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

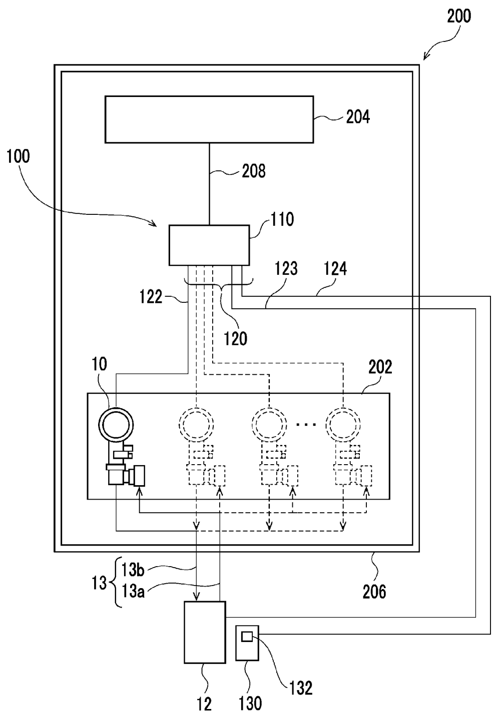
(72) Inventor: **TAKAHASHI, Kakeru**
Tokyo, 188-8585 (JP)

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

(54) **CRYOPUMP SYSTEM, CRYOPUMP MONITORING METHOD, AND CRYOPUMP MONITORING PROGRAM**

(57) Cryopump monitoring technique that is helpful in easily identifying a state of a cryopump system (100). The cryopump system (100) includes a sensor (22, 23, 54, 55) that measures a measurement parameter related to the cryopump system (100), a cryopump controller (110) that is configured to receive the measurement parameter from the sensor (22, 23, 54, 55), to determine an operation parameter of the cryopump system (100) such that the measurement parameter follows a target value, and to operate the cryopump system (100) with the determined operation parameter, and a cryopump monitor (130) that is configured to acquire time-series data of the measurement parameter and time-series data of the operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a cryopump system, a cryopump monitoring method, and a cryopump monitoring program.

Description of Related Art

[0002] A cryopump is a vacuum pump that captures gas molecules through condensation and adsorption on a cryopanel cooled to a cryogenic temperature and that exhausts the gas molecules. The cryopump is mounted on a vacuum process device in order to realize a clean vacuum environment required for semiconductor circuit manufacturing processes or the like (for example, Japanese Unexamined Patent Publication No. 7-293438) .

SUMMARY OF THE INVENTION

[0003] During the operation of the cryopump, various types of data are continuously acquired from the cryopump. Examples of data to be acquired can include a cooling temperature of each of a cryopanel in the cryopump and a radiation shield surrounding the cryopanel, an internal pressure of a cryocooler that cools the cryopump, and an operation frequency of a motor for driving the cryocooler. In one vacuum process device, a plurality of cryopumps are often mounted, and such data is acquired for each cryopump. Such various and large amounts of data related to the cryopump can be used in monitoring or diagnosing the cryopump.

[0004] In order to verify that a diagnosis result is accurate, and further, in order to report such verification to a user of the cryopump as necessary, a design engineer of the cryopump may be required to organize and analyze a large amount of acquired data so that the state of the cryopump can be identified. Although such work is actually performed by an engineer using his/her own know-how, it is time-consuming. In addition, it is practically difficult for a user who does not have such know-how to perform the operation described above.

[0005] An exemplary object of an aspect of the present invention is to provide a cryopump monitoring technique helpful in easily identifying a state of a cryopump system.

[0006] According to an aspect of the present invention, there is provided a cryopump system including a sensor that measures a measurement parameter related to the cryopump system, a cryopump controller that is configured to receive the measurement parameter from the sensor, to determine an operation parameter of the cryopump system such that the measurement parameter follows a target value, and to operate the cryopump system with the determined operation parameter, and a cryopump monitor that is configured to acquire time-series data of the measurement parameter and time-series data of the operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

[0007] According to another aspect of the present invention, there is provided a cryopump monitoring method including acquiring time-series data of a measurement parameter related to a cryopump system, acquiring time-series data of an operation parameter of the cryopump system, which is controlled such that the measurement parameter follows a target value, and displaying a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

[0008] Any combination of the components described above and substitutions of expressions of the present invention between methods, devices, systems, recording media, computer programs, and the like are also effective as aspects of the present invention.

[0009] With the present invention, a cryopump monitoring technique that is helpful in easily identifying a state of the cryopump system can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Fig. 1 is a schematic view showing a cryopump system according to an embodiment.

Fig. 2 is a schematic view showing an example of a cryopump that can be used in the cryopump system according to the embodiment.

Fig. 3 is a schematic view showing an example of a compressor that can be used in the cryopump system according to the embodiment.

Fig. 4 is a flowchart showing a cryopump monitoring method according to the embodiment.

Fig. 5 is a schematic view showing an example of a cryopump monitor that can be used in the cryopump system according to the embodiment.

Fig. 6 is a schematic view showing an example of time-series graph display on the cryopump monitor according to the embodiment.

Fig. 7 is a schematic view showing another example of the time-series graph display on the cryopump monitor according to the embodiment.

Fig. 8 is a schematic view showing still another example of the time-series graph display on the cryopump monitor according to the embodiment.

Fig. 9 is a schematic view showing another example of the cryopump system according to the embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0011] 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.

[0012] Fig. 1 is a schematic view showing a cryopump system 100 according to the embodiment. The cryopump system 100 is mounted on a vacuum process device 200 and is used in order to evacuate a vacuum chamber 202 of the vacuum process device 200 to a desired degree of vacuum. The vacuum process device 200 is configured to process a workpiece, such as a wafer, in a vacuum environment in the vacuum chamber 202 through a desired vacuum process. The vacuum process device 200 may be, for example, an ion implanter, a sputtering device, a vapor deposition device, or other vacuum process devices.

[0013] The vacuum process device 200 includes a host controller 204 and a casing 206, in addition to the vacuum chamber 202. The host controller 204 is configured to control communication between the vacuum process device 200 and the cryopump system 100. The host controller 204 may be configured as a control device that controls the vacuum process device 200 or may configure a part of such a control device. The casing 206 forms the exterior of the vacuum process device 200 and houses various components of the vacuum process device 200. The vacuum chamber 202 and the host controller 204 are disposed in the casing 206.

[0014] The casing 206 may be an enclosure that covers the entire surface of the vacuum process device 200. The casing 206 may include a frame structure in which the components of the vacuum process device 200 are provided and which supports the components, a panel member which partitions the inside of the vacuum process device 200 from the outside, and a door which can be opened and closed for accessing the inside of the vacuum process device 200 from the outside. The panel member and the door may be mounted on the frame structure. The casing 206 may include a radiation shielding material such as lead in order to prevent radiation, which can be generated by the vacuum process device 200, from leaking to the outside.

[0015] Alternatively, the casing 206 may not cover the entire surface of the vacuum process device 200. For example, a part of the casing 206 may be opened, and a part of the vacuum process device 200 may be seen from the outside.

[0016] The cryopump system 100 includes at least one cryopump 10, at least one compressor 12, a cryopump controller 110, a network 120, and a cryopump monitor 130.

[0017] The cryopump 10 is attached to the vacuum chamber 202 in order to evacuate the vacuum chamber 202 of the vacuum process device 200. Accordingly, the cryopump 10 is disposed in the casing 206 of the vacuum process device 200 together with the vacuum chamber 202. An exemplary configuration of the cryopump 10 that can be used in the cryopump system 100 according to the embodiment will be described later with reference to Fig. 2.

[0018] The compressor 12 is provided in order to supply and discharge a refrigerant gas to and from an expander (to be described later) provided in the cryopump 10. The compressor 12 is connected to the expander of the cryopump 10 by a gas line 13 and is disposed outside the casing 206 of the vacuum process device 200. The gas line 13 includes a high pressure line 13a that connects the compressor 12 to the expander such that the refrigerant gas is supplied from the compressor 12 to the expander and a low pressure line 13b that connects the compressor 12 to the expander such that the refrigerant gas is collected from the expander to the compressor 12. An exemplary configuration of the compressor 12 that can be used in the cryopump system 100 according to the embodiment will be described later with reference to Fig. 3.

[0019] In the cryopump system 100, a plurality of cryopumps 10, for example, several to tens of cryopumps 10 or more may be provided. In addition, in order to supply and discharge the refrigerant gas to and from the cryopumps 10, a plurality of compressors 12 may be provided in the cryopump system 100.

[0020] The cryopump controller 110 is configured to control the cryopump system 100 in a comprehensive manner based on a command received from the host controller 204. In addition, the cryopump controller 110 is configured to transmit information related to the cryopump system 100 to the host controller 204. Accordingly, the cryopump controller 110 can control the cryopump 10 and the compressor 12 based on the command from the host controller 204 and can transmit information related to the cryopump 10 and information related to the compressor 12 to the host controller 204.

[0021] The cryopump controller 110 is connected to the host controller 204 by a first communication line 208 so as to be able to communicate therewith. The first communication line 208 may be a communication cable such as RS-232C. As an example, similar to the host controller 204, the cryopump controller 110 is disposed in the casing 206 of the vacuum process device 200. As another example, the cryopump controller 110 may be disposed in the casing 206 of the vacuum process device 200.

[0022] Although details will be described later, the cryopump system 100 includes a sensor that measures a measurement parameter related to the cryopump system 100. In the cryopump system 100, a plurality of sensors (for example, a first temperature sensor 22 and a second temperature sensor 23 provided in the cryopump 10, a first pressure sensor 54 and a second pressure sensor 55 provided in the compressor 12, and the like) that measure measurement parameters different from each other may be provided. In a case where the cryopump system 100 includes the plurality of cryopumps 10, such a plurality of sensors may be provided for each of the cryopumps 10.

[0023] The cryopump controller 110 may be configured to receive measurement parameters from the sensors, to determine an operation parameter of the cryopump system 100 (for example, the operation frequency of an expander motor 30) such that the measurement parameters follow target values, and to operate the cryopump 10 with the determined operation parameter. In a case where the cryopump system 100 includes the plurality of cryopumps 10, the cryopump controller 110 may be configured to receive the measurement parameters from the sensors of the cryopump 10 for each of the plurality of cryopumps 10, to determine the operation parameter of the cryopump 10 such that the measurement parameters follow the target values, and to operate the cryopump 10 with the determined operation parameter.

[0024] The network 120 connects the cryopump 10 to the cryopump controller 110 so as to be able to communicate with each other. The cryopump system 100 transmits information related to the cryopump 10 between the cryopump 10 and the cryopump controller 110 via the network 120. The cryopump 10 is connected to the cryopump controller 110 by a second communication line 122. The second communication line 122 may be a communication cable such as RS-485.

[0025] The network 120 further connects the compressor 12 to the cryopump controller 110 so as to be able to communicate with each other. The cryopump system 100 transmits information related to the compressor 12 between the compressor 12 and the cryopump controller 110 via the network 120. The compressor 12 is connected to the cryopump controller 110 by a third communication line 123. The third communication line 123 may be a communication cable such as RS-485.

[0026] The cryopump monitor 130 is connected to the network 120 and is configured to display information related to the cryopump 10, which is transmitted via the network 120. In addition thereto or instead thereof, the cryopump monitor 130 may be configured to display information related to the compressor 12, which is transmitted via the network 120.

[0027] As shown, the cryopump monitor 130 may be connected to the network 120 without going through the host controller 204. That is, the cryopump monitor 130 may be configured not to communicate with the host controller 204 of the vacuum process device 200. In the shown example, the cryopump monitor 130 is connected to the cryopump controller 110 by a fourth communication line 124. The fourth communication line 124 may be a communication cable such as RS-485.

[0028] The cryopump monitor 130 is disposed outside the casing 206 of the vacuum process device 200. The cryopump monitor 130 may be disposed at a place separated from the casing 206. As shown, the cryopump monitor 130 may be provided in the compressor 12 or in the vicinity thereof. The cryopump monitor 130 may be provided on a monitor provision surface provided in the vicinity of the compressor 12. The monitor provision surface may be, for example, a wall surface in the vicinity of the compressor 12 or a surface of a device in the vicinity of the compressor 12.

[0029] The cryopump monitor 130 may be detachably provided in the cryopump system 100 and may be connected to the network 120 as necessary at a timing when the cryopump system 100 needs to be monitored. The cryopump monitor 130 is not necessarily provided in the cryopump system 100 at all times. For example, the cryopump monitor 130 may be detachably mounted on the compressor 12.

