when the cooling fan 50 operates. The first oil line 46 and the second oil line 48 merge again downstream of the air-cooled heat exchanger 26, that is, between the air-cooled heat exchanger 26 and the oil inlet of the compressor main body 16.

[0061] However, the second oil line 48 bypasses the air-cooled heat exchanger 26, unlike the examples of Figs. 1 and 2. The second oil line 48 is provided outside the air-cooled heat exchanger 26 in the compressor 12 and does not pass through the air-cooled heat exchanger 26.

[0062] The second oil line 48 may include an on-off valve 58 operated to be closed when the cooling fan 50 is operated and to be opened when the cooling fan 50 is stopped.

[0063] Therefore, the fan controller 54 may be configured to receive, from at least one sensor, a sensor signal indicating a measurement result of the sensor and to operate the cooling fan 50 and the on-off valve 58 based on the measurement result. The fan controller 54 may close the on-off valve 58 while operating the cooling fan 50 and open the on-off valve 58 while stopping the cooling fan 50. For example, Fig. 3 shows a case where a sensor signal of the second sensor 62 is input to the fan controller 54. As described above, another sensor (for example, the first sensor 61, the third sensor 63, the fourth sensor 64, or the fifth sensor 65) may be used.

[0064] In this manner, when the liquid-cooled heat exchanger 24 which is the main cooling device of the compressor 12, operates normally, the air-cooled heat exchanger 26, which is the backup cooling device, is stopped, and an oil cooled by the liquid-cooled heat exchanger 24 flows in the second oil line 48. As an oil flow bypasses the air-cooled heat exchanger

26, an increase in the pressure loss of the oil circulation line 20 can be suppressed. It is possible to prevent insufficiency of the flow rate of the oil circulating in the oil circulation line 20 and to avoid defective cooling of the compressor 12.

[0065] On the other hand, when the liquid-cooled heat exchanger 24 does not operate normally, the on-off valve 58 is closed to operate the air-cooled heat exchanger 26. In this manner, the defective cooling of the liquid-cooled heat exchanger 24 can be complemented or replaced by the air-cooled heat exchanger 26.

[0066] In the example of Fig. 3, as in the examples of Figs. 1 and 2, a plurality of oil lines may be provided in the air-cooled heat exchanger 26, and the oil lines may be cooled by the cooling fan 50.

[0067] The present invention has been described based on the example. It is clear for those skilled in the art that the present invention is not limited to the embodiment, various design changes are possible, various modification examples are possible, and such modification examples are also within the scope of the present invention. Various characteristics described in relation to one embodiment are also applicable to other embodiments. A new embodiment generated through combination also has the effects of each of the combined embodiments.

[0068] In the embodiment described above, the oil circulation line 20 branches into the first oil line 46 and the second oil line 48 in the air-cooled heat exchanger 26, but may branch into more oil lines, for example, three or four oil lines.

[0069] In the embodiment described above, the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 are connected in series in the compressor cooling system 22, and the liquid-cooled heat exchanger 24 is provided upstream of the air-cooled heat exchanger 26. However, the compressor cooling system 22 can have other configurations.

[0070] For example, the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 may be connected in series, and the air-cooled heat exchanger 26 may be provided upstream of the liquid-cooled heat exchanger 24. Alternatively, the liquid-cooled heat exchanger 24 and the air-cooled heat exchanger 26 may be connected in parallel.

[0071] The cooling fan 50 of the air-cooled heat exchanger 26 may generate an airflow in a direction opposite to the example described above and may be configured to blow air from the outside into the air-cooled heat exchanger 26. The cooling fan 50 may be configured to blow air to the refrigerant gas line 18, the first oil line 46, and the second oil line 48.

[0072] Although the present invention has been described using specific phrases based on the embodiment, the embodiment merely shows one aspect of the principles and applications of the present invention, and many modification examples and changes in disposition are allowed without departing from the concept of the present invention specified in the claims.

Industrial Applicability

[0073] The present invention can be used in the field of an oil lubrication-type compressor for a cryocooler.

