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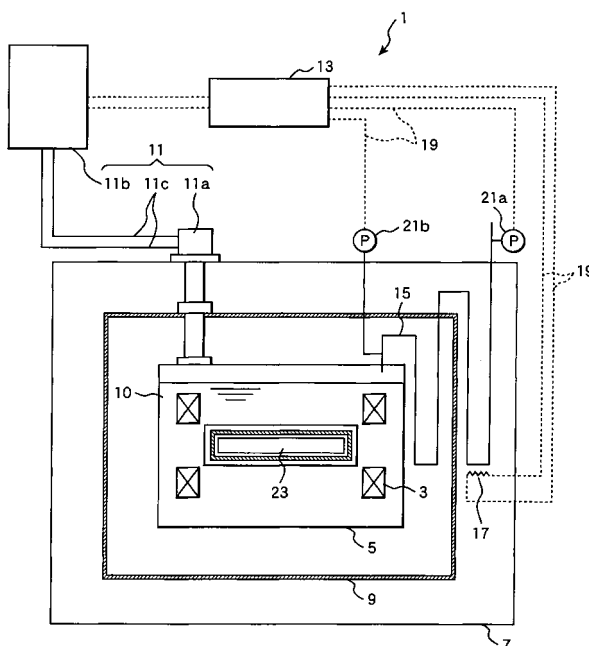
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(54) **Superconducting magnet apparatus**

(57) A superconducting magnet apparatus comprising a coil container for accommodating superconducting coils and liquefied cooling medium for cooling the coils down to the critical temperature or lower of a superconductor constituting the coils, a vacuum chamber for accommodating the coil container and for vacuum insula-

tion from the atmosphere, and a conduit communicating the coil container at one end thereof and extending to the outside of the vacuum chamber at the other end. At least one heating device for heating the conduit is disposed at one or more positions of the conduit located within the vacuum chamber.

FIG. 1



Description

FIELD OF THE INVENTION;

[0001] The present invention relates to a superconducting magnet apparatus wherein a superconducting coil is encased in a coil container, the magnet apparatus containing a liquefied cooling medium for cooling the superconductor coil to a temperature lower than a critical point.

RELATED ART:

[0002] In superconducting magnet apparatuses, superconducting coils are cooled down by liquefied cooling medium such as liquid helium. Therefore, a cryostat for the superconducting magnet apparatus comprises a coil container for accommodating a superconductor coil and a cooling medium, wherein the coil container is disposed in a vacuum chamber for forming a vacuum layer for vacuum thermal insulation. The coil container is provided with a suitable conduit communicated with the inside of the coil container, wherein the conduit is used for charging the cooling medium into the coil container and the conduit is used for discharging the cooling medium in a gaseous phase into the outside of the coil container. Refer to Patent publication No. 1, for example.

[0003] Further, as an example of construction of the cryostat for the superconducting magnet apparatus, there is proposed such a construction that a nitrogen container for accommodating liquefied nitrogen, which is a different cooling medium than the liquefied helium, is disposed between the vacuum chamber and the coil container. Refer to Patent document No. 2, for example.

Patent document No. 1: Japanese patent laid-open 05-55032 (Page 3, Fig. 1)

Patent document No. 1: Japanese patent laid-open 09-64425 (Pages 6 - 8, Fig. 1)

[0004] When the superconducting coil is supplied with current to generate magnetic field, there may occur mechanical disturbances such as movement of a part of coil conductors forming the superconducting coil or breakage of an impregnated resin material impregnated into coils for covering and binding the coils. This may cause thermal disturbance that elevates temperature of the coil conductors whereby the impregnated resin is broken. If the temperature increase due to the thermal disturbance prevails the cooling of the surrounding of the coils by the cooling medium, the superconducting state breaks into normal conducting state thereby to generate resistance in the coil conductors, accompanying heat generation. The phenomenon wherein the temperature rise spreads over the entire superconductor is called "quench".

[0005] Once the quench phenomenon occurs, a volume of the cooling medium in the vicinity of the superconducting coil is expanded by several hundred times a volume of the liquid cooling medium due to evapora-

tion of the cooling medium. When the cooling medium gas is generated by evaporation, a pressure in the coil container increases, the cooling medium gas is discharged through discharging conduits connected to the coil container towards outside of the vacuum chamber thereby to suppress an increase in the pressure in the coil container.

[0006] However, as the pressure in the coil container decreases due to discharging of the cooling medium gas, the pressure in the coil container becomes equal to that of the atmospheric pressure outside of the vacuum chamber. As a result, air may enter the connecting portions or openings of the conduit passing through the vacuum chamber the conduit being connected to the coil container. Thus, if the air or gas that enters the conduit contains components such as air, nitrogen, which may freeze, the components may freeze in the way of the conduit.

[0007] For example, since the discharging conduit is open to the atmosphere, air may enter therein. Therefore, water or nitrogen contained or accompanied in air may freeze. When the superconducting magnet apparatus is equipped with a refrigerator for cooling the cooling medium in the coil container, the pressure in the coil container becomes negative due to cooling by operation of the refrigerator. Therefore, entering of the freezable components such as water or nitrogen becomes remarkable. If gas containing freezable components enters the conduit disposed outside of the vacuum chamber from the coil container, the components freeze in the middle of the conduit thereby to clog them.

[0008] When the quench phenomenon occurs in the coil container in the state that the conduit is clogged with frozen components, the following problems may arise. That is, when the volume of the cooling medium in the vicinity of the superconducting coil vaporizes by heat from the superconducting coil to expand by several hundreds times the volume of the liquid cooling medium, the vaporized cooling medium can not be discharged from the coil container through the conduit disposed outside of the vacuum chamber from the coil container. As a result, the pressure in the coil container may increase to a pressure higher than the withstanding pressure of the coil container, which leads to destruction of the coil container.

[0009] Expansion of the cooling medium occurs not only in the quench phenomenon, but also in the case when vacuum of the vacuum chamber is broken, which prevents vacuum thermal insulation and heat is introduced outside of the vacuum chamber. If there is freezing in the conduit disposed outside of the vacuum chamber from the coil container, the vaporized cooling medium cannot be discharged through the conduit and the pressure in the coil container increases over the withstanding pressure of the coil container resulting in destruction thereof.

[0010] Accordingly, countermeasures to the destruction of the coil container due to volume expansion of the

cooling medium caused by quench phenomenon or vacuum breakage are necessary when the clogging of the conduits occurs.

[0011] There is disclosed a technology in Patent document No. 2 that in order to prevent freezing in the conduit communicated with a nitrogen container or reduction in pressure of the nitrogen container, another nitrogen container or a tank, which is filled with nitrogen is connected to the nitrogen container. By supplying pressurized nitrogen from the additional container to the nitrogen container, the pressure of the nitrogen can be kept higher than the atmospheric pressure or a positive pressure. This structure prevents air entering into the conduits and pressure reduction of the nitrogen container so that freezing in the conduits is avoided.

[0012] However, Patent publication No. 2 does not pay attention to preventing breakage of the coil container, which may occur when the conduit disposed outside of the vacuum chamber from the coil container is clogged by freezing and when quench or vacuum breakage takes place. Further, the structure of Patent document No. 2 does not prevent the destruction of the coil container due to the clogging of the conduits caused by freezing or vacuum breakage.

SUMMARY OF THE INVENTION:

[0013] It is one of the objects of the present invention to prevent destruction of the coil container, which may occur when the quench phenomenon or vacuum breakage caused by clogging of the conduits due to freezing.