[0030] In the embodiment, the cryopump monitor 130 is configured to acquire time-series data of a measurement parameter and time-series data of an operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other. An exemplary configuration of the cryopump monitor 130 that can be used in the cryopump system 100 according to the embodiment will be described later with reference to Fig. 5.

[0031] Internal configurations of the cryopump controller 110 and the cryopump monitor 130 are realized by an element or a circuit including a CPU and a memory of a computer as a hardware configuration and are realized by a computer program or the like as a software configuration, but are shown in the drawings as functional blocks 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. For example, the cryopump monitor 130 can be mounted in combination with a processor 132 such as a central processing unit (CPU) and a microcomputer and a software program executed by the processor 132. The software program may be a computer program (for example, a cryopump monitoring program) for causing the processor 132 to execute the cryopump monitoring method according to the embodiment.

[0032] Fig. 2 is a schematic view showing an example of the cryopump 10 that can be used in the cryopump system 100 according to the embodiment. The cryopump 10 includes an expander 14, a cryopump container 16, a radiation shield 18, and a cryopanel 20. In addition, the cryopump 10 includes a pressure sensor 21, a rough valve 24, a purge valve 26, and a vent valve 28, and the components are provided in the cryopump container 16.

[0033] The compressor 12 is configured to collect a refrigerant gas from the expander 14, to pressurize the collected refrigerant gas, and to supply the refrigerant gas to the expander 14 again. The expander 14 is also called a cold head and configures a cryocooler together with the compressor 12. The expander 14 is also called a "cryocooler" in some cases. A thermodynamic cycle, through which chill is generated, is configured by performing circulation of the refrigerant gas between the compressor 12 and the expander 14 with an appropriate combination of pressure fluctuations and volume fluctuations of the refrigerant gas in the expander 14, and thereby the expander 14 can provide cryogenic temperature cooling. Although the refrigerant gas is typically a helium gas, other appropriate gases may be used. In order to facilitate understanding, a direction in which the refrigerant gas flows is indicated with arrows in Fig. 1. Although the cryocooler is, for example, a two-stage Gifford-McMahon (GM) cryocooler, the cryocooler may be a pulse tube cryocooler, a Stirling cryocooler, or other types of cryocoolers.

[0034] The cryopump container 16 is a vacuum chamber designed to maintain vacuum during an evacuation operation of the cryopump 10 and to withstand the pressure of an ambient environment (for example, the atmospheric pressure). The cryopump container 16 includes a cryopanel accommodation unit 16a including an intake port 17 and a cryocooler accommodation unit 16b. The cryopanel accommodation unit 16a has a dome shape in which the intake port 17 is opened and an opposite side thereof is closed, and the radiation shield 18 and the cryopanel 20 are accommodated therein. The cryocooler accommodation unit 16b has a cylindrical shape, and has one end fixed to a room temperature portion of the expander 14 and the other end connected to the cryopanel accommodation unit 16a. The expander 14 is inserted therein. In addition, the pressure sensor 21 measures a pressure in the cryopump container 16.

[0035] The radiation shield 18 is thermally coupled to a first cooling stage of the expander 14 and is cooled to a first cooling temperature (for example, 80K to 120K). The cryopanel 20 is thermally coupled to a second cooling stage of the expander 14 and is cooled to a second cooling temperature (for example, 10K to 20K) lower than the first cooling temperature. The radiation shield 18 is disposed in the cryopump container 16 to surround the cryopanel 20 and shields against input heat into the cryopanel 20 from the cryopump container 16 and the ambient environment. A gas that enters from the intake port 17 of the cryopump 10 is captured through condensation or adsorption in the cryopanel 20. Since various known configurations can be adopted as appropriate as configurations of the cryopump 10, such as the dispositions and shapes of the radiation shield 18 and the cryopanel 20, description thereof will not be made in detail herein.

[0036] In addition, the first temperature sensor 22 that measures the temperature of the radiation shield 18 and the second temperature sensor 23 that measures the temperature of the cryopanel 20 are provided in the cryopump container 16. The cryopump controller 110 may be connected to the first temperature sensor 22 to receive a first measured temperature signal indicating a first cooling temperature measured by the first temperature sensor 22 and may be connected to the second temperature sensor 23 to receive a second measured temperature signal indicating a second cooling temperature measured by the second temperature sensor 23.

[0037] The rough valve 24 is attached to the cryopump container 16, for example, the cryocooler accommodation unit 16b. The rough valve 24 is connected to a rough pump (not shown) provided outside the cryopump 10. The rough pump is a vacuum pump for evacuating the cryopump 10 to an operation start pressure thereof. Through control by the cryopump controller 110, the cryopump container 16 communicates with the rough pump when the rough valve 24 is opened, and the cryopump container 16 is cut off from the rough pump when the rough valve 24 is closed. By opening the rough valve 24 and operating the rough pump, the cryopump 10 can be decompressed.

[0038] The purge valve 26 is attached to the cryopump container 16, for example, to the cryopanel accommodation unit 16a. The purge valve 26 is connected to a purge gas supply device (not shown) provided outside the cryopump 10. Through control by the cryopump controller 110, a purge gas is supplied to the cryopump container 16 when the purge valve 26 is opened, and the purge gas supply to the cryopump container 16 is cut off when the purge valve 26 is closed. The purge gas may be, for example, a nitrogen gas or other dry gases. The temperature of the purge gas may be adjusted, for example, to the room temperature or may be heated to a temperature higher than the room temperature. By opening the purge valve 26 and introducing the purge gas into the cryopump container 16, the cryopump 10 can be pressurized. In addition, the temperature of the cryopump 10 can be increased from a cryogenic temperature to the room temperature or a temperature higher than the room temperature.

[0039] The vent valve 28 is attached to the cryopump container 16, for example, the cryocooler accommodation unit 16b. The vent valve 28 is provided in order to exhaust a fluid from the inside to the outside of the cryopump 10. The fluid exhausted from the vent valve 28 is basically a gas, but may be a liquid or a mixture of a gas and a liquid. The vent valve 28 can be opened and closed through control by the cryopump controller 110. Along with this, the vent valve 28 can be mechanically opened by a differential pressure inside and outside the cryopump container 16. When an excessive pressure is generated in the cryopump container 16, the vent valve 28 is configured to also function as a safety valve for releasing the pressure to the outside.

[0040] In addition, the expander 14 is provided with the variable speed expander motor 30 that drives the expander 14. The expander motor 30 includes an inverter, and the operation frequency (that is, rotation speed) of the expander motor 30 can be changed by the control of the cryopump controller 110. The operation frequency of the expander motor 30 determines the number of times of a heat cycle (in the case of a GM cryocooler, a GM cycle) performed in the expander 14 per unit time, that is, the frequency of the heat cycle.

[0041] The cryopump 10 may include an input and output circuit 32 that puts transmission and reception between the cryopump 10 and the cryopump controller 110 together. The input and output circuit 32 may be, for example, an I/O module or a remote I/O unit. The input and output circuit 32 is electrically connected to each of devices of the cryopump 10, such as the pressure sensor 21, the first temperature sensor 22, the second temperature sensor 23, the rough valve 24, the purge valve 26, the vent valve 28, and the expander motor 30 to transmit and receive a signal to and from each of the devices. In addition, the input and output circuit 32 is connected to the cryopump controller 110 by the second communication line 122 so as to be able to communicate therewith.

[0042] Therefore, the cryopump 10 transmits a measured pressure signal indicating a measured pressure in the cryopump container 16 from the pressure sensor 21 to the cryopump controller 110 via the input and output circuit 32 (and the second communication line 122). The cryopump 10 transmits a measured temperature signal indicating a measured temperature from each of the first temperature sensor 22 and the second temperature sensor 23 to the cryopump controller 110 via the input and output circuit 32. In addition, the cryopump 10 transmits a valve state signal indicating the open or closed state of each valve (that is, the rough valve 24, the purge valve 26, and the vent valve 28) to the cryopump controller 110 via the input and output circuit 32. The cryopump 10 transmits a motor state signal indicating the on or off state and operation frequency of the expander motor 30 to the cryopump controller 110 via the input and output circuit 32.

[0043] In addition, the cryopump 10 receives a valve control signal from the cryopump controller 110, which indicates an operation command to each valve, with the input and output circuit 32, and the input and output circuit 32 transmits the valve control signal to a corresponding valve. The valve which has received the valve control signal is opened and closed in accordance with the valve control signal. Similarly, the cryopump 10 receives a motor control signal from the cryopump controller 110, which indicates an operation command to the expander motor 30, with the input and output circuit 32, and the input and output circuit 32 transmits the motor control signal to the expander motor 30. The expander motor 30 is turned on and off or an operation frequency thereof is controlled in accordance with the motor control signal.

[0044] As described above, the cryopump controller 110 may be configured to receive measurement parameters from the sensors, to determine an operation parameter of the cryopump 10 such that the measurement parameters follow target values, and to operate the cryopump 10 with the determined operation parameter.

[0045] For example, the cryopump controller 110 may be configured to control the expander 14 based on a first cooling temperature measured by the first temperature sensor 22 during the evacuation operation of the vacuum chamber 202 by the cryopump 10. For example, the cryopump controller 110 may control the operation frequency of the expander motor 30 through feedback-control to minimize a deviation between the first measured temperature and a first target temperature. The cryopump controller 110 may determine the operation frequency of the expander motor 30 as a function of a deviation between a measured temperature and a target temperature (for example, through PID control). The cryopump controller 110 outputs the determined operation frequency to the expander motor 30, and the expander motor 30 is operated at the determined operation frequency.

[0046] The first target temperature is usually set to a constant value. For example, the first target temperature is determined as a specification according to a process performed by the vacuum process device 200 to which the cryopump 10 is attached. The target temperature may be changed as necessary during the operation of the cryopump 10.

[0047] When a heat load to the cryopump 10 has increased, the temperature of the radiation shield 18 can increase. In a case where a measured temperature from the first temperature sensor 22 is higher than the target temperature, the cryopump controller 110 increases the operation frequency of the expander motor 30. As a result, the frequency of the heat cycle in the expander 14 is also increased, and the radiation shield 18 is cooled toward the target temperature. On the contrary, in a case where a measured temperature from the first temperature sensor 22 is lower than the target temperature, the operation frequency of the expander motor 30 is decreased, and the temperature of the radiation shield 18 is increased toward the target temperature. In such a manner, the first cooling temperature can be kept in a temperature range in the vicinity of the first target temperature. Since the operation frequency of the expander motor 30 can be appropriately adjusted according to the heat load, such control is helpful in reducing the power consumption of the cryopump 10.

[0048] In order to adjust the cooling capacity of the expander 14, the expander 14 may include a heating device 34 such as an electric heater thermally coupled to the radiation shield 18 such that the radiation shield 18 can be heated, instead of or in addition to controlling the operation frequency of the expander motor 30. The cryopump controller 110 may be configured to control switching of the on or off state of the heating device 34 and/or power input into the heating device 34. In this case, the cryopump controller 110 may control an input into the heating device 34 through feedback-control to minimize a deviation between a first measured temperature and the first target temperature. The cryopump controller 110 may determine the input into the heating device 34 as a function of a deviation between a measured temperature and a target temperature (for example, through PID control). In a case where a measured temperature from the first temperature sensor 22 is higher than the target temperature, the cryopump controller 110 decreases the input into the heating device 34 (or turns off the heating device 34). Accordingly, the radiation shield 18 is cooled toward the target temperature. On the contrary, in a case where the measured temperature from the first temperature sensor 22 is lower than the target temperature, the input into the heating device 34 is increased (or the heating device 34 is turned on), and the temperature of the radiation shield 18 is increased toward the target temperature.

[0049] Controlling the cryopump 10 according to the first target temperature as described above is called "single-stage temperature control" in some cases. In the single-stage temperature control, the temperature of the cryopanel 20 is not directly controlled. That is, as a result of the single-stage temperature control, the cryopanel 20 is cooled to a temperature determined by a two-stage cooling capacity of the expander 14 and a heat load from the outside.

[0050] Similarly, the cryopump controller 110 can also execute so-called "two-stage temperature control" in which the expander 14 is controlled such that the temperature of the cryopanel 20 follows a target temperature. In this case, the cryopump controller 110 may be configured to control the expander 14 based on a second cooling temperature measured by the second temperature sensor 23. For example, the cryopump controller 110 may control the operation frequency of the expander motor 30 (or an input into a heating device that heats the cryopanel 20) through feedback-control to minimize a deviation between a second measured temperature and a second target temperature. Accordingly, the temperature of the cryopanel 20 can be made to follow the target temperature. In the two-stage temperature control, a first-stage cooling temperature (that is, the temperature of the radiation shield 18) is not directly controlled. The first-stage cooling temperature in the two-stage temperature control is determined by a first-stage cooling capacity of the expander 14 and a heat load from the outside.