Reference Signs List

[0074]

10	cryocooler
12	compressor
18	refrigerant gas line
24	liquid-cooled heat exchanger
26	air-cooled heat exchanger
46	first oil line
48	second oil line
50	cooling fan
56	orifice
58	on-off valve

Claims

1. An oil lubrication-type compressor for a cryocooler comprising:

an air-cooled heat exchanger that includes a cooling fan and a first oil line disposed to be forcibly cooled by the cooling fan; and
a second oil line that bypasses the first oil line.

2. The oil lubrication-type compressor for a cryocooler according to claim 1,
wherein the second oil line is disposed to be forcibly cooled by the cooling fan.

3. The oil lubrication-type compressor for a cryocooler according to claim 2, wherein the air-cooled heat exchanger includes an orifice provided at at least one of the first oil line and the second oil line so that a difference between a flow rate of an oil of the first oil line and a flow rate of an oil of the second oil line is reduced.

4. The oil lubrication-type compressor for a cryocooler according to claim 1, wherein the second oil line bypasses the air-cooled heat exchanger.

5. The oil lubrication-type compressor for a cryocooler according to claim 4, wherein the second oil line includes an on-off valve that operates to be closed when the cooling fan is operated and to be opened when the cooling fan is stopped.

6. The oil lubrication-type compressor for a cryocooler according to claim 1, wherein the air-cooled heat exchanger cools a refrigerant gas line.

7. The oil lubrication-type compressor for a cryocooler according to any one of claims 1 to 6, further comprising: a liquid-cooled heat exchanger that is connected in series upstream of the air-cooled heat exchanger.

8. The oil lubrication-type compressor for a cryocooler according to claim 7, further comprising:

   an oil temperature sensor that is provided upstream or downstream of the liquid-cooled heat exchanger or that is provided downstream of the air-cooled heat exchanger,
   wherein the cooling fan operates based on an oil temperature measured by the oil temperature sensor.

9. The oil lubrication-type compressor for a cryocooler according to claim 7,

   wherein the liquid-cooled heat exchanger further includes a refrigerant gas temperature sensor that is provided upstream or downstream of the liquid-cooled heat exchanger on a refrigerant gas line, and
   the cooling fan operates based on a refrigerant gas temperature measured by the refrigerant gas temperature sensor.