[0014] A superconducting magnet apparatus according to the present invention comprises a coil container for accommodating a superconducting coil and a liquefied cooling medium for cooling the superconducting coil down to a critical temperature or lower of the superconductor, a vacuum chamber for surrounding the coil container and for vacuum insulating the coil container from the exterior, and a conduit one end of which is located in the coil container and the other end of which is located outside of the vacuum chamber, wherein a heating device for heating the conduit is disposed at one or more positions of the conduit inside of the vacuum chamber.

BRIEF DESCRIPTION OF THE DRAWINGS:

[0015]

Fig. 1 is a diagrammatic, partly cross sectional view of a superconducting magnet apparatus according to the first embodiment of the present invention.

Fig. 2 is a perspective view of a nuclear magnetic resonance imaging apparatus, which employs the superconducting magnet apparatus of the present invention is applied.

Fig. 3 is a block diagram of an NMR apparatus, which employs the superconducting magnet apparatus according to the present invention.

Fig. 4 is a diagrammatic cross sectional view of a superconducting magnet apparatus according to the second embodiment of the present invention.

Fig. 5 is a diagrammatic cross sectional view of a superconducting magnet apparatus according to the third embodiment of the present invention.

Fig. 6 is a diagrammatic cross sectional view of a superconducting magnet apparatus according to the fourth embodiment of the present invention.

Fig. 7 is a diagrammatic cross sectional view of a superconducting magnet apparatus according to the fifth embodiment of the present invention.

Fig. 8 is a diagrammatic cross sectional view of a superconducting magnet apparatus according to the sixth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS:

[0016] The superconducting magnet apparatus according to the present invention removes the problem of destruction of the coil container by heating the conduit with a heating device to melt the frozen components, even when gas containing freezable components enters the conduit and freeze therein, which leads to quench phenomenon or vacuum breakage. Accordingly, it is possible to prevent the destruction of the coil container due to the quench phenomenon or vacuum breakage when the conduit is clogged by frozen components.

[0017] The conduit is preferably arranged zigzag inside of the vacuum chamber and the heating device is preferably disposed at positions where the conduit is bent or curved. Since fluid flowing the conduit tends to lower the flow rate or stay at the bent positions, freezing tends to occur. Accordingly, when the bent positions are heated with heaters, the clogging of the conduit due to freezing in the conduit outside of the vacuum chamber from the coil container is firmly prevented. As a result, the destruction of the coil container, which may be caused by quench or vacuum breakage due to freezing and clogging of the conduit is prevented with certainty.

[0018] The conduit has a portion whose inner diameter is smaller than that of other portions, and the heating device is disposed at the position of the conduit where the inner diameter is smaller than the other position. Since the position where the inner diameter is smaller than that of the other position tends to more easily clog by freezing than other position, the above structure prevents clogging of the conduit with certainty and prevents destruction of the coil container by quench or vacuum breakage.

[0019] The conduit is one for discharging cooling medium gas in the coil container to outside of the coil container, and is provided with a valve, which opens when the pressure in the coil container becomes a predetermined pressure. The heating device is disposed at a position where the inner diameter is smaller than the other. Clogging of the conduit due to freezing may sometimes

shut down the valve disposed to the discharging conduit. Further, there is a portion, which is narrower than other portions the clogging due to freezing tends to take place easily. Accordingly, the structure of the present invention more surely prevents the clogging of the conduit disposed at outside of the vacuum chamber from the coil container due to freezing. In addition, If clogging due to freezing in the conduit for communicating between the outside of the vacuum chamber and the coil container takes place, the breakage of the coil container due to quench phenomenon or vacuum breakage can be definitely prevented.

[0020] The magnet device is provided with a thermal shield plate surrounding the coil container in the vacuum chamber, and is a heater disposed between the thermal shield of the conduit and the coil container. The device may be provided with a heater disposed at a position between the thermal shield and the vacuum chamber.

[0021] Since the freezing points of the freezable components contained the gas coming into the conduit extending from the coil container through the thermal shield plate or case to outside of the vacuum chamber change depending on the kinds of the components, the positions of the heater disposed to the discharging conduit are adjusted depending on the compositions coming into the discharging conduit. As a result, the clogging of the conduit due to freezing of the freezable components can be surely prevented so that the breakage of the coil container due to quenching or vacuum breakage is avoided.

[0022] The magnet device is also provided with a pressure detector for detecting a pressure of the discharging conduit at a position in the vacuum container or for detecting the pressure P_1 of the coil container and a pressure detector for detecting a pressure P_2 of the conduit outside of the vacuum chamber. By comparing the pressure P_1 and pressure P_2 , the clogging due to freezing in the conduit can be detected and it is possible to know timing for starting or stopping operation of the heater.

[0023] The magnet device is further provided with a controller for operating the heater, when the pressure P_1 exceeds the pressure P_2 by a predetermined pressure. By this structure, it is possible to prevent clogging of the discharging conduit due to freezing of the freezable components, when the controller judges the clogging of the conduit.

[0024] The superconducting magnet of the present invention is provided with a pressure detecting means or a pressure detecting means for detecting a pressure of the discharging conduit at a position in the vacuum chamber, a refrigerator for cooling the cooling medium filled in the coil container and a control section for controlling the refrigerator, wherein the control section controls the refrigerator to stop when the pressure in the discharging conduit in the vacuum chamber is detected by the pressure detector to have a value larger than a predetermined value.

[0025] By this structure, when the gaseous cooling medium generated by evaporation in the coil container is discharged from the conduit, it is possible to prevent negative pressure of the coil container after the cooling medium in the coil container is discharged, since the cooling of the cooling medium in the coil container is stopped. Therefore, it is possible that clogging of the conduit due to freezing that is caused by the gas containing freezable components entering the conduit is prevented, the entering of the gas being caused by negative pressure in the coil container.

[0026] As a result, after the gas is discharged in the coil container, liquid cooling medium remains in the container so that even if the liquid cooling medium vaporizes at the time of quenching or vacuum breakage occurs, the vaporized gas can be discharged through the conduit, which is not clogged. That is, the breakage of the coil container due to quenching or vacuum breakage can be avoided.

[0027] Further, the present invention provides a magnet apparatus comprising a pressure detecting means for detecting a pressure in a conduit disposed in a vacuum chamber, a refrigerator for cooling a cooling medium filled in the coil container and a control section for controlling the refrigerator, wherein the control section stops cooling of the cooling medium filled in the coil container by the refrigerator when the pressure detector detects a pressure of the conduit in the vacuum chamber higher than the predetermined pressure and starts heating the conduit by the heater.

[0028] As a result, even if the gas containing freezable components enters the conduit, the clogging of the conduit due to freezing can be avoided. Therefore, it is possible to prevent breakage of the coil container due to quenching or vacuum breakage upon clogging of the conduit.

[0029] The superconducting magnet apparatus according to the present invention may comprise a coil container for accommodating the superconducting coil and a cooling medium for cooling the coil down to the temperature lower than the critical temperature of the coil, a vacuum chamber surrounding the coil container for vacuum thermal-insulation of the coil container, a conduit one end of which is connected to the coil container and the other end of which is connected to outside of the vacuum chamber, a heating means disposed in the coil container for heating the cooling medium in the coil container, a pressure detecting means for detecting the pressure in the conduit positioned in the vacuum chamber or for detecting a pressure in the coil container, and a control section for controlling the heating means, wherein when the pressure in the conduit disposed outside of the vacuum chamber or the pressure of the conduit in the coil container becomes lower than the predetermined pressure, the control means makes the heating means to work.