[0051] In addition, in a regeneration operation of the cryopump 10, the cryopump controller 110 may control the rough valve 24, the purge valve 26, the vent valve 28, and the expander motor 30 based on a pressure in the cryopump container 16 (or as necessary, based on the temperature of the cryopanel 20 and a pressure in the cryopump container 16) .

[0052] Fig. 3 is a schematic view showing an example of the compressor 12 that can be used in the cryopump system 100 according to the embodiment. The compressor 12 includes a high pressure gas outlet 50, a low pressure gas inlet 51, a high pressure flow path 52, a low pressure flow path 53, the first pressure sensor 54, the second pressure sensor 55, a bypass line 56, a compressor main body 57, and a compressor casing 58.

[0053] The high pressure gas outlet 50 is provided in the compressor casing 58 as a working gas discharge port of the compressor 12, and the low pressure gas inlet 51 is provided in the compressor casing 58 as a working gas suction port of the compressor 12. The high pressure line 13a is connected to the high pressure gas outlet 50, and the low pressure line 13b is connected to the low pressure gas inlet 51. The high pressure flow path 52 connects a discharge port of the compressor main body 57 to the high pressure gas outlet 50, and the low pressure flow path 53 connects the low pressure gas inlet 51 to a suction port of the compressor main body 57. The compressor casing 58 accommodates the high pressure flow path 52, the low pressure flow path 53, the first pressure sensor 54, the second pressure sensor 55, the bypass line 56, and the compressor main body 57. The compressor 12 is also called a compressor unit.

[0054] The compressor main body 57 is configured to internally compress a working gas sucked from the suction port and to discharge the working gas from the discharge port. The compressor main body 57 may be, for example, a scroll type pump, a rotary type pump, or other pumps that pressurize the working gas. The compressor main body 57 may include a variable speed compressor motor 57a. The compressor motor 57a includes an inverter and can change a motor operation frequency through control by the cryopump controller 110. In such a manner, the compressor main body 57 may be configured to change the flow rate of the working gas to be discharged. Alternatively, the compressor main body 57 may be configured to discharge the working gas at a fixed and constant flow rate. The compressor main body 57 is called a compression capsule in some cases.

[0055] The first pressure sensor 54 is disposed in the high pressure flow path 52 to measure the pressure of a working gas flowing in the high pressure flow path 52. The second pressure sensor 55 is disposed in the low pressure flow path 53 to measure the pressure of the working gas flowing in the low pressure flow path 53. Accordingly, the first pressure sensor 54 and the second pressure sensor 55 can also be called a high pressure sensor and a low pressure sensor, respectively.

[0056] The bypass line 56 connects the high pressure flow path 52 to the low pressure flow path 53 such that a working gas bypasses the expander 14 and returns from the high pressure flow path 52 to the low pressure flow path 53. A relief valve 60 for opening and closing the bypass line 56 and controlling the flow rate of the working gas flowing in the bypass line 56 is provided in the bypass line 56. The relief valve 60 is configured to open when a differential pressure that is equal to or higher than a set pressure acts between an inlet and an outlet thereof. The relief valve 60 may be an on/off valve or a flow rate control valve or may be, for example, a solenoid valve. The set pressure can be set as appropriate based on empirical knowledge of a designer, experiments or simulations by the designer, or the like. Accordingly, a differential pressure between the high pressure line 13a and the low pressure line 13b can be prevented from exceeding the set pressure and becoming excessive.

[0057] For example, the relief valve 60 may be opened and closed under the control by the cryopump controller 110. The cryopump controller 110 may compare a measured differential pressure between the high pressure line 13a and the low pressure line 13b to the set pressure and control the relief valve 60 such that the relief valve 60 is opened in a case where the measured differential pressure is equal to or higher than the set pressure, and the relief valve 60 is closed in a case where the measured differential pressure is lower than a set differential pressure. The cryopump controller 110 may acquire the measured differential pressure between the high pressure line 13a and the low pressure line 13b from measured pressures from the first pressure sensor 54 and the second pressure sensor 55. As another example, the relief valve 60 may be configured to operate as a so-called safety valve, that is, may be mechanically opened when the differential pressure that is equal to or higher than the set pressure acts between the inlet and the outlet.

[0058] The cryopump controller 110 may be configured to receive measurement parameters from the sensors, to determine an operation parameter of the compressor 12 such that the measurement parameters follow target values, and to operate the compressor 12 with the determined operation parameter. For example, the cryopump controller 110 may be configured to control the operation frequency of the compressor motor 57a based on a measured pressure (for example, a first pressure measured by the first pressure sensor 54, a second pressure measured by the second pressure sensor 55, or a differential pressure between the first pressure and the second pressure). The cryopump controller 110 may control the operation frequency of the compressor motor 57a through feedback-control to minimize a deviation between the measured pressure and a target pressure. The cryopump controller 110 may determine the operation frequency of the compressor motor 57a as a function of a deviation between the measured pressure and the target pressure (for example, through PID control). The cryopump controller 110 outputs the determined operation frequency to the compressor motor 57a, and the compressor motor 57a is operated at the determined operation frequency.

[0059] The compressor 12 can include other various components. For example, an oil separator, an adsorber, or the like may be provided in the high pressure flow path 52. A storage tank and other components may be provided in the low pressure flow path 53. In addition, an oil circulation system that cools the compressor main body 57 with an oil, a cooling system that cools the oil with cooling water, and the like may be provided in the compressor 12.

[0060] The operation of the cryopump 10 having the configuration will be described below. In a case of operating the cryopump 10, first, the vacuum chamber 202 is evacuated to a predetermined pressure (for example, approximately 100 Pa or approximately 10 Pa) by another suitable roughing pump before the operation. A gate valve is usually provided between the vacuum chamber 202 and the intake port 17 of the cryopump 10, and the gate valve is closed during evacuation of the vacuum chamber 202. Then (or in parallel with the evacuation of the vacuum chamber 202), the cryopump 10 is operated. The radiation shield 18 and the cryopanel 20 are cooled to a first cooling temperature and a second cooling temperature, respectively, by driving the expander 14. The intake port 17 may be provided with a baffle thermally coupled to the radiation shield 18, and the baffle is also cooled to the first cooling temperature together with the radiation shield 18. Then, the gate valve is opened, and the evacuation of the vacuum chamber 202 by the cryopump 10 is started.

[0061] The baffle and the radiation shield 18 cooled to a first cooling temperature cool a gas flying from the vacuum chamber 202 toward the cryopump 10. A gas having a sufficiently low vapor pressure (for example, 10^{-8} Pa or less) at the first cooling temperature condenses on surfaces thereof. The gas may be called a type 1 gas. The type 1 gas is, for example, steam. In such a manner, the cryopump 10 can exhaust the type 1 gas. Some of the gas having a vapor pressure that is not sufficiently low at the first cooling temperature enters the cryopump 10 from the intake port 17. Alternatively, the rest of the gas is reflected by the baffle and returns to the vacuum chamber 202 without entering the cryopump 10.

[0062] A gas that has entered the cryopump 10 is cooled by the cryopanel 20. A gas having a sufficiently low vapor pressure (for example, 10^{-8} Pa or less) at a second cooling temperature condenses on the surface of the cryopanel 20. The gas may be called a type 2 gas. The type 2 gas is, for example, argon. In such a manner, the cryopump 10 can exhaust the type 2 gas.

[0063] A gas having a vapor pressure that is not sufficiently low at a second cooling temperature is adsorbed by an adsorbent such as activated carbon provided on the surface of the cryopanel 20. The gas may be called a type 3 gas. The type 3 gas is, for example, hydrogen. In such a manner, the cryopump 10 can exhaust the type 3 gas. Therefore, the cryopump 10 can exhaust various gases through condensation or adsorption and can cause the degree of vacuum of the vacuum chamber 202 to reach a desired level.

[0064] Fig. 4 is a flowchart showing the cryopump monitoring method according to the embodiment. The present method includes acquiring time-series data of a measurement parameter related to the cryopump system 100 (S10), acquiring time-series data of an operation parameter of the cryopump system 100, which is controlled such that the measurement parameter follows a target value (S20), and displaying a time-series graph of the measurement parameter and a time-series graph of an operation parameter with time axes thereof aligned with each other (S30).

[0065] As described above, the cryopump system 100 is provided with various types of sensors that measure measurement parameters related to the cryopump system 100, such as the first temperature sensor 22, the second temperature sensor 23, the first pressure sensor 54, and the second pressure sensor 55. The measurement parameters continuously measured by such sensors during the operation of the cryopump system 100 are input into the cryopump controller 110 in order to control the cryopump system 100. The cryopump controller 110 determines an operation parameter of the cryopump system 100 based on the acquired measurement parameters.

[0066] Time-series data of the measurement parameters and the operation parameter acquired in such a manner may be stored in a storage unit provided in the cryopump controller 110. Alternatively, the time-series data of the measurement parameters and the time-series data of the operation parameter may be stored in an external storage device that can be connected to the cryopump controller 110. The time-series data may be relatively long-term data and may be, for example, time-series data over at least one month, at least half a year, or at least one year of an operation period.

[0067] In S10, the processor 132 (see Fig. 1) of the cryopump monitor 130 acquires time-series data of a measurement parameter from the cryopump controller 110. The processor 132 may acquire the time-series data of the measurement parameter from the external storage device in which the time-series data is stored.

[0068] The processor 132 may acquire time-series data for a plurality of measurement parameters. For example, the processor 132 may acquire the time-series data for each of first to fourth measurement parameters. The first measurement parameter may be a first cooling temperature measured by the first temperature sensor 22. The second measurement parameter may be a second cooling temperature measured by the second temperature sensor 23. The third measurement parameter may be a first pressure measured by the first pressure sensor 54. The fourth measurement parameter may be a second pressure measured by the second pressure sensor 55.

[0069] In S20, the processor 132 acquires the time-series data of the operation parameter from the cryopump controller 110 (or the external storage device). The processor 132 may acquire the time-series data for a plurality of operation parameters and may acquire the time-series data for, for example, the operation frequency of the expander motor 30 and the operation frequency of the compressor motor 57a. In a case where the heating device 34 is provided in the expander 14, the processor 132 may acquire time-series data of an input into the heating device 34 instead of or in addition to the operation frequency of the expander motor 30.

[0070] In S30, the processor 132 generates a time-series graph of the measurement parameter based on the acquired time-series data of the measurement parameter. In a case where the time-series data of the plurality of measurement parameters is acquired, the processor 132 generates a time-series graph for each measurement parameter. In addition, the processor 132 generates a time-series graph of the operation parameter based on the acquired time-series data of the operation parameter. In a case where the time-series data of the plurality of operation parameters is acquired, the processor 132 generates a time-series graph for each operation parameter. The time-series graph is a graph in which time is represented by one of a vertical axis or a horizontal axis (for example, the horizontal axis), and a measurement parameter (or an operation parameter) is represented by the other (for example, the vertical axis).

[0071] As shown in Fig. 5, the cryopump monitor 130 includes a display 134 that displays information related to the cryopump system 100. The processor 132 is configured to control the display 134 to display the generated time-series graph of at least one of the measurement parameters and/or the operation parameters on the display 134.

[0072] For example, the processor 132 may be configured to set a display area for displaying a specific time-series graph on the display 134. A single display area may be set on the display 134, and a time-series graph of one measurement parameter (or operation parameter) may be displayed in the display area. Alternatively, a plurality of display areas for displaying corresponding time-series graphs may be set on the display 134, and the time-series graphs corresponding to the respective display areas may be displayed. For example, a first display area and a second display area may be set on the display 134, and a time-series graph of the measurement parameter may be displayed in the first display area, and a time-series graph of the operation parameter may be displayed in the second display area.

[0073] The processor 132 may be configured to switch a plurality of graph display screens on the display 134. In this case, for example, at least one display area may be set on a first graph display screen, and at least one display area may be set on a second graph display screen. Time-series graphs of measurement parameters (or operation parameters) different from each other may be displayed in the display area of the first graph display screen and the display area of the second graph display screen. For example, a time-series graph of the measurement parameter and the operation parameter related to the cryopump 10 may be displayed on the first graph display screen, and a time-series graph of the measurement parameter and the operation parameter related to the compressor 12 may be displayed on the second graph display screen.