FIG. 1

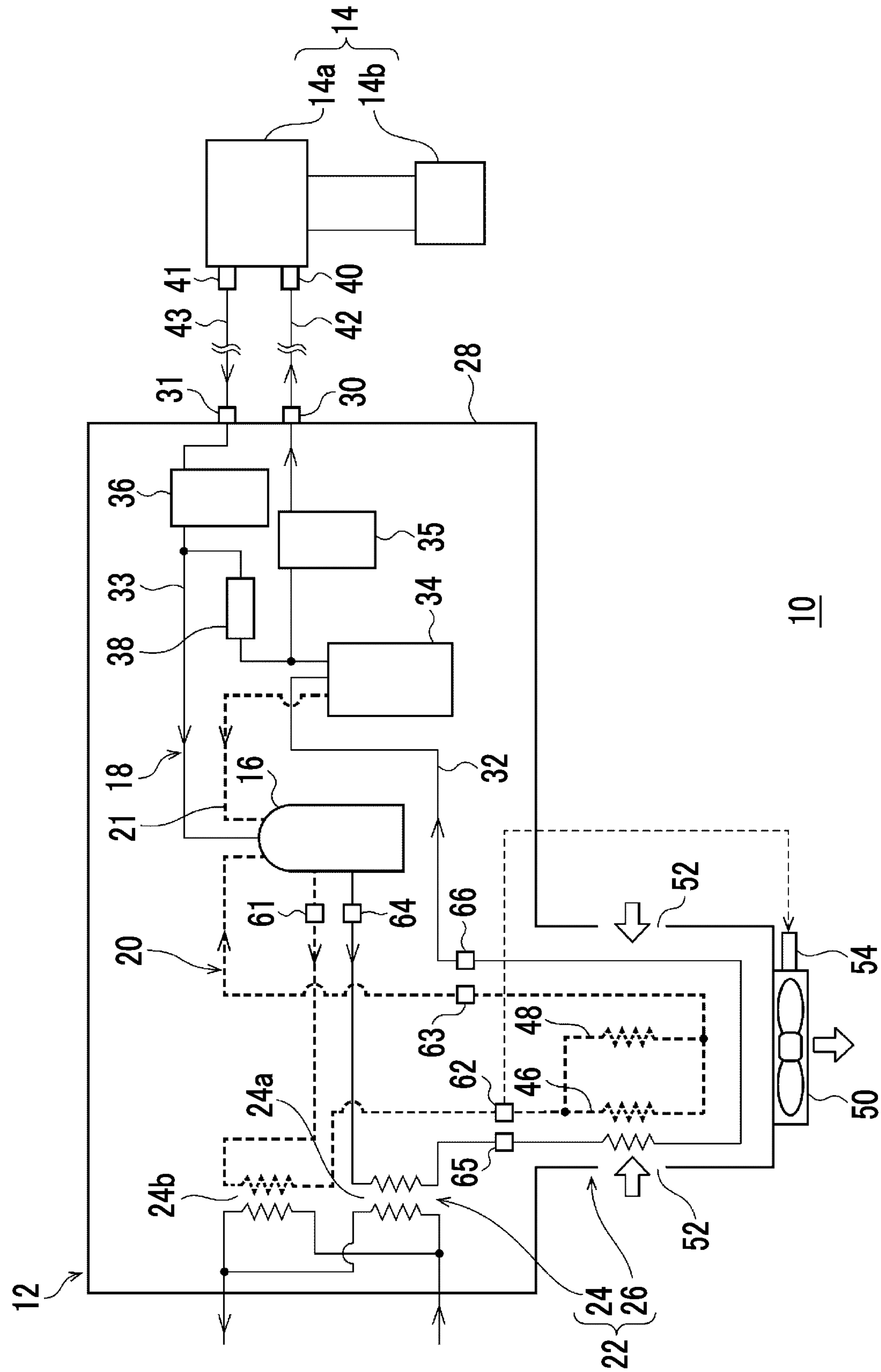

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FIG. 2

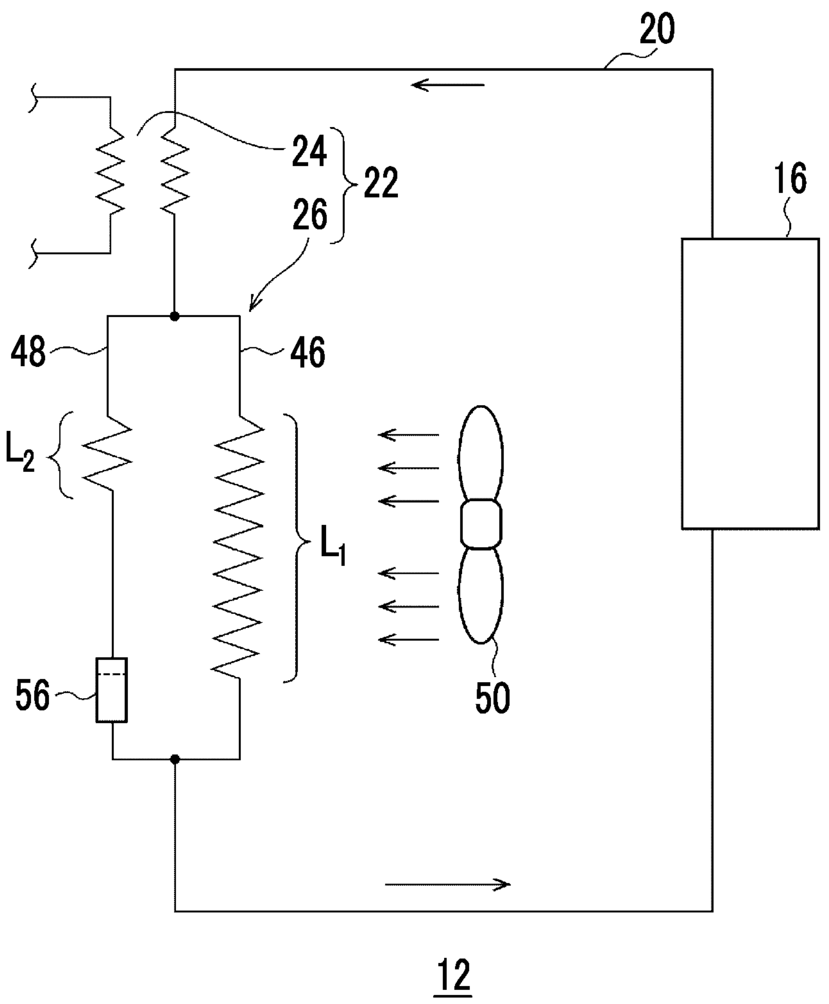
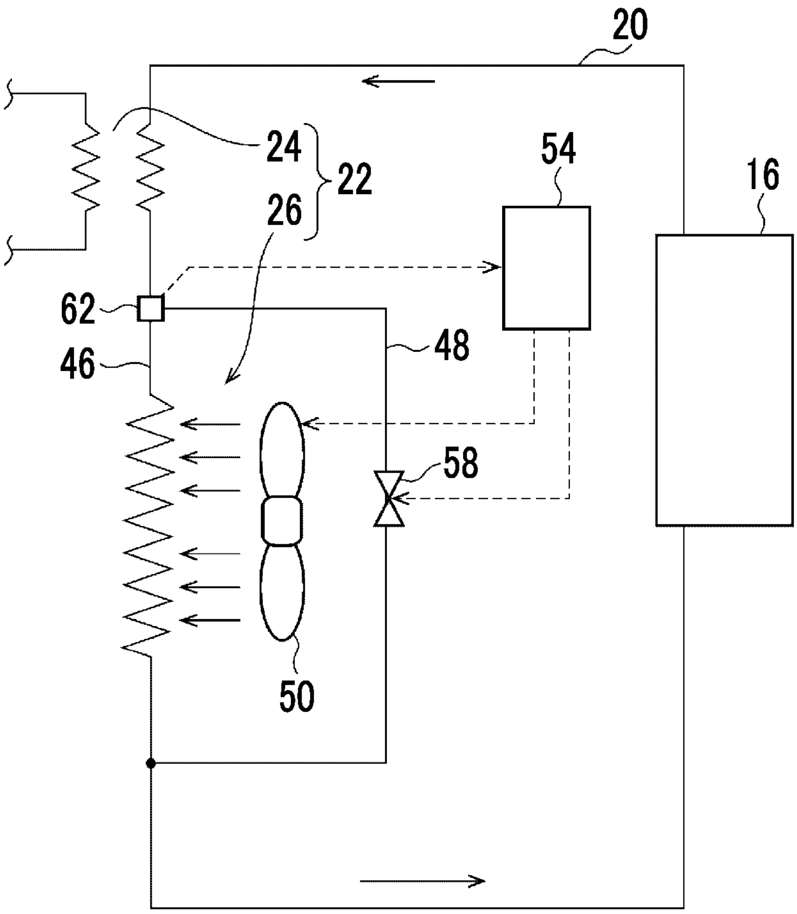


FIG. 3



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INTERNATIONAL SEARCH REPORT

International application No. **PCT/JP2023/015355**

A. CLASSIFICATION OF SUBJECT MATTER

F25B 9/00(2006.01)i; ***F25B 1/00***(2006.01)i
FI: F25B9/00 A; F25B1/00 387Z

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)

F25B9/00; F25B1/00

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2019-505751 A (SUMITOMO (SHI) CRYOGENICS OF AMERICA, INC.) 28 February 2019 (2019-02-28) paragraphs [0008], [0016], fig. 2	1, 4-6
Y	fig. 1	7
X	JP 2011-99669 A (SUMITOMO HEAVY INDUSTRIES, LTD.) 19 May 2011 (2011-05-19) fig. 3B	1, 4-6
Y	fig. 3B	7
A	US 2017/0175743 A1 (SUMITOMO(SHI) CRYOGENICS OF AMERICA) 22 June 2017 (2017-06-22) entire text, all drawings	1-9

☐ 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	Date of mailing of the international search report
27 June 2023	**04 July 2023**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

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

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/015355

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2019-505751 A	28 February 2019	US 2017/0176070 A1 paragraphs [0009], [0017], fig. 2 KR 10-2018-0081828 A CN 108474370 A	
JP 2011-99669 A	19 May 2011	US 2011/0107790 A1 fig. 3B CN 102052282 A	
US 2017/0175743 A1	22 June 2017	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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