[0030] By this structure, since the pressure in the coil container can always be kept at a pressure higher than

the pressure of the space where the conduit outside the vacuum chamber is opened or the conduit is communicated, it is possible to prevent the gas containing freezable components from entering the conduit. Accordingly, since the clogging of the conduit due to freezing is prevented, breakage of the coil container due to quenching or vacuum breakage can be avoided.

[0031] Further, another superconducting magnet apparatus according to the present invention comprises a coil container for accommodating superconducting coils and liquefied cooling medium for cooling the superconducting coils down to the critical temperature or lower, a vacuum chamber for accommodating the coil container and vacuum thermal insulation from the outside, and a conduit one end of which is connected to the coil container and the other end of which is located outside of the vacuum chamber, wherein there is disposed at one position of the conduit located in the vacuum chamber one burst section for discharging gaseous cooling medium upon its breakage when the pressure in the conduit exceeds a predetermined pressure.

[0032] According to this structure, when the pressure in the conduit exceeds the predetermined pressure, which is caused by quenching or vacuum breakage upon clogging of the conduit due to freezing of the freezable components in the gas, the breakage of the coil container is avoided. When the burst section and the heating means are combined, the breakage of the coil container can be more surely avoided.

[0033] The present invention provides a nuclear resonance imaging apparatus comprising any one of the superconducting magnet apparatuses, a table for placing an inspected body or an examinee in a magnetic field formed between the superconducting coils, an analytical section for analyzing magnetic resonance signals from the inspected body and an imaging section for imaging the signals.

[0034] Further, the present invention provides a nuclear magnetic resonance apparatus comprising any one of the superconducting magnet apparatuses mentioned-above, a probe for detecting nuclear magnetic resonance signals from an inspected body or a sample placed in a sample tube in a magnetic field formed between the superconducting coils, and an analytical section for analyzing the signals detected by the probe. It is possible to prevent the destruction of the coil container due to the quench phenomenon or vacuum breakage when the conduit is clogged by frozen components. The imaging apparatus has a high reliability because breakage of the coil container is surely avoided.

(Embodiment 1)

[0035] The superconducting magnet apparatuses of the present invention will be explained by reference to Figs. 1 to 3 in the following.

[0036] Fig. 1 is a diagrammatic, partly cross sectional view of a superconducting magnet apparatus according

to the first embodiment of the present invention. Fig. 2 is a perspective view of a magnetic resonance imaging apparatus to which the present invention is applied.

[0037] Fig. 3 is a block diagram of an NMR apparatus, which employs a superconducting magnet apparatus according to the present invention.

[0038] Figs. 4, 5 and 6 are diagrammatic cross sectional view showing different methods of dispositions of heaters of superconducting magnet apparatuses according to the second embodiment of the present invention.

[0039] The superconducting magnet apparatus 1 shown in Fig. 1 comprises a cryostat, which comprises a coil container 5 for accommodating superconducting coils 3, a vacuum chamber 7 for accommodating the coil container 5, a thermal shield plate or case 9, which surrounds the coil container 5 and disposed in the vacuum chamber 7, etc. The superconducting magnet apparatus 1 is provided with a refrigerator 11 for cooling the liquefied cooling medium 10 such as liquid helium in the coil container 5 and the thermal shield plate 9, a control device 13 for controlling etc.

[0040] The coil container 5, which stores the cooling medium 10, is made of a container being able to be hermetic. The coil container 5 is provided with a filling port for filling the cooling medium, a discharging conduit for discharging gaseous helium in the coil container 5, and a conduit for detecting a pressure in the coil container 5. In Fig. 1, the discharging conduit 15 for discharging gaseous helium in the coil container 5 is shown. The discharging conduit 15 is communicated with the coil container at its one end and is located outside of the vacuum chamber 7 at the other end. The other end of the conduit located outside of the vacuum chamber is open to the atmosphere or is normally closed but is opened in accordance with the pressure in the coil container 5.

[0041] The conduit such as the conduit 15, which is arranged outside of the vacuum chamber 7 from the coil container 5, is so disposed as to zigzag in the vacuum chamber 7 so as to thermally insulate the conduit. The curved portion of the discharging conduit 15 is provided with a heater 17 to heat the curved portion. The heater 17 is electrically connected to the controller 13 by means of a wiring 19.

[0042] The portion of the discharging conduit 15 outside of the vacuum chamber 7 and portion connected to the coil container have a first pressure detecting means 21a and second pressure detecting means 21b, respectively. The first and second pressure detecting means 21a, 21b are electrically connected to the controller 13 by means of wiring 19. Since the second pressure detecting means 21b disposed at the position where the conduit is connected to the coil container 5 detects the pressure, which is the same as that in the coil container, the pressure detecting means 21b can be disposed in the coil container to detect the pressure in the coil container.

[0043] The vacuum chamber 7 is composed of a hermetic vessel. The space inside of the vacuum chamber 7 and outside of the coil container 5 is the interior of the vacuum chamber 7 can be vacuum by means of a vacuum pump (not shown), which is installed when needed. After the space is made vacuum, the vacuum is kept to form vacuum layer. The thermal shield plate or case 9 shields radiant heat to thermally isolate the coil container 5, whereby the coil container 5 is disposed in the vacuum space in the vacuum chamber 7.

[0044] The refrigerator 11 comprises a cooling head 11a, which is so disposed as to penetrate the vacuum chamber 7 until it arrives at the coil container 5 from the outside of the vacuum chamber 7, a compressor 11b, which for compressing the cooling medium, a cooling circulating conduit 11c, which for circulating the cooling medium through the cooling head 11a and the compressor 11b, etc. The cooling head 11a cools the gaseous phase in the coil container 5 thereby to cool the liquefied cooling medium 10 and cools the thermal shield plate 9.

[0045] The cooling head 11a, which is disposed in the vertical direction to cool the gaseous phase in the coil container, can effectively cools the cooling medium 10 in the coil container 5 and increases the efficiency of the refrigerator.

[0046] The controller 13 controls the heater 17 in accordance with a pressure difference between the portion of the conduit outside of the vacuum chamber and the portion connected to the coil container or an absolute pressure. If the discharging conduit 15 is clogged, the pressure in the coil container 5 becomes higher than that where the conduit is not clogged. As a result, the pressure difference between the discharging conduit 15 outside of the vacuum chamber 7 and the conduit connected to the coil container 5. Accordingly, when the pressure in the discharging conduit 15 detected by the second pressure detecting means 21b is higher than the predetermined value with respect to the pressure in the conduit outside of the coil container detected by the first pressure detecting means 21a, the control section 13 starts to control the heater to heat the curved conduit.

[0047] Examples of a magnetic resonance imaging apparatus (hereinafter referred to as MRI) and a nuclear magnetic resonance apparatus (hereinafter referred to as NMR) will be explained in the following. Since Fig. 1 is a diagrammatic view for showing a superconducting magnetic apparatus, structures, locations, etc of coil container 5, vacuum chamber 7 and superconductor coil 3 may be changed appropriately.

[0048] MRI, as shown in Fig. 2, comprises a superconductor magnet apparatus 1, a bed 25, which is capable of going in and out from the space 23 where magnetic field is formed by the opposing superconductor coils 3 of the superconducting magnet apparatus 1, a computer 27 that is an analysis section of signals from a examinee on the bed 25 and controls the superconducting magnet apparatus 1, bed 25, etc. The superconducting magnet apparatus 1 and computer 27 are elec-

trically connected by means of wiring 29.