[0074] In addition, the processor 132 may be configured to collectively display a plurality of time-series graphs in a specific display area. For example, the same measurement parameter (for example, the first cooling temperature) for the plurality of cryopumps 10 may be collectively displayed in the specific display area. In addition, the same operation parameter (for example, the operation frequency of the expander motor 30) for the plurality of cryopumps 10 may be collectively displayed in the specific display area.

[0075] In the embodiment, the processor 132 is configured to display a time-series graph of a measurement parameter and a time-series graph of an operation parameter on the display 134 with time axes thereof aligned with each other. An example of such graph display will be described later.

[0076] Fig. 5 is a schematic view showing an example of the cryopump monitor 130 that can be used in the cryopump system 100 according to the embodiment. As shown, on the display 134 of the cryopump monitor 130, for example, a first display area 136a, a second display area 136b, and a third display area 136c are set.

[0077] In this example, a time-series graph of a first cooling temperature T1 measured by the first temperature sensor 22 is displayed in the first display area 136a as a first measurement parameter. In the first time-series graph, a vertical axis represents the first cooling temperature T1, and a horizontal axis represents time. In the second display area 136b, the operation frequency of the expander motor 30 is displayed as a first operation parameter. In a second time-series graph, a vertical axis represents the operation frequency of the expander motor 30, and a horizontal axis represents time. In the third display area 136c, a time-series graph of a second cooling temperature T2 measured by the second temperature sensor 23 is displayed as a second measurement parameter. In a third time-series graph, a vertical axis represents the second cooling temperature T2, and a horizontal axis represents time.

[0078] The display areas, specifically, the first display area 136a, the second display area 136b, and the third display area 136c are set to be arranged in a vertical direction on the display 134. For this reason, the horizontal axes of the time-series graphs displayed in the display areas, that is, the time axes are aligned with each other. In other words, the same position on the horizontal axis of the time-series graph displayed in each display area represents the same time point.

[0079] The first display area 136a, the second display area 136b, and the third display area 136c are set to an upper portion, a middle portion, and a lower portion on the display 134, respectively. The second display area 136b is adjacent to a lower side of the first display area 136a, and the third display area 136c is adjacent to the lower side of the second display area 136b. Therefore, the time-series graph of the operation frequency of the expander motor 30 is displayed adjacent to the lower side of the time-series graph of the first cooling temperature T1. Further, the time-series graph of the second cooling temperature T2 is displayed adjacent to the lower side of the two time-series graphs.

[0080] The plurality of display areas are set to be able to identify the time-series graphs displayed in the respective display areas. In Fig. 5, as an example, the first display area 136a, the second display area 136b, and the third display area 136c are set on the display 134 to be arranged in the vertical direction with a slight gap therebetween. As another example, two display areas adjacent to each other (for example, the first display area 136a and the second display area 136b) may be set to be arranged without a gap. Alternatively, two display areas may be set to overlap each other at least partially. In short, insofar as time-series graphs of different parameters can be identified on the display 134, the display areas for the time-series graphs may be separated from each other or may overlap each other on the display 134.

[0081] As will be described later, the time-series graph of the first measurement parameter and the time-series graph of the first operation parameter may be displayed to be arranged so that a target value of the first measurement parameter and a limit value of the first operation parameter are close to each other. In order to realize this, a display position of the target value of the first measurement parameter may be determined at an edge portion (for example, a lower edge portion) of the first display area 136a, and a display position of the limit value of the first operation parameter may be determined at an edge portion (for example, an upper edge portion of the second display area 136b) close to the edge portion of the first display area 136a, among edge portions of the second display area 136b.

[0082] Fig. 6 is a schematic view showing an example of time-series graph display on the cryopump monitor 130 according to the embodiment. In this graph display, as described with reference to Fig. 5, the first cooling temperature T1 is displayed in the first display area 136a, the operation frequency of the expander motor 30 is displayed in the second display area 136b, and the second cooling temperature T2 is displayed in the third display area 136c.

[0083] In the example, the vertical axis of the first display area 136a is set on the right side of the area, and a numerical value (80K, 90K, 100K) indicating the first cooling temperature T1 is displayed on the right side. In addition, the vertical axis of the second display area 136b is set on the left side of the area, and a numerical value (50 Hz to 100 Hz) indicating the operation frequency of the expander motor 30 is displayed on the left side. Similarly, the vertical axis of the third display area 136c is set on the left side of the area, and a numerical value (10K to 20K) indicating the second cooling temperature T2 is displayed on the left side.

[0084] In addition, in the example of Fig. 6, since the lower edge portion of the first display area 136a and the upper edge portion of the second display area 136b are in contact with each other, a horizontal line indicating 80K in the first display area 136a and a horizontal line indicating 100 Hz in the second display area 136b match each other. On the other hand, a lower edge portion of the second display area 136b and an upper edge portion of the third display area 136c are separated from each other, and a horizontal line indicating 50 Hz in the second display area 136b and a horizontal line indicating 20K in the third display area 136c are drawn separately.

[0085] In the embodiment, as shown in Fig. 6, the cryopump monitor 130 can display the time-series graphs of the first cooling temperature T1, the operation frequency of the expander motor 30, and the second cooling temperature T2 with the time axes thereof aligned with each other.

[0086] Therefore, a measurement parameter and an operation parameter determined based on the measurement parameter can be visually and integrally read, such as the first cooling temperature T1 and the operation frequency of the expander motor 30. The state of the cryopump system, for example, the behaviors of the measurement parameter and the operation parameter at a certain time point or within a certain time range can be easily identified.

[0087] In addition, even for different measurement parameters such as the first cooling temperature T1 and the second cooling temperature T2, behaviors thereof can be identified on the same time axis.

[0088] In the example, the cryopump system 100 includes four cryopumps (Pump 1, Pump 2, Pump 3, and Pump 4). Accordingly, in Fig. 6, four time-series graphs corresponding to the four cryopumps are displayed for each of the first cooling temperature T1, the operation frequency of the expander motor 30, and the second cooling temperature T2 (that is, a total of 12 graphs are displayed). The four graphs of the first cooling temperature T1 are collectively displayed in the first display area 136a, the four graphs of the operation frequency of the expander motor 30 are collectively displayed in the second display area 136b, and the four graphs of the second cooling temperature T2 are collectively displayed in the third display area 136c. Therefore, the measurement parameter (or the operation parameter) can be easily compared between the different cryopumps 10.

[0089] However, for the first cooling temperature T1, four graphs overlap each other in most of the portions of the graph. This is because the single-stage temperature control described above is performed. In each of the four cryopumps, the first cooling temperature T1 is controlled to match a target temperature (in this example, 80K) within a predetermined temperature range (for example, a range of $\pm 0.1°C$) .

[0090] However, as shown in parts surrounded by dashed-line squares 138a, 138b, and 138c in Fig. 6, the first cooling temperature T1 of a certain cryopump 10 deviates from the target temperature and a situation where the target temperature is exceeded occurs in some cases. Such a situation can occur due to a case where a heat load to the cryopump 10 from the outside such as the vacuum chamber 202 is excessively large, degradation of the cryopump 10 over time caused by a long-term operation of the cryopump 10, and the like. In this case, to return the first cooling temperature T1 to the target temperature, the operation frequency of the expander motor 30 is increased to finally reach an upper limit value determined in advance (95 Hz in this example) and is maintained at the upper limit value. Nevertheless, it can be seen from Fig. 6 that the first cooling temperature T1 continues to rise.

[0091] In the example, as shown in Fig. 6, the time-series graph of the first cooling temperature T1 and the time-series graph of the operation frequency of the expander motor 30 are displayed to be arranged so that a target value (for example, 80K) of the first cooling temperature T1 and a limit value (for example, an upper limit value, for example, 95 Hz) of the operation frequency of the expander motor 30 are close to each other. Specifically, a display position of the target value of the first cooling temperature T1 is determined at the lower edge portion of the first display area 136a, and a display position of the upper limit value of the operation frequency of the expander motor 30 is determined at the upper edge portion of the second display area 136b. Accordingly, it is possible for an observer to continuously and integrally recognize the behavior of the cryopump system 100 in which the first cooling temperature T1 exceeds the target temperature and rises when the operation frequency of the expander motor 30 reaches the upper limit value.

[0092] The processor 132 of the cryopump monitor 130 may be configured to display a mark 140 indicating that diagnosis has been performed on the cryopump 10 at a position 142 of a diagnosis time on the time axis of the time-series graph on the display 134. In such a manner, it is possible to easily identify that there is a related diagnosis result on the time-series graph of the measurement parameter and/or the operation parameter.

[0093] Diagnosis may be performed by the cryopump controller 110 based on an acquired measurement parameter and/or an acquired operation parameter. The diagnosis may be performed by applying a diagnosis method based on comparison between the acquired parameter and a diagnosis threshold value, a known cryopump diagnosis method already proposed, or other appropriate diagnosis methods, and the diagnosis will not be described in detail herein.

[0094] In the shown example, a symbol "!" is displayed as the mark 140 to indicate the position 142 on the time axis corresponding to the diagnosis time. The mark 140 may include, for example, words indicating a diagnosis result such as "failure", "abnormality occurrence", and "normal".

[0095] In addition, the mark 140 may be displayed to indicate a parameter to be focused on in the diagnosis result. In the shown example, at a diagnosis time point indicated by the mark 140, the operation frequency of the expander motor 30 reaches the upper limit value, and as a result, the first cooling temperature T1 starts deviating from the target temperature. Therefore, the mark 140 includes an arrow indicating the position of the diagnosis time point on the time-series graph of the first cooling temperature T1.

[0096] In addition, the processor 132 may be configured to display diagnosis information of the cryopump 10 associated with the mark 140 on the display 134 in response to designation of the mark 140 by an operator. The diagnosis information of the cryopump 10 may be a diagnosis report including a document, a drawing, and a photograph describing a diagnosis result. In a case where disassembly inspection of the cryopump 10 is performed during diagnosis, a photograph or a description document of the disassembly inspection may be included in the diagnosis information. For example, the diagnosis information of the cryopump 10 may be associated with the mark 140 in a hypertext format or other appropriate formats. The mark 140 can be designated by an appropriate input operation by the operator, for example, operating a pointer displayed on the display 134. In such a manner, the detailed diagnosis result can be easily identified, which is convenient.

[0097] Fig. 7 is a schematic view showing another example of time-series graph display on the cryopump monitor 130 according to the embodiment. In a case where the heating device 34 is controlled instead of controlling the operation frequency of the expander motor 30, an input into the heating device 34 may be displayed in the second display area 136b. As in the example described above, the first cooling temperature T1 and the second cooling temperature T2 are displayed in the first display area 136a and the third display area 136c, respectively. Three time-series graphs of the first cooling temperature T1, the input into the heating device 34, and the second cooling temperature T2 are displayed on the display 134 with the time axes thereof aligned with each other.

[0098] As described with reference to Fig. 6, the first cooling temperature T1 of the cryopump 10 deviates from the target temperature and a situation where the target temperature is exceeded occurs in some cases (the dashed-line squares 138a, 138b, and 138c in Fig. 6). In this case, to return the first cooling temperature T1 to the target temperature, an input into the heating device 34 is reduced to finally reach a lower limit value determined in advance (0 W in this example) and is maintained at the lower limit value determined in advance. In short, the heating device 34 is turned off. However, it can be seen from Fig. 7 that the first cooling temperature T1 continues to rise even when the heating device 34 is turned off.

[0099] The time-series graph of the first cooling temperature T1 and the time-series graph of an input into the heating device 34 are displayed to be arranged so that the target value (for example, 80K) of the first cooling temperature T1 and a limit value (for example, a lower limit value, for example, 0 W) of the input into the heating device 34 are close to each other. Specifically, a display position of the target value of the first cooling temperature T1 is determined at the lower edge portion of the first display area 136a, and a display position of the lower limit value of the input into the heating device 34 is determined at the upper edge portion of the second display area 136b. The vertical axis of the second display area 136b representing the input into the heating device 34 has a value that decreases as it goes upward. Accordingly, it is possible for the observer to continuously and integrally recognize the behavior of the cryopump system 100 in which the first cooling temperature T1 exceeds the target temperature when the input into the heating device 34 reaches the lower limit value.