[0049] The space 23 of the superconducting magnet apparatus shown in Fig. 2 corresponds to the space 23 formed in the center of the coil container 5 shown in Fig. 1. Accordingly, in MRI shown in Fig. 2, the opposing superconducting coils 3 are accommodated in the upper and lower portions of a disc shape, and the space 23 is confined by the outer periphery of the vacuum chamber 7. Though the MRI shown in Fig. 2 is provided with the bed for placing a body for examination, the bed 25 may be substituted by a table, etc for placing subjects to be examined.

[0050] On the other hand, NMR, as shown in Fig. 3, comprises a superconducting magnet apparatus 1, a sample tube 29 for accommodating a sample and disposed in space 23 formed by opposing superconducting coils 3 of the superconducting magnet apparatus 1, a probe 31 for detecting magnetic nuclear signals from the sample in the sample tube 29, a spectrometer 33 for analyzing the nuclear magnetic resonance signals detected by the probe 31, a computer 35 for controlling the superconducting magnet apparatus 1, the spectrometer 33, etc.

[0051] The computer 35, the superconducting magnet apparatus 1 and the spectrometer 33, and the spectrometer 33 and the probe 31 are electrically connected by means of wiring 37, respectively. The space 23 of the superconducting magnet apparatus 1 of NMR shown in Fig. 3 corresponds to the space 23 in the center of the coil container 5 shown in Fig. 1. Accordingly, in NMR shown in Fig. 3, the superconducting magnet apparatus 1 is shown as the state where the superconducting magnet apparatus shown in Fig. 1 is turned by 90 degrees. That is, the space 23 is formed along the vertical axis of the magnet.

[0052] In NMR shown in Fig. 3, a refrigerator 11 may not be disposed so as to avoid vibration by the refrigerator 11.

[0053] In the structure of the superconducting magnet apparatus 1, a discharging conduit 15 may be clogged due to freezing of water or nitrogen in the air entering the conduit 15. If the discharging conduit 15 in the superconducting magnet apparatus 1 is clogged due to freezing, the pressure over the clogged portion of the conduit through the interior of the coil container 5 increases. If the pressure detected by the second pressure detecting means 21b becomes higher than a predetermined value higher than the pressure detected by the first pressure detecting means 21a, the heater 17 is supplied with current to heat the discharging conduit 15, thereby to melt the frozen components and to remove clogging as well. As a result, even if quenching or vacuum breakage takes place, the gaseous cooling medium in the coil container 5 can be released through the conduit 15 thereby to prevent breakage of the coil container.

[0054] As discussed above, the superconducting magnet apparatus according to the embodiment pre-

vents the breakage of the coil container 5 due to quenching or vacuum breakage.

(Embodiment 2)

[0055] The heater 17 can be installed at a position other than the bent position of the discharging conduit 15 in the vacuum chamber 7. The provision of the heater 17 at the position other than the bent position will be explained in the following.

[0056] For example, in the superconducting magnet apparatus 1, the discharging conduit 15 may be provided with a gravitational check valve 39, as shown in Fig. 4. The gravitational check valve 39 opens when the pressure in the coil container 5 exceeds a predetermined pressure. When the pressure in the coil container becomes lower than the predetermined pressure, the valve closes by gravity. If the gravitational valve 39 is disposed at the discharging conduit 15, there may be a case where the valve does not open because of freezing. Therefore, the clogging of the discharging conduit 15 due to freezing tends to occur in the case of the gravitational valve.

[0057] Accordingly, in the case of the gravitational valve, the heater 17 is disposed at a position to heat the gravitational valve 39 so that the clogging of the discharging conduit 15 extending from the coil container 5 to the outside of the vacuum chamber 7 is surely prevented and that the breakage of the coil container is surely prevented.

[0058] As was explained in the case of the gravitational valve, if there is a portion where the inner diameter is smaller than that of the other portion in the discharging conduit, the smaller inner diameter portion easily clogs due to freezing than does the other portion. Accordingly, in the above case, a heater 17 is disposed at the position for heating the smaller inner diameter portion. As a result, the clogging of the discharging conduit is surely prevented.

(Embodiment 3)

[0059] In case where the superconducting magnet is provided with the thermal shield plate or shield case 9, there is a temperature difference between the inside of the thermal shield 9 and outside of the thermal shield 9. Therefore, the position where the freezing takes place may be different in accordance with the freezing point of the freezable components contained in the gas entering the discharging conduit disposed outside of the vacuum chamber 7. Accordingly, if the freezing takes place at a position outside of the thermal shield plate or case 9, the heater 17 is disposed at the discharging conduit 15 outside of the thermal shield 9, as shown in Fig. 5.

[0060] On the other hand, if the freezing takes place at the discharging conduit inside of the thermal shield 9, the heater 17 is disposed at the discharging conduit 15

inside of the thermal shield 9.

[0061] Whether the heater 17 is disposed inside of the thermal shield 9 or outside of the thermal shield 9 is applied to case where the heater 17 is disposed at the position where the discharging conduit 15 is bent. Although Fig. 1 shows that the heater 17 is disposed at the bent position of the discharging conduit 15 outside of the thermal shield 9, the heater 17 may be disposed at a bent position of the discharging conduit 15 inside of the thermal shield 9, depending on the freezing point of the components in the gas.

[0062] The superconducting magnet apparatus 1 of this embodiment is provided with a first pressure detecting means 21a for detecting a pressure of the discharging conduit at a position located outside of the vacuum chamber 7 and a second pressure detecting means 21b for detecting a pressure of the discharging conduit 15 at a position inside of the vacuum chamber 7. The control section 13 supplies current to the heater 17 when the pressure detected by the first pressure detecting means 21a exceeds the predetermined pressure so that the control section judges the clogging of the discharging conduit 15 and eliminates the clogging by heating the conduit with the heater.

[0063] The superconducting magnet apparatus may not be provided with a control section, which compares the pressures detected by the first and second pressure detecting means 21a, 21b and automatically supply current to the heater. In this case, an operator can compare the detected pressures to find clogging of the conduit and judge whether the current is supplied to the heater or not. It is possible to cause the heater 17 work if the magnetic apparatus has no pressure detecting means and the conduit is in a condition that the clogging of the conduit 15 may take place.

[0064] In this embodiment, the heater 17 is disposed at only one position for the purpose of explaining the position of the heater. However, the heater 17 may be disposed at positions where clogging due to freezing may take place. By providing a plurality of heaters 17, the clogging of the conduit 15 can surely be prevented.

[0065] In the following, a second method of operation of the superconducting magnet apparatus is explained by reference to Fig. 1. In this method, the control section stops cooling of the cooling medium in the coil container with the refrigerator 11 when the pressure in the coil container detected by the second pressure detecting means 21b exceeds the predetermined pressure. Further, the control section supplies current to the heater to heat the conduit when the pressure in the coil container exceeds the predetermined pressure.

[0066] The control section 13 of the superconducting magnet apparatus 1 starts to heat the conduit 15 connected to the coil container 5 with the heater 17 when the pressure in the coil container or the pressure in the conduit in the coil container exceeds the predetermined pressure.

[0067] Accordingly, in the case of maintenance work

or replacing work, where the cooling medium in the coil container is vaporized and discharged from the coil container, cooling of the cooling medium in the coil container is stopped when the pressure in the coil container exceeds the predetermined pressure. As a result, it is possible to prevent a negative pressure in the coil container, which leads to introduction of gas containing freezable components such as water, nitrogen, etc into the conduit when the cooling medium is discharged from the coil container. If the cooling medium remains in the coil container 5, the cooling medium expands its volume by heat due to quenching or vacuum breakage, which may lead to breakage of the coil container. The heater 17 may be disposed at any positions in accordance with kinds of freezable components or the structure of the superconducting magnet apparatus.