[0100] In a case where both the operation frequency of the expander motor 30 and the input into the heating device 34 are controlled in order to control the first cooling temperature T1 so that the first cooling temperature T1 becomes the target temperature, both the time-series graphs of the operation frequency of the expander motor 30 and the input into the heating device 34 may be displayed together with the time-series graph of the first cooling temperature T1.

[0101] Fig. 8 is a schematic view showing still another example of time-series graph display on the cryopump monitor 130 according to the embodiment. The cryopump monitor 130 may display a measurement parameter and an operation parameter related to the compressor 12 with time axes thereof aligned with each other. Thus, the cryopump monitor 130 may set a fourth display area 136d and a fifth display area 136e on the display 134. In the fourth display area 136d, time-series graphs of a first pressure PH measured by the first pressure sensor 54 and a second pressure PL measured by the second pressure sensor 55 are collectively displayed. In the fifth display area 136e, a time-series graph of a differential pressure DP between the first pressure PH and the second pressure PL and a time-series graph of an operation frequency F of the compressor motor 57a are collectively displayed. In other words, the fifth display area 136e where the differential pressure DP is displayed and a sixth display area where the operation frequency F is displayed are set on the display 134 so as to overlap each other. The mark 140 may be displayed for the measurement parameter and the operation parameter related to the compressor 12.

[0102] The two display areas shown in Fig. 8 may be set on the same screen as the first to third display areas (136a to 136c) related to the cryopump 10 or may be set on a different screen that can be switched.

[0103] As shown by the mark 140 in Fig. 8, during the operation of the compressor 12, regardless of the fact that the operation frequency F of the compressor motor 57a reaches an upper limit value (78 Hz in this example) determined in advance, the differential pressure DP between the first pressure PH and the second pressure PL deviates from a target differential pressure (for example, 1.5 MPa) and falls below the target differential pressure in some cases (a vertical axis on the right side in the fifth display area 136e, which indicates the differential pressure DP, indicates a smaller value as it goes upward.)

[0104] In the example, as shown in Fig. 8, the time-series graph of the differential pressure DP and the time-series graph of the operation frequency of the compressor motor 57a are displayed to be arranged so that a target value (for example, 1.5 MPa) of the differential pressure DP and a limit value (for example, an upper limit value, for example, 78 Hz) of the operation frequency of the compressor motor 57a are close to each other. Accordingly, it is possible for the observer to continuously and integrally recognize the behavior of the cryopump system 100 in which the differential pressure DP deviates from the target value and decreases when the operation frequency of the compressor motor 57a reaches the upper limit value.

[0105] The present invention has been described hereinbefore based on the examples. 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.

[0106] Although a case where the cryopump monitor 130 displays a time-series graph as an image on the display 134 has been described as an example in the embodiment described above, the cryopump monitor 130 may be configured to display the time-series graph in another format. For example, the cryopump monitor 130 may be configured to print the display of the time-series graph on a paper surface.

[0107] In addition, the cryopump monitor 130 may be disposed remotely from the cryopump 10 or the vacuum process device 200 and may be connected to the cryopump controller 110 so as to be able to communicate therewith via, for example, the Internet or other appropriate communication network. The cryopump controller 110 may output time-series data of a measurement parameter and/or the operation parameter to the communication network, and the cryopump monitor 130 may receive the data output from the cryopump controller 110 from the communication network.

[0108] The cryopump monitor 130 may be a standalone device. In other words, the cryopump monitor 130 may be configured not to communicate with the cryopump controller 110. In this case, the cryopump monitor 130 may acquire such time-series data from a computer-readable medium in which the time-series data of the measurement parameter and/or the operation parameter is stored. The time-series data may be output and stored in advance in the computer-readable medium from the cryopump controller 110 (or another controller or a storage device). Such a computer-readable medium may be connected to the cryopump monitor 130, and the time-series data may be read into the cryopump monitor 130. The computer-readable medium may be, for example, a computer-readable medium in various known forms such as a hard disk and a USB memory.

[0109] The cryopump monitor 130 may be a computer (for example, a general-purpose computer such as a personal computer) on which the cryopump monitoring program according to the embodiment is implemented. Alternatively, the cryopump monitor 130 may be mounted on an electronic device such as a smartphone that can be carried by a worker. Alternatively, the cryopump monitor 130 may be mounted on a monitor device mounted on the vacuum process device 200.

[0110] Although a case where the plurality of cryopumps 10 are controlled by the common cryopump controller 110 has been described as an example in the embodiment described above, the present invention is not limited thereto. As shown in Fig. 9, the cryopump system 100 may include a plurality of controllers 110a that individually control the plurality of cryopumps 10, instead of the cryopump controller 110. As described above, in each of the cryopumps 10, a sensor (for example, as shown in Figs. 2 and 3, the first temperature sensor 22 and the second temperature sensor 23 provided in the cryopump 10, the first pressure sensor 54 and the second pressure sensor 55 provided in the compressor 12, and the like) that measures a measurement parameter related to the cryopump 10 may be provided. Each of the controllers 110a may be configured, for the corresponding cryopump 10, to receive the measurement parameter from the sensor of the cryopump 10, to determine the operation parameter of the cryopump 10 so that the measurement parameter follows the target value, and to operate the cryopump 10 with the determined operation parameter.

[0111] For each of the plurality of cryopumps 10, the cryopump monitor 130 may be configured to acquire time-series data of a measurement parameter and time-series data of an operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with the time axes thereof aligned with each other. In this case, the cryopump monitor 130 may acquire the time-series data of the measurement parameter and/or the operation parameter from each controller 110a via the communication network. Alternatively, the cryopump monitor 130 may acquire such time-series data from the computer-readable medium in which the time-series data of the measurement parameter and/or the operation parameter is stored. In such a manner, as shown in Fig. 6, the cryopump monitor 130 may display time-series graphs of the first cooling temperature T1, the operation frequency of the expander motor 30, and the second cooling temperature T2.

[0112] Although a case where the compressor 12 is controlled by the cryopump controller 110 has been described as an example in the embodiment described above, the present invention is not limited thereto. As shown in Fig. 9, the cryopump system 100 may include a compressor controller 12a that controls the compressor 12. The compressor controller 12a may be configured to autonomously (that is, independently of the control of the cryopump 10) control the compressor 12. Therefore, the compressor controller 12a may be configured to receive the measurement parameter related to the compressor

12 from the sensor, to determine the operation parameter of the compressor 12 such that the measurement parameter follows the target value, and to operate the compressor 12 with the determined operation parameter. For example, the compressor controller 12a may be configured to control the operation frequency of the compressor motor 57a based on a measured pressure (for example, the first pressure measured by the first pressure sensor 54, the second pressure measured by the second pressure sensor 55, or a differential pressure between the first pressure and the second pressure). The compressor controller 12a may be provided separately from the cryopump controller 110 and may be mounted on the compressor 12. Also in the cryopump system 100 exemplified with reference to Figs. 1 to 3, the compressor controller 12a that controls the compressor 12 may be provided as described above.

[0113] The cryopump monitor 130 may be configured to acquire time-series data of a measurement parameter and time-series data of an operation parameter related to the compressor 12 and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with the time axes thereof aligned with each other. In this case, the cryopump monitor 130 may acquire the time-series data of the measurement parameter and/or the operation parameter from the compressor controller 12a via the communication network. Alternatively, the cryopump monitor 130 may acquire such time-series data from the computer-readable medium in which the time-series data of the measurement parameter and/or the operation parameter is stored. In such a manner, as shown in Fig. 8, the cryopump monitor 130 may display time-series graphs of the first pressure PH measured by the first pressure sensor 54, the second pressure PL measured by the second pressure sensor 55, the differential pressure DP between the first pressure PH and the second pressure PL, and the operation frequency F of the compressor motor 57a.

[0114] The embodiment of the present invention can also be expressed as each of the following items with numbers.

1. A cryopump system including:

    a sensor that measures a measurement parameter related to the cryopump system;
    a cryopump controller that is configured to receive the measurement parameter from the sensor, to determine an operation parameter of the cryopump system such that the measurement parameter follows a target value, and to operate the cryopump system with the determined operation parameter; and
    a cryopump monitor that is configured to acquire time-series data of the measurement parameter and time-series data of the operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

2. The cryopump system according to item 1,
in which the cryopump monitor is configured to display the time-series graph of the measurement parameter and the time-series graph of the operation parameter to be arranged so that the target value of the measurement parameter and a limit value of the operation parameter are close to each other.

3. The cryopump system according to item 2,
in which the cryopump monitor is configured to determine a display position of the target value of the measurement parameter at an edge portion of a first display area where the time-series graph of the measurement parameter is displayed and to determine a display position of the limit value of the operation parameter at an edge portion close to the edge portion of the first display area, among edge portions of a second display area where the time-series graph of the operation parameter is displayed.

4. The cryopump system according to any one of items 1 to 3,
in which the cryopump monitor is configured to display a mark indicating that diagnosis of the cryopump system has been performed at a position of a diagnosis time on the time axis.

5. The cryopump system according to item 4,
in which the cryopump monitor is configured to display diagnosis information of the cryopump system associated with the mark in response to designation of the mark by an operator.

6. The cryopump system according to any one of items 1 to 5, further including:

    a second sensor that measures a second measurement parameter related to the cryopump system, which is different from the measurement parameter,
    in which the cryopump monitor is configured to acquire time-series data of the second measurement parameter and to also display a time-series graph of the second measurement parameter together with the time-series graphs of the measurement parameter and the operation parameter with the time axes thereof aligned with each other.

7. The cryopump system according to any one of items 1 to 6, further including:

    a plurality of cryopumps; and
    a plurality of sensors that each measure a measurement parameter related to a corresponding cryopump among the plurality of cryopumps,
    in which the cryopump controller is configured

to, for each of the plurality of cryopumps, receive the measurement parameter from a corresponding sensor among the plurality of sensors, to determine an operation parameter of the cryopump such that the measurement parameter follows a target value, and to operate the cryopump with the determined operation parameter, and

the cryopump monitor is configured to, for each of the plurality of cryopumps, acquire time-series data of the measurement parameter and time-series data of the operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

8. The cryopump system according to item 7, in which the cryopump monitor is configured to collectively display a plurality of the time-series graphs of the measurement parameters for the plurality of cryopumps and to collectively display a plurality of the time-series graphs of the operation parameters for the plurality of cryopumps.

9. The cryopump system according to any one of items 1 to 6, further including:

a plurality of cryopumps;

a plurality of sensors that each measure a measurement parameter related to a corresponding cryopump among the plurality of cryopumps; and

a plurality of controllers that individually control the plurality of cryopumps, instead of the cryopump controller,

in which each controller is configured to, for the corresponding cryopump among the plurality of cryopumps, receive the measurement parameter from a corresponding sensor among the plurality of sensors, to determine an operation parameter of the cryopump such that the measurement parameter follows a target value, and to operate the corresponding cryopump with the determined operation parameter, and

the cryopump monitor is configured to, for each of the plurality of cryopumps, acquire time-series data of the measurement parameter and time-series data of the operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

10. A cryopump monitoring method comprising:

acquiring time-series data of a measurement parameter related to a cryopump system;

acquiring time-series data of an operation parameter of the cryopump system, which is controlled such that the measurement parameter follows a target value; and

displaying a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

11. The cryopump monitoring method according to item 10, in which the displaying includes displaying the time-series graph of the measurement parameter and the time-series graph of the operation parameter to be arranged so that the target value of the measurement parameter and a limit value of the operation parameter are close to each other.

12. The cryopump monitoring method according to item 11, in which the displaying includes determining a display position of the target value of the measurement parameter at an edge portion of a first display area where the time-series graph of the measurement parameter is displayed and determining a display position of the limit value of the operation parameter at an edge portion close to the edge portion of the first display area, among edge portions of a second display area where the time-series graph of the operation parameter is displayed.

13. The cryopump monitoring method according to any one of items 10 to 12, in which the displaying includes displaying a mark indicating that diagnosis of the cryopump system has been performed at a position of a diagnosis time on the time axis.

14. The cryopump monitoring method according to item 13, in which the displaying includes displaying diagnosis information of the cryopump system associated with the mark in response to designation of the mark by an operator.

15. The cryopump monitoring method according to any one of items 10 to 12, further comprising:

acquiring time-series data of a second measurement parameter related to the cryopump system, which is different from the measurement parameter,

in which the displaying includes also displaying a time-series graph of the second measurement parameter together with the time-series graphs of the measurement parameter and the operation parameter with the time axes thereof aligned with each other.