[0068] As has been discussed, in the superconducting magnet apparatus of the present invention, if the pressure in the coil container 5 exceeds the predetermined pressure, cooling of the cooling medium with the refrigerator is stopped. Accordingly, it is possible to prevent negative pressure in the coil container and to prevent clogging due to freezing in the conduit such as the discharging conduit 15. Thus, even if the remaining liquid cooling medium is vaporized by quench or vacuum breakage after the cooling medium in the coil container is removed. Since the conduit is not clogged, vaporized cooling medium is discharged from the coil container. That is, it is possible to prevent destruction of the coil container 5 due to quench or vacuum breakage caused by clogging of the conduit.

[0069] Further, in the superconducting magnet apparatus 1 of this embodiment, when the pressure in the coil container 5 exceeds the predetermined pressure, the heater 17 is supplied with current to heat the conduit 15. Therefore, even if freezable components such as water or nitrogen enter the conduit 15, the freezing in the conduit 15 is prevented.

[0070] The heater 17 for heating the conduit or the first pressure detecting means 21a may be omitted. It is possible to employ both of the above mentioned control method and the previously mentioned control method.

(Embodiment 4)

[0071] As shown in Fig. 6, the heater 17 may be disposed to a position not located at the bent position of the discharging conduit 15. However, the heater 17 electrically connected to a power source (not shown) by means of wiring 19 should be disposed as close to the conduit 15 as possible.

(Embodiment 5)

[0072] In the following, the fifth embodiment according to the present invention is explained by reference to Fig. 7.

[0073] Fig. 7 shows a diagrammatic cross sectional

view of the superconducting magnet apparatus according to the present invention. In the explanation, the same reference numerals as those in the previous embodiments indicate the same components; thus explanation will be omitted to avoid redundancy. Only different point and features from the previous embodiments are described in the following.

[0074] The difference of this embodiment from the first embodiment resides in that a purge heater is connected to the control section for forming a heating section with the heater so that the cooling medium in the coil container is heated with the purge heater when the pressure in the coil container becomes lower than a predetermined pressure.

[0075] The superconducting magnet apparatus 41 in this embodiment has, as shown in Fig. 7, a control section 13 to which a heater 17 and a purge heater 43, disposed in the cooling medium in the coil container, for heating the cooling medium are electrically connected. The control section 13 supplies current to the purge heater 43 to heat the liquid cooling medium when the pressure, detected by the second pressure detecting means 21b, in the coil container 5 becomes lower than the predetermined pressure. The predetermined pressure at which the control section starts to supply current to the purge heater 43 is set to a pressure higher than the atmospheric pressure.

[0076] Accordingly, at the time of maintenance work of the superconducting magnet apparatus 41, such as charging of cooling medium, where the coil container 5 is exposed to the atmospheric pressure, the pressure of the coil container can be kept positive pressure since the cooling medium is heated by the purge heater 43 to be vaporized when the pressure in the coil container becomes lower than the predetermined pressure.

[0077] Therefore, it is possible to prevent the gas containing freezable components such as nitrogen, water etc from entering the conduit 15 arranged from the coil container 5 through the outside of the vacuum chamber 7 so that clogging of the conduit can be avoided. That is, the breakage of the coil container due to quenching or vacuum breakage caused by clogging is prevented.

[0078] AS shown in Fig. 7, when the purge heater 43 and the heater 17 for heating the discharging conduit 15 are combined, it is possible to more surely prevent breakage of the coil container at the time of quenching of vacuum breakage caused by the clogging of the conduit for communicating the coil container through the outside of the vacuum chamber. It is also possible, however, not to dispose the heater 17 but to dispose only the control section 13 and the purge heater 43.

(Sixth embodiment)

[0079] In the following, the sixth embodiment of the present invention is explained by reference to Fig. 8.

[0080] Fig. 8 is a diagrammatic cross sectional view of the superconducting magnetic apparatus of the

present invention. Descriptions of the same elements as those in the previous embodiments are omitted to avoid redundancy, but only different points are explained.

[0081] Different points of the sixth embodiment from the previous embodiments resides in that in place of the heating means such as heaters, a burst portion is disposed whereby gaseous cooling medium is discharged through the burst portion when the pressure in the conduit exceeds a predetermined pressure. That is, the superconducting magnet apparatus 45, as shown in Fig. 8, is provided with a burst portion 47 at a space position where the discharging conduit 15 is located at a position surrounded by the thermal shield 9 in the vacuum chamber 7.

[0082] The burst portion 47 is so designed as to break its wall when the pressure in the discharging conduit exceeds the predetermined pressure so that the conduit communicates the vacuum chamber. The burst portion may be made of a bellows of which wall thickness is thinner than that of other portion. A pressure at which the burst portion is broken should be lower than the pressure to which the coil container 5 withstands.

[0083] Accordingly, if the pressure in the coil container 5 exceeds the withstanding pressure of the burst portion 47 due to clogging of the conduit 15, the burst portion is broken and the cooling medium in the coil container flows out in the vacuum chamber 7. Therefore, it is possible to prevent that the pressure in the coil container 5 exceeds the withstanding pressure of the coil container 5 so as to prevent the coil container 5 from breakage.

[0084] The vacuum chamber 7 may be provided with a pressure releasing mechanism such as a safety valve for releasing the pressure in the vacuum chamber when the pressure exceeds the predetermined pressure. As far as the pressure mechanism is disposed, the pressure in the vacuum chamber would not exceed the withstanding pressure of the vacuum chamber and the vacuum chamber would not be broken, even if the cooling medium flows into the vacuum chamber from the broken burst portion 47.

[0085] In this embodiment, the burst portion 47 is disposed to the discharging conduit 15 within the space confined by the thermal shield 9 in the vacuum chamber 7. However, since the position where the clogging of the conduit may change according to freezing points of the components in the gas, the burst portion may be disposed to the conduit located in the space between the wall of the vacuum chamber and the thermal shield 9. Further, the above-mentioned burst portions may be employed in one apparatus so that the breakage of the coil container due to quenching or vacuum breakage caused by clogging of the conduit is more surely prevented.

[0086] Although this embodiment shows a structure that employs only the burst portion 47 disposed to the conduit 15 within the vacuum chamber 7, the burst portion 47 may be combined with the heaters or a purge

heater shown in the previous embodiments. Further, a mechanism for stopping cooling the cooling medium with the refrigerator may be combined with the above elements.

[0087] In the previous embodiments only the discharging conduit as a passage disposed from the coil container 5 through outside of the vacuum chamber 7 is shown. However, there are other conduits connected to the coil container 5. The structure of this embodiment may be applied to such the other conduit arrangement.

[0088] In the previous embodiments, the refrigerator 11 is employed; the refrigerator may be omitted, however. The refrigerator is not limited to the vertical type as shown in figures, but a inclined type or horizontal type refrigerator may be employed.

[0089] The present invention can be applied to not only superconducting magnet apparatuses for MRI or NMR, but to various applications of the superconducting magnet apparatuses for other apparatuses.