16. The cryopump monitoring method according to any one of items 10 to 15,

in which the cryopump system includes a plur-

ality of cryopumps,
the acquiring the time-series data of the measurement parameter includes acquiring time-series data of the measurement parameter for each of the plurality of cryopumps,
the acquiring the time-series data of the operation parameter includes acquiring, for each of the plurality of cryopumps, time-series data of the operation parameter of the cryopump, which is controlled such that the measurement parameter follows a target value, and
the displaying includes displaying, for each of the plurality of cryopumps, the time-series graph of the measurement parameter and the time-series graph of the operation parameter with time axes thereof aligned with each other.

17. The cryopump monitoring method according to item 16,
in which the displaying includes collectively displaying a plurality of time-series graphs of the measurement parameters for the plurality of cryopumps and collectively displaying a plurality of time-series graphs of the operation parameters for the plurality of cryopumps.
18. A cryopump monitoring program causing a computer to execute:

acquiring time-series data of a measurement parameter related to a cryopump system;
acquiring time-series data of an operation parameter of the cryopump system, which is controlled such that the measurement parameter follows a target value; and
displaying a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

[0115] 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.

Brief Description of the Reference Symbols

[0116]

10 cryopump
100 cryopump system
110 cryopump controller
130 cryopump monitor
136a first display area
136b second display area

Claims

1. A cryopump system (100) comprising:

a sensor (22, 23, 54, 55) that measures a measurement parameter related to the cryopump system (100);
a cryopump controller (110) that is configured to receive the measurement parameter from the sensor (22, 23, 54, 55), to determine an operation parameter of the cryopump system (100) such that the measurement parameter follows a target value, and to operate the cryopump system (100) with the determined operation parameter; and
a cryopump monitor (130) that is configured to acquire time-series data of the measurement parameter and time-series data of the operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

2. The cryopump system (100) according to claim 1, wherein the cryopump monitor (130) is configured to display the time-series graph of the measurement parameter and the time-series graph of the operation parameter to be arranged so that the target value of the measurement parameter and a limit value of the operation parameter are close to each other.

3. The cryopump system (100) according to claim 2, wherein the cryopump monitor (130) is configured to determine a display position of the target value of the measurement parameter at an edge portion of a first display area (136a) where the time-series graph of the measurement parameter is displayed and to determine a display position of the limit value of the operation parameter at an edge portion close to the edge portion of the first display area (136a), among edge portions of a second display area (136b) where the time-series graph of the operation parameter is displayed.

4. The cryopump system (100) according to any one of claims 1 to 3,
wherein the cryopump monitor (130) is configured to display a mark (140) indicating that diagnosis of the cryopump system (100) has been performed at a position of a diagnosis time on the time axis.

5. The cryopump system (100) according to claim 4, wherein the cryopump monitor (130) is configured to display diagnosis information of the cryopump system (100) associated with the mark (140) in response to designation of the mark (140) by an operator.

6. The cryopump system (100) according to any one of claims 1 to 3, further comprising:

a second sensor that measures a second measurement parameter related to the cryopump system (100), which is different from the measurement parameter,
wherein the cryopump monitor (130) is configured to acquire time-series data of the second measurement parameter and to also display a time-series graph of the second measurement parameter together with the time-series graphs of the measurement parameter and the operation parameter with the time axes thereof aligned with each other.

7. The cryopump system (100) according to any one of claims 1 to 3, further comprising:

a plurality of cryopumps (10); and
a plurality of sensors (22, 23, 54, 55) that each measure a measurement parameter related to a corresponding cryopump (10) among the plurality of cryopumps (10),
wherein the cryopump controller (110) is configured to, for each of the plurality of cryopumps (10), receive the measurement parameter from a corresponding sensor (22, 23, 54, 55) among the plurality of sensors (22, 23, 54, 55), to determine an operation parameter of the cryopump (10) such that the measurement parameter follows a target value, and to operate the cryopump (10) with the determined operation parameter, and
the cryopump monitor (130) is configured to, for each of the plurality of cryopumps (10), acquire time-series data of the measurement parameter and time-series data of the operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

8. The cryopump system (100) according to claim 7, wherein the cryopump monitor (130) is configured to collectively display a plurality of the time-series graphs of the measurement parameters for the plurality of cryopumps (10) and to collectively display a plurality of the time-series graphs of the operation parameters for the plurality of cryopumps (10).

9. The cryopump system (100) according to any one of claims 1 to 3, further comprising:

a plurality of cryopumps (10);
a plurality of sensors (22, 23, 54, 55) that each measure a measurement parameter related to a corresponding cryopump (10) among the plurality of cryopumps (10); and
a plurality of controllers (110a) that individually control the plurality of cryopumps (10), instead of the cryopump controller (110),
wherein each controller (110a) is configured to, for the corresponding cryopump (10) among the plurality of cryopumps (10), receive the measurement parameter from a corresponding sensor (22, 23, 54, 55) among the plurality of sensors (22, 23, 54, 55), to determine an operation parameter of the cryopump (10) such that the measurement parameter follows a target value, and to operate the corresponding cryopump (10) with the determined operation parameter, and
the cryopump monitor (130) is configured to, for each of the plurality of cryopumps (10), acquire time-series data of the measurement parameter and time-series data of the operation parameter and to display a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

10. A cryopump monitoring method comprising:

acquiring time-series data of a measurement parameter related to a cryopump system (100);
acquiring time-series data of an operation parameter of the cryopump system (100), which is controlled such that the measurement parameter follows a target value; and
displaying a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

11. The cryopump monitoring method according to claim 10,
wherein the displaying includes displaying the time-series graph of the measurement parameter and the time-series graph of the operation parameter to be arranged so that the target value of the measurement parameter and a limit value of the operation parameter are close to each other.

12. The cryopump monitoring method according to claim 11,
wherein the displaying includes determining a display position of the target value of the measurement parameter at an edge portion of a first display area (136a) where the time-series graph of the measurement parameter is displayed and determining a display position of the limit value of the operation parameter at an edge portion close to the edge portion of the first display area (136a), among edge portions of a second display area (136b) where the time-series graph of the operation parameter is displayed.

13. The cryopump monitoring method according to any one of claims 10 to 12,
wherein the displaying includes displaying a mark (140) indicating that diagnosis of the cryopump system (100) has been performed at a position of a diagnosis time on the time axis.

14. The cryopump monitoring method according to claim 13,
wherein the displaying includes displaying diagnosis information of the cryopump system (100) associated with the mark (140) in response to designation of the mark (140) by an operator.

15. The cryopump monitoring method according to any one of claims 10 to 12, further comprising:

acquiring time-series data of a second measurement parameter related to the cryopump system (100), which is different from the measurement parameter,
wherein the displaying includes also displaying a time-series graph of the second measurement parameter together with the time-series graphs of the measurement parameter and the operation parameter with the time axes thereof aligned with each other.

16. A cryopump monitoring program causing a computer to execute:

acquiring time-series data of a measurement parameter related to a cryopump system (100);
acquiring time-series data of an operation parameter of the cryopump system (100), which is controlled such that the measurement parameter follows a target value; and
displaying a time-series graph of the measurement parameter and a time-series graph of the operation parameter with time axes thereof aligned with each other.

FIG. 1

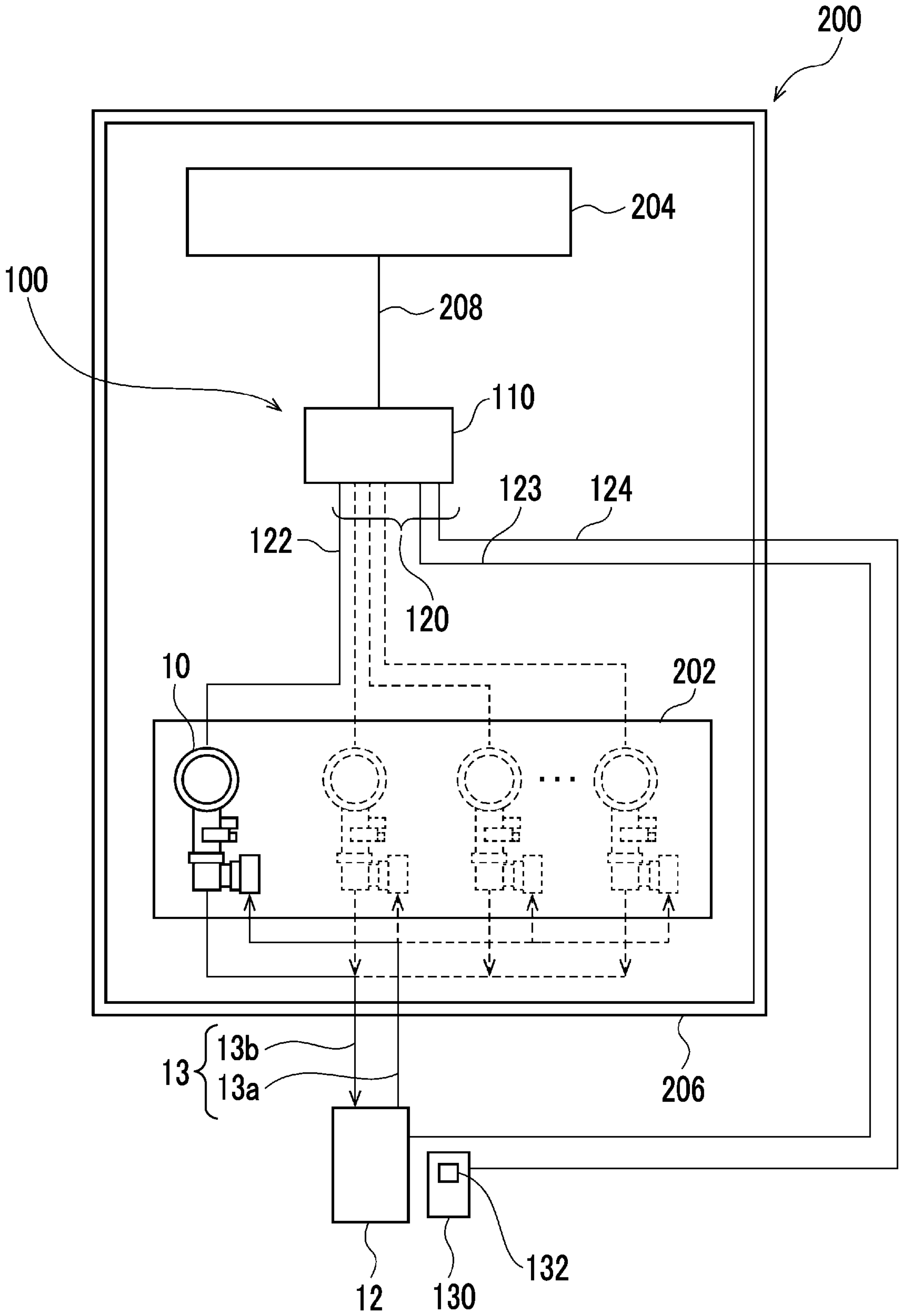

200
204
100
208
110
123
124
122
120
10
202
13b
13
13a
206
12
130
132

FIG. 2

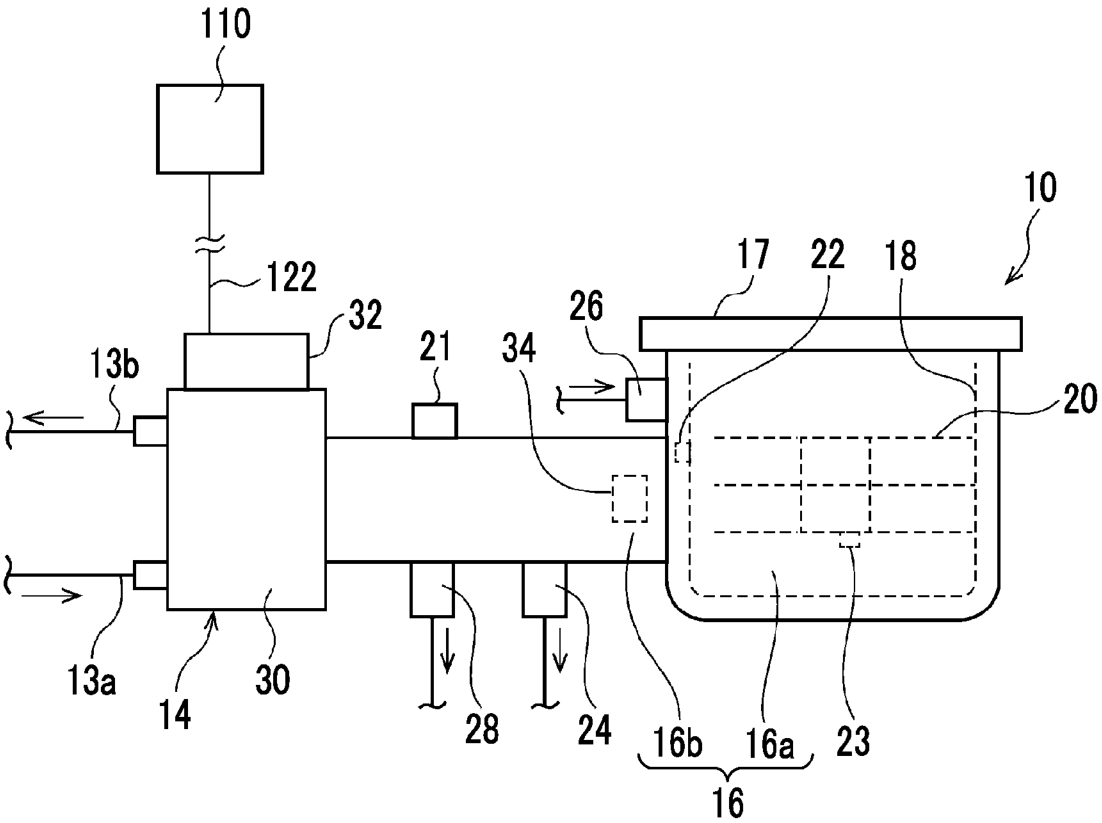

110
122
32
13b
21
34
26
17
22
18
10
20
13a
14
30
28
24
16b
16a
23
16

FIG. 3

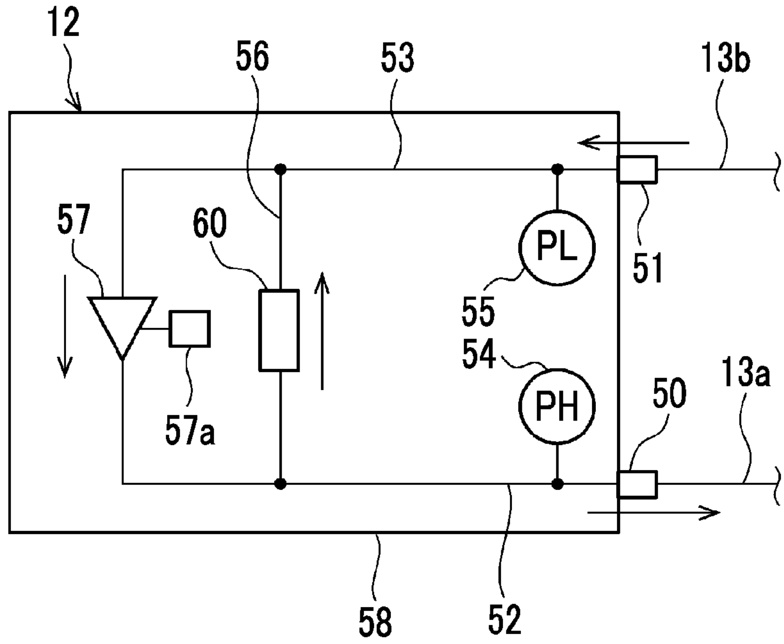

12
56
53
13b
57
60
PL
51
55
54
PH
50
13a
57a
58
52

FIG. 4

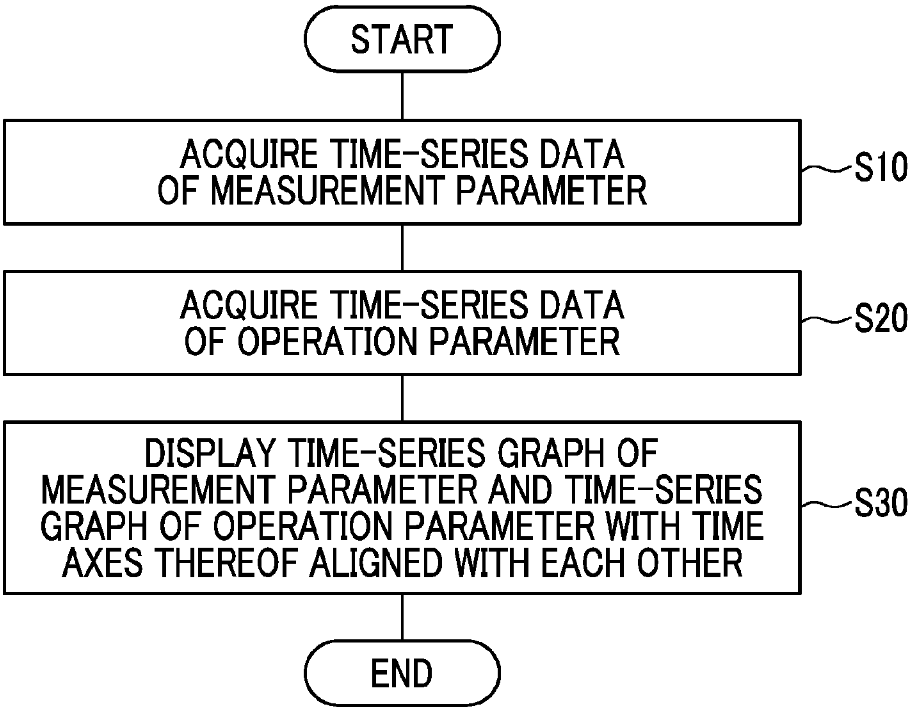
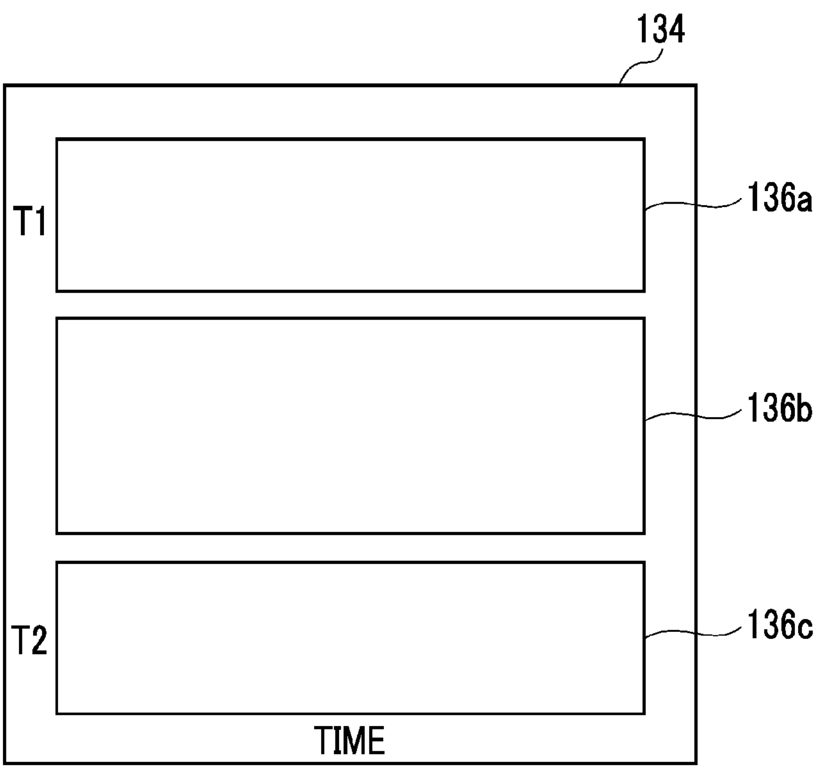