Claims

1. A superconducting magnet apparatus comprising a coil container for accommodating one or more superconducting coils and liquefied cooling medium for cooling the coils down to the critical temperature or lower of a superconductor constituting the coils, a vacuum chamber for accommodating the coil container and for vacuum insulation of the coil container from the atmosphere, and a conduit communicating the coil container at one end thereof and extending to the outside of the vacuum chamber at the other end, wherein at least one heating device for heating the conduit is disposed at one or more positions of the conduit located within the vacuum chamber.
2. The superconducting magnet apparatus according to claim 1, wherein the conduit is arranged zigzag in the vacuum chamber, and wherein the heating device is disposed at a bent position of the conduit.
3. The superconducting apparatus according to claim 1, wherein the conduit has a neck portion where an inner diameter is smaller than the other portion, the heating device being disposed to the neck portion.
4. The superconducting apparatus according to claim 1, wherein the conduit is a discharging conduit for discharging gaseous cooling medium in the coil container, and wherein the apparatus is provided with a valve that opens when a pressure in the coil container exceeds a predetermined pressure, the heating device being at a position to heat the valve.
5. The superconducting apparatus according to claim 1, wherein the apparatus has a thermal shield plate surrounding the coil container in the vacuum cham-

ber, the heating device being disposed to the conduit at a position between the thermal shield plate and the coil container.

6. The superconducting apparatus according to claim 1, wherein the apparatus has a thermal shield plate surrounding the coil container, the heating device being disposed to the conduit at a position between the thermal shield plate and the vacuum chamber. 5
7. The superconducting apparatus according to claim 1, wherein the apparatus is provided with a first pressure detecting means for detecting a pressure in the conduit positioned in the vacuum chamber or in the coil container and a second pressure detecting means for detecting a pressure in the conduit positioned outside of the vacuum chamber. 10
8. The superconducting apparatus according to claim 1, wherein the apparatus is provided with a control section for effecting heating with the heating device when the detected pressure by the second pressure detecting means is higher than a detected pressure by the first pressure detecting means by a predetermined value. 20
9. The superconducting apparatus according to claim 1, which further comprises a pressure detecting means for detecting a pressure in the conduit in the vacuum chamber or a pressure in the coil container, a refrigerator for cooling the cooling medium in the coil container, and a control section for controlling the refrigerator, wherein the control section stops cooling of the cooling medium in the coil container by the refrigerator when the detected pressure by the pressure detecting means is higher than a detected pressure. 30
10. The superconducting magnet apparatus according to claim 1, further comprising a pressure detecting means for detecting a pressure in the conduit in the vacuum container or a pressure in the coil container, a refrigerator for cooling the cooling medium in the coil container, and a control section for controlling the refrigerator, wherein the control section stops cooling of the cooling medium by the refrigerator when the detected pressure by the pressure detecting means is higher than a predetermined pressure, and causes the heating device start to heat. 40
11. The superconducting magnet apparatus according to claim 1, which further comprises a control section for controlling the refrigerator, wherein the control section effects the heating device to work when the detected pressure in the conduit in the vacuum chamber or the detected pressure in the coil container becomes lower than a predetermined value. 45

12. The superconducting magnet apparatus according to claim 1, further comprising a heating device for heating the cooling medium, a pressure detecting means for detecting a pressure in the conduit in the vacuum chamber or a pressure in the coil container, and a control section for controlling the heating device, wherein the control section causes the heating device work when the detected pressure in the conduit in the vacuum chamber or the detected pressure in the coil container becomes lower than a predetermined value. 50

13. The superconducting magnet apparatus according to claim 1, which comprises at least one burst portion for letting gaseous cooling medium flow out therefrom, the burst portion being disposed to the conduit within the vacuum container and being so designed as to be broken when the pressure in the conduit becomes higher than a predetermined value. 55

14. A nuclear magnetic resonance imaging apparatus comprising the superconducting magnetic apparatus according to claim 1, an analysis section for analyzing nuclear magnetic resonance signals from the examinee in a space formed between the superconducting coils, and an imaging section for imaging the signals.

15. A nuclear magnetic resonance apparatus comprising the superconducting magnetic apparatus according to claim 1, a probe for detecting nuclear magnetic resonance signals from a sample tube placed in a space formed between the superconducting coils for accommodating a sample therein, and an analysis section for analyzing nuclear magnetic resonance signals from the sample.

FIG. 1

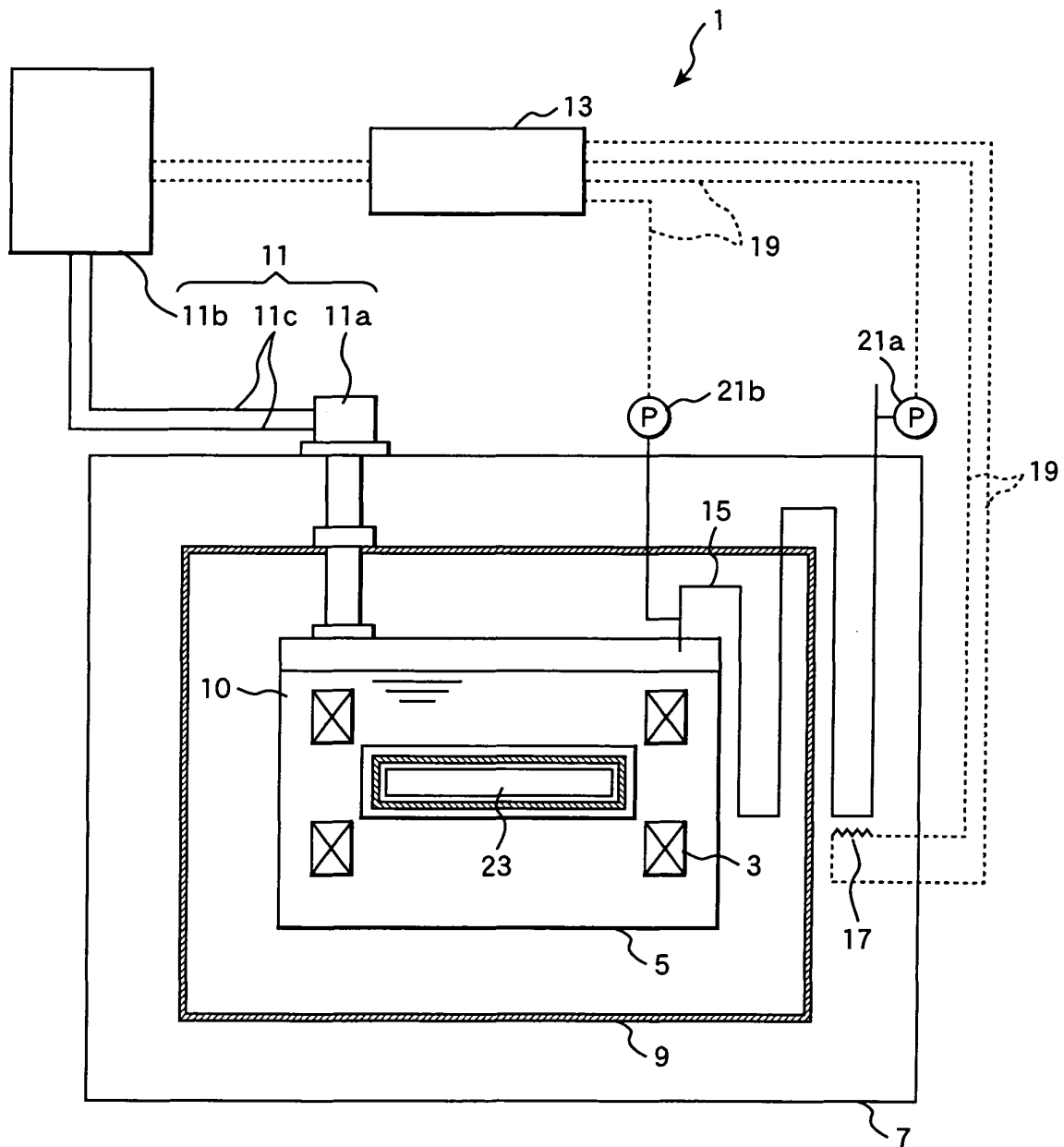


FIG. 2

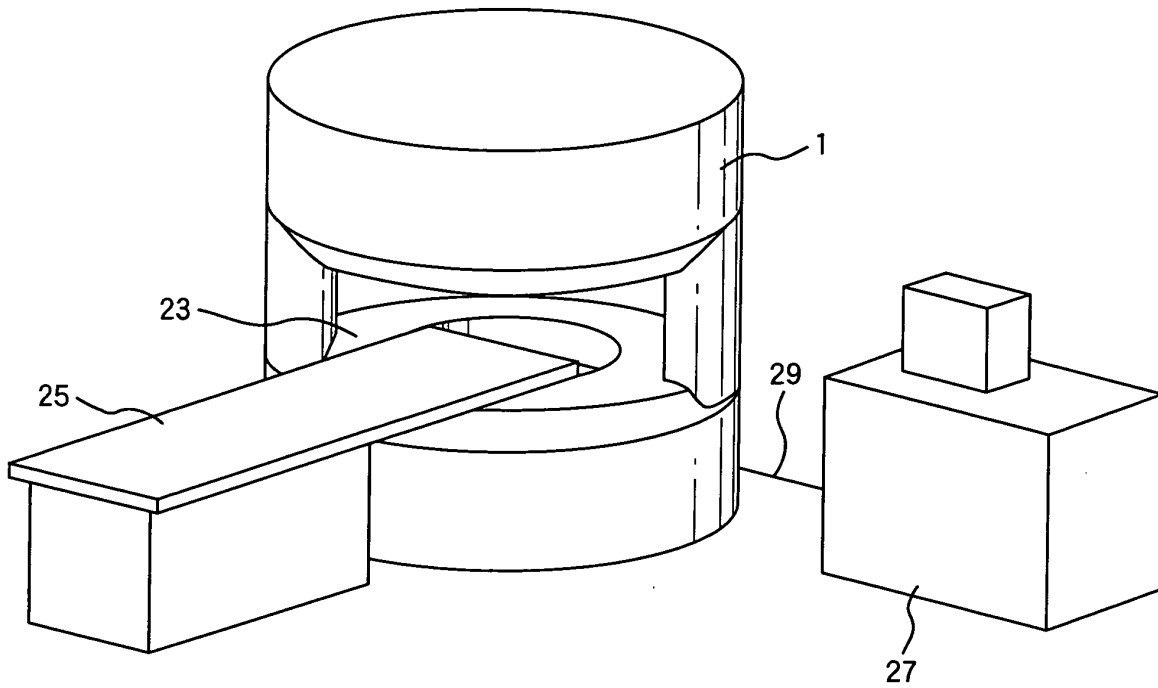


FIG. 3

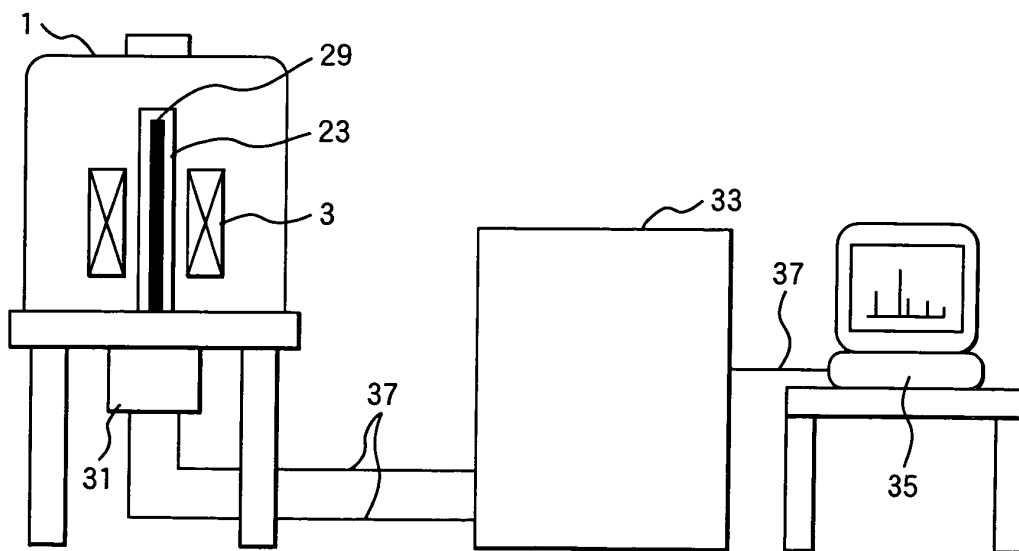