FIG. 5



130

FIG. 6

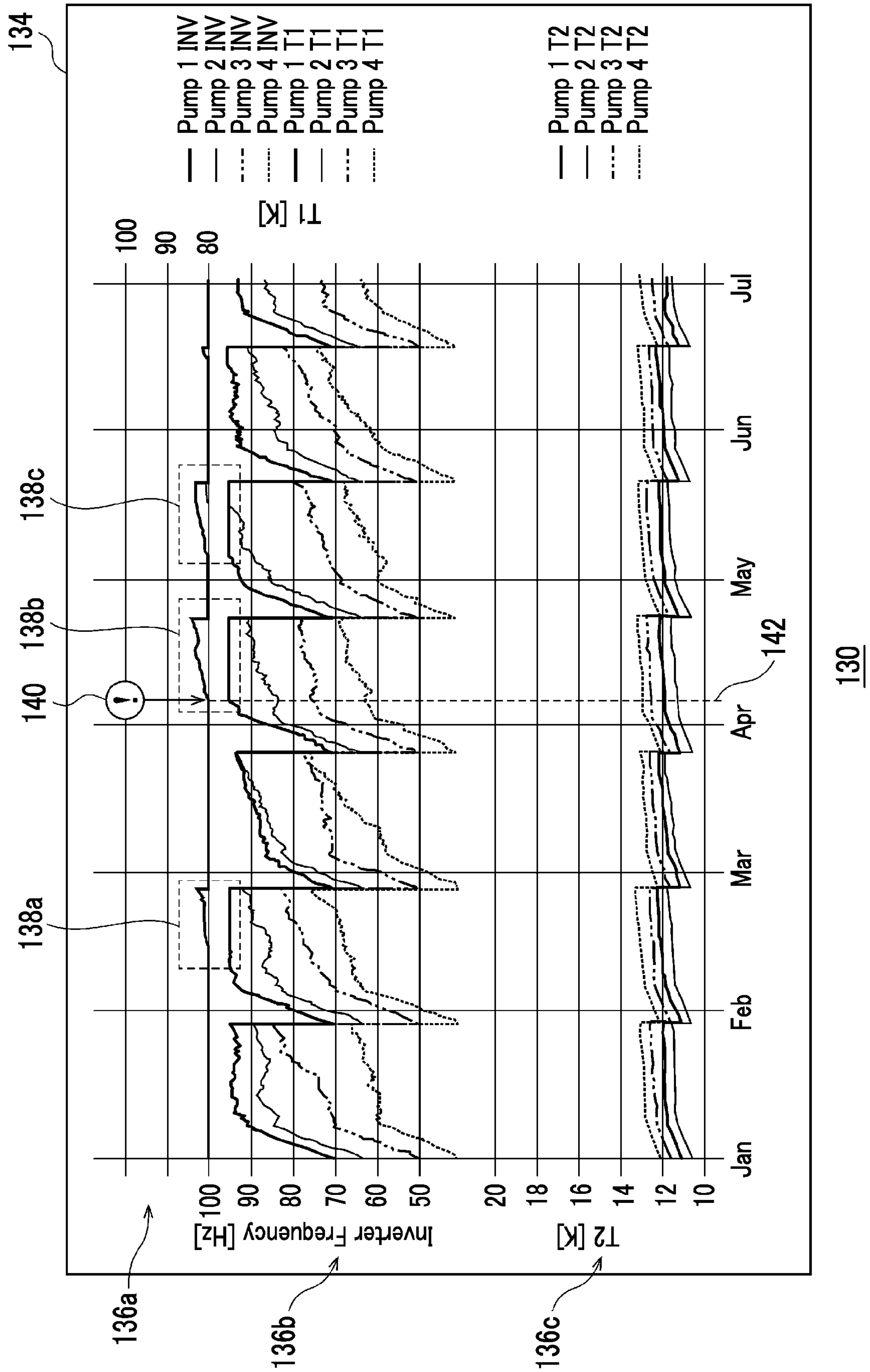
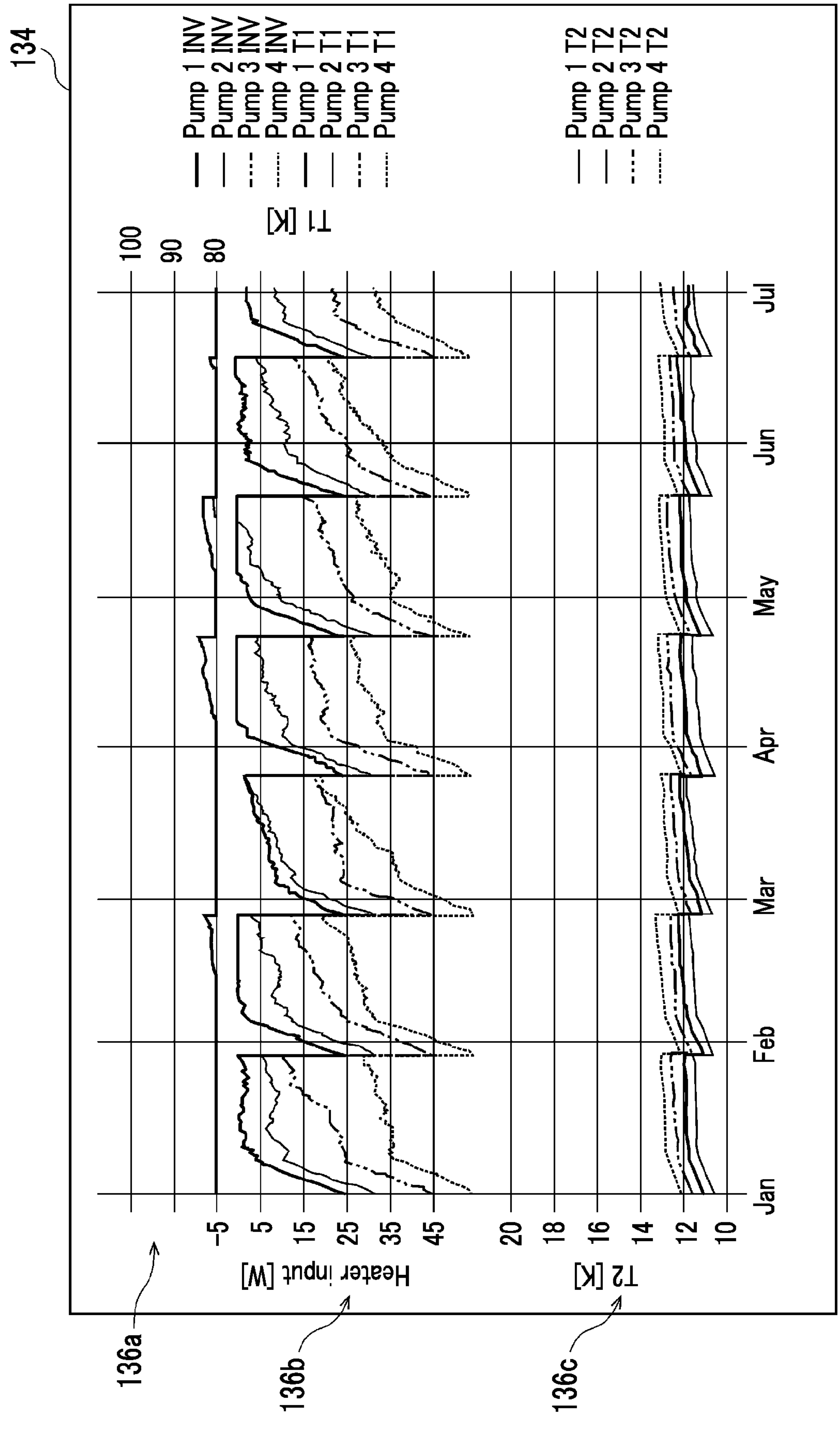
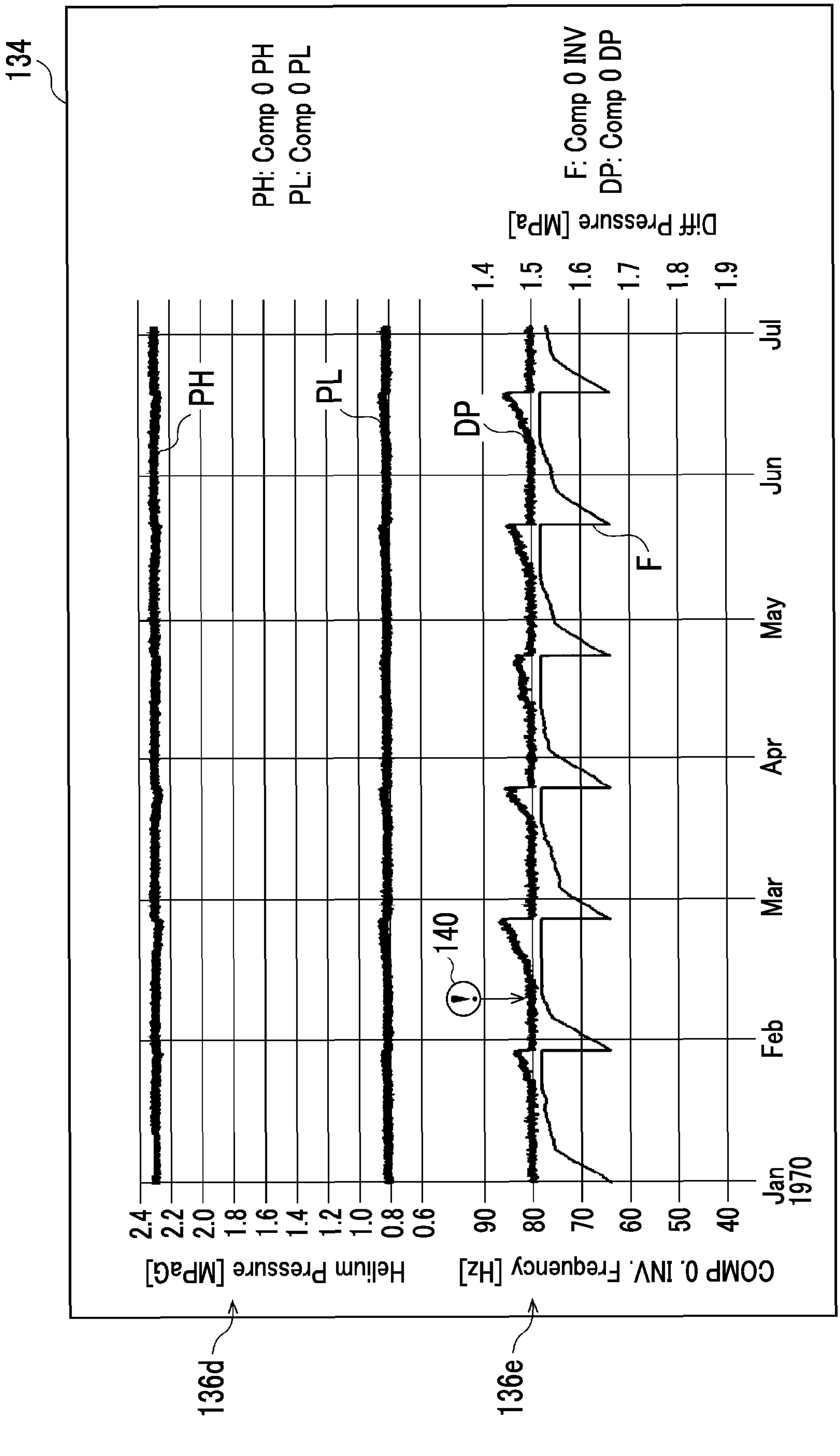

134
138a
138b
138c
140
142
130
136a
136b
136c
Inverter Frequency [Hz]
T2 [K]
T1 [K]
100
90
80
70
60
50
20
18
16
14
12
10
Jan
Feb
Mar
Apr
May
Jun
Jul
Pump 1 INV
Pump 2 INV
Pump 3 INV
Pump 4 INV
Pump 1 T1
Pump 2 T1
Pump 3 T1
Pump 4 T1
Pump 1 T2
Pump 2 T2
Pump 3 T2
Pump 4 T2

FIG. 7


134
136a
136b
136c
Heater input [W]
T2 [K]
T1 [K]
-5
5
15
25
35
45
20
18
16
14
12
10
100
90
80
Jan
Feb
Mar
Apr
May
Jun
Jul
Pump 1 INV
Pump 2 INV
Pump 3 INV
Pump 4 INV
Pump 1 T1
Pump 2 T1
Pump 3 T1
Pump 4 T1
Pump 1 T2
Pump 2 T2
Pump 3 T2
Pump 4 T2

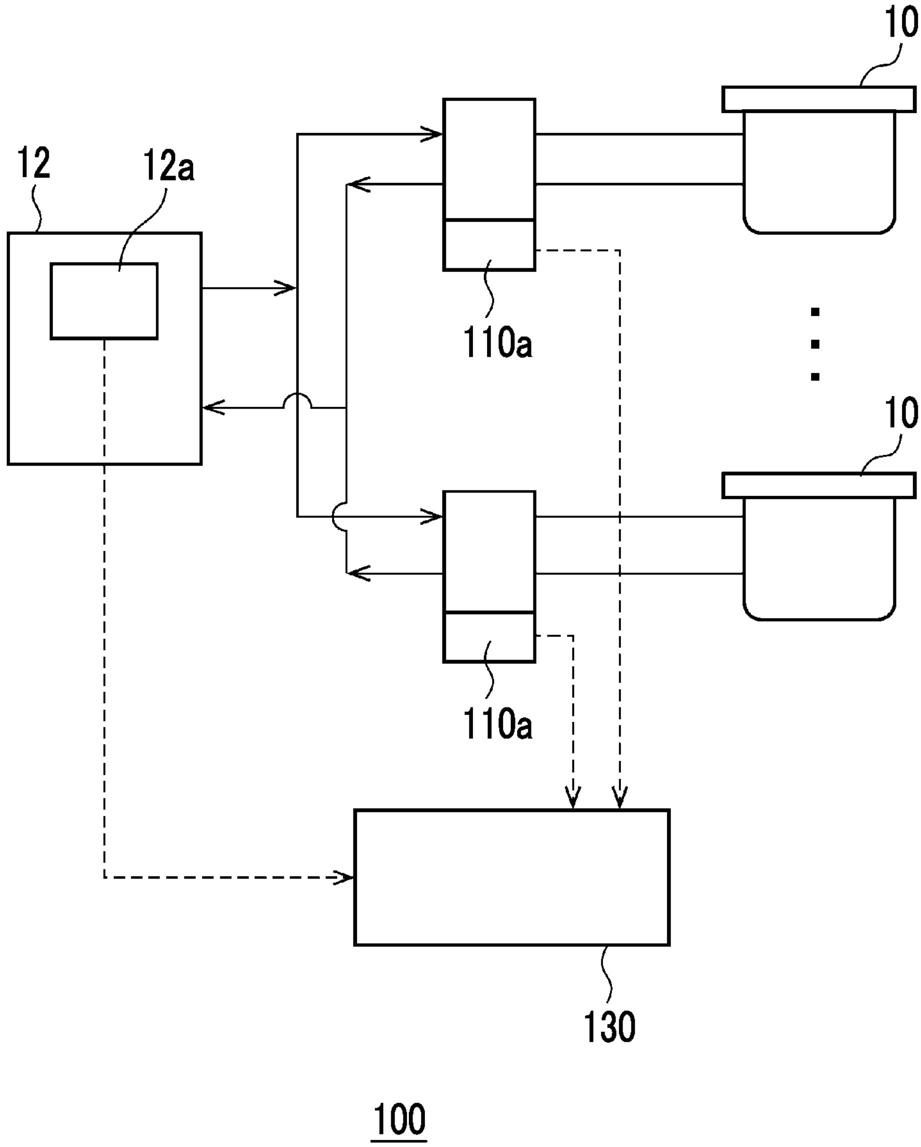
130

FIG. 8


134
PH: Comp 0 PH
PL: Comp 0 PL
F: Comp 0 INV
DP: Comp 0 DP
Diff Pressure [MPa]
1.4
1.5
1.6
1.7
1.8
1.9
Helium Pressure [MPaG]
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
COMP 0. INV. Frequency [Hz]
90
80
70
60
50
40
PH
PL
DP
F
140
Jan
1970
Feb
Mar
Apr
May
Jun
Jul
136d
136e

130

FIG. 9



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EUROPEAN SEARCH REPORT

Application Number
EP 24 18 4551

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2022/006417 A1 (INOUE HIROSHI [JP] ET AL) 6 January 2022 (2022-01-06) * paragraphs [0003], [0029], [0031], [0032], [0033], [0036], [0038] - [0040], [0042], [0048], [0049], [0079]; claim 8; figures 1-3 * -----	1-16	INV. F04B37/08 F04B37/14 F04B49/06 F04C18/02 F04C25/02 F04D19/04 F04D27/00
A	US 2008/010030 A1 (CHEUNG WAN SUP [KR] ET AL) 10 January 2008 (2008-01-10) * paragraph [0001]; claim 1; figure 1 * -----	1,10,16	
A	US 2022/090604 A1 (HIROTA KIYONORI [JP]) 24 March 2022 (2022-03-24) * paragraph [0001]; claim 1; figures 1-3 * -----	1,10,16	
			TECHNICAL FIELDS SEARCHED (IPC)
			F04B F04C B01D F04D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	4 October 2024	de Martino, Marcello

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EP 24 18 4551

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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