FIG. 4

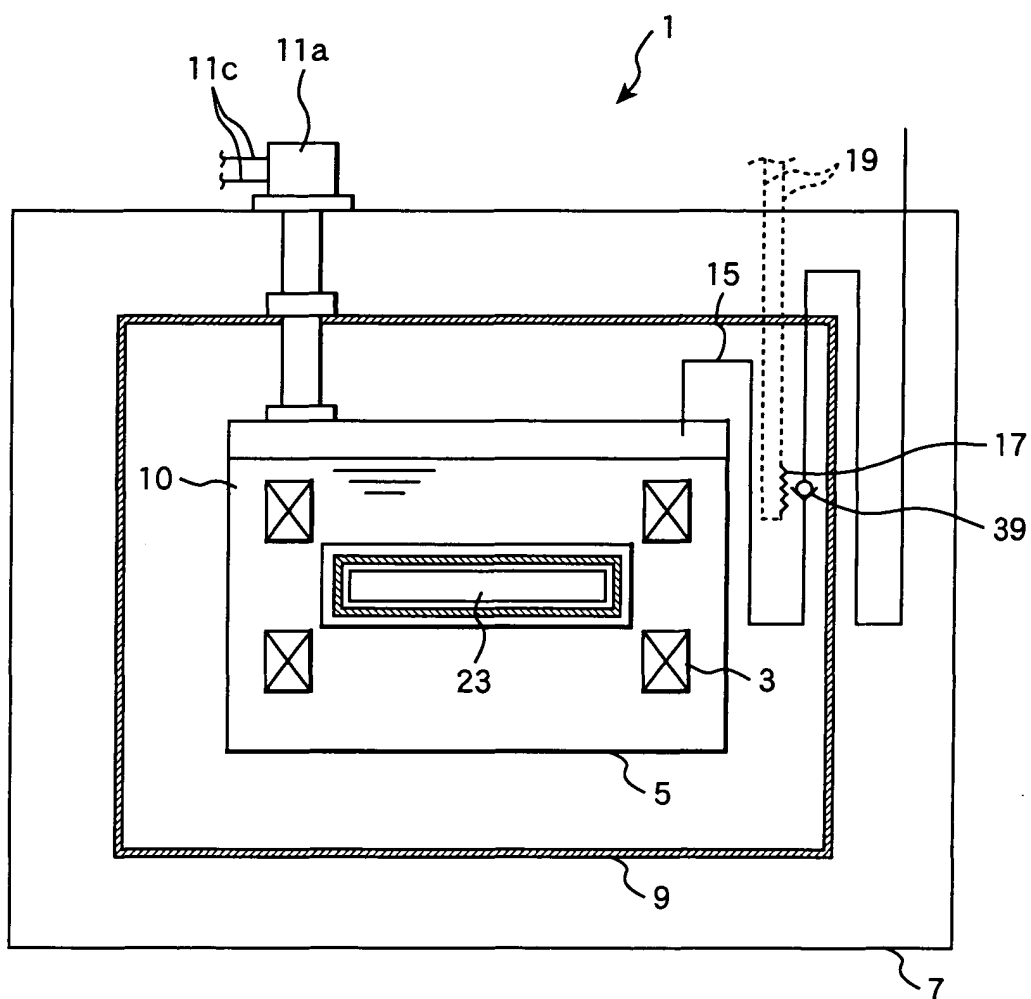


FIG. 5

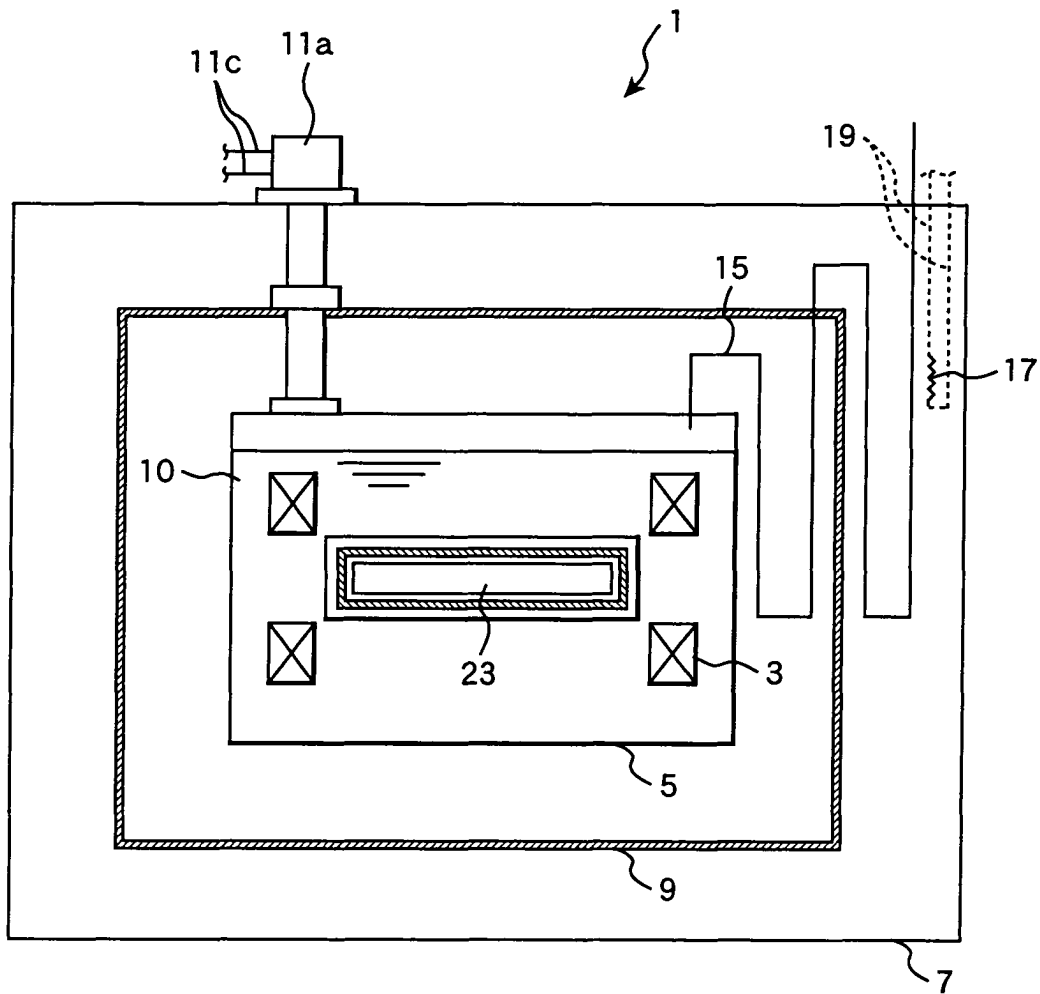


FIG. 6

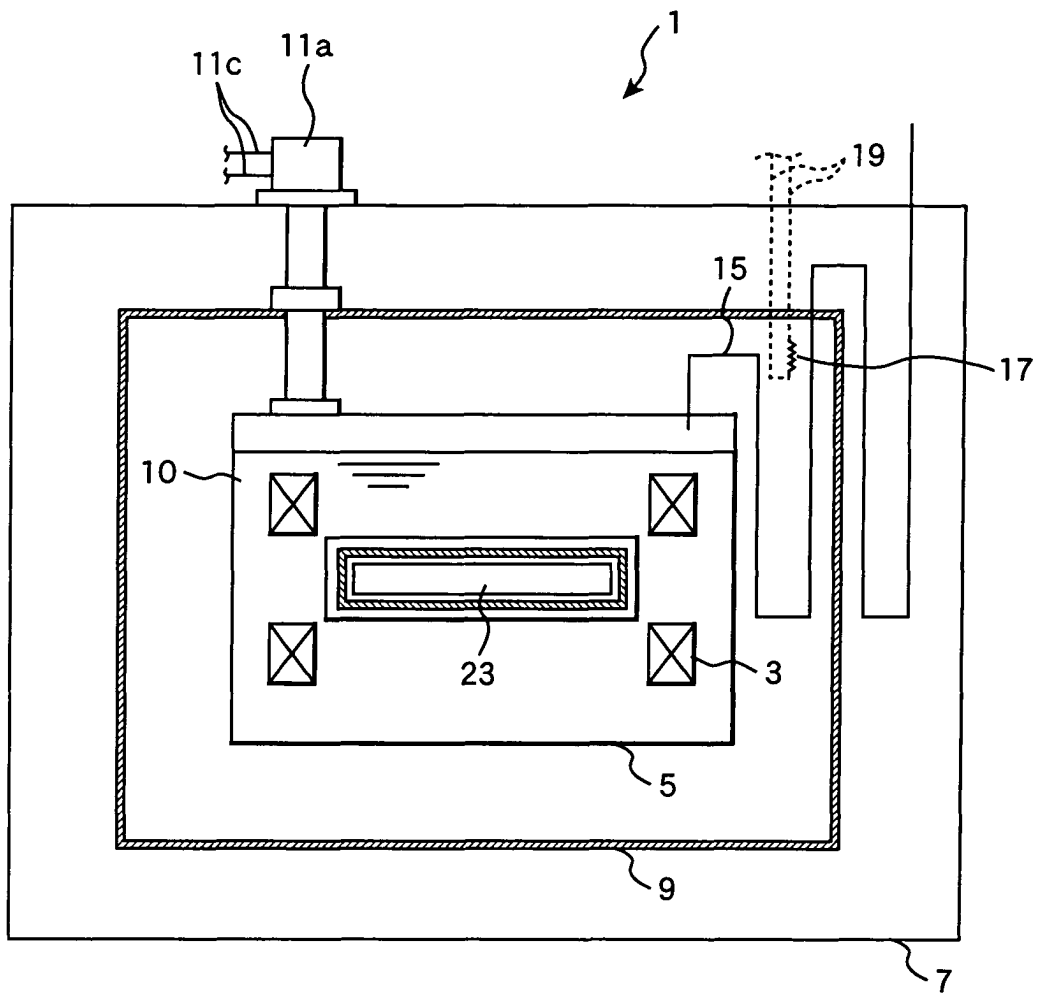


FIG. 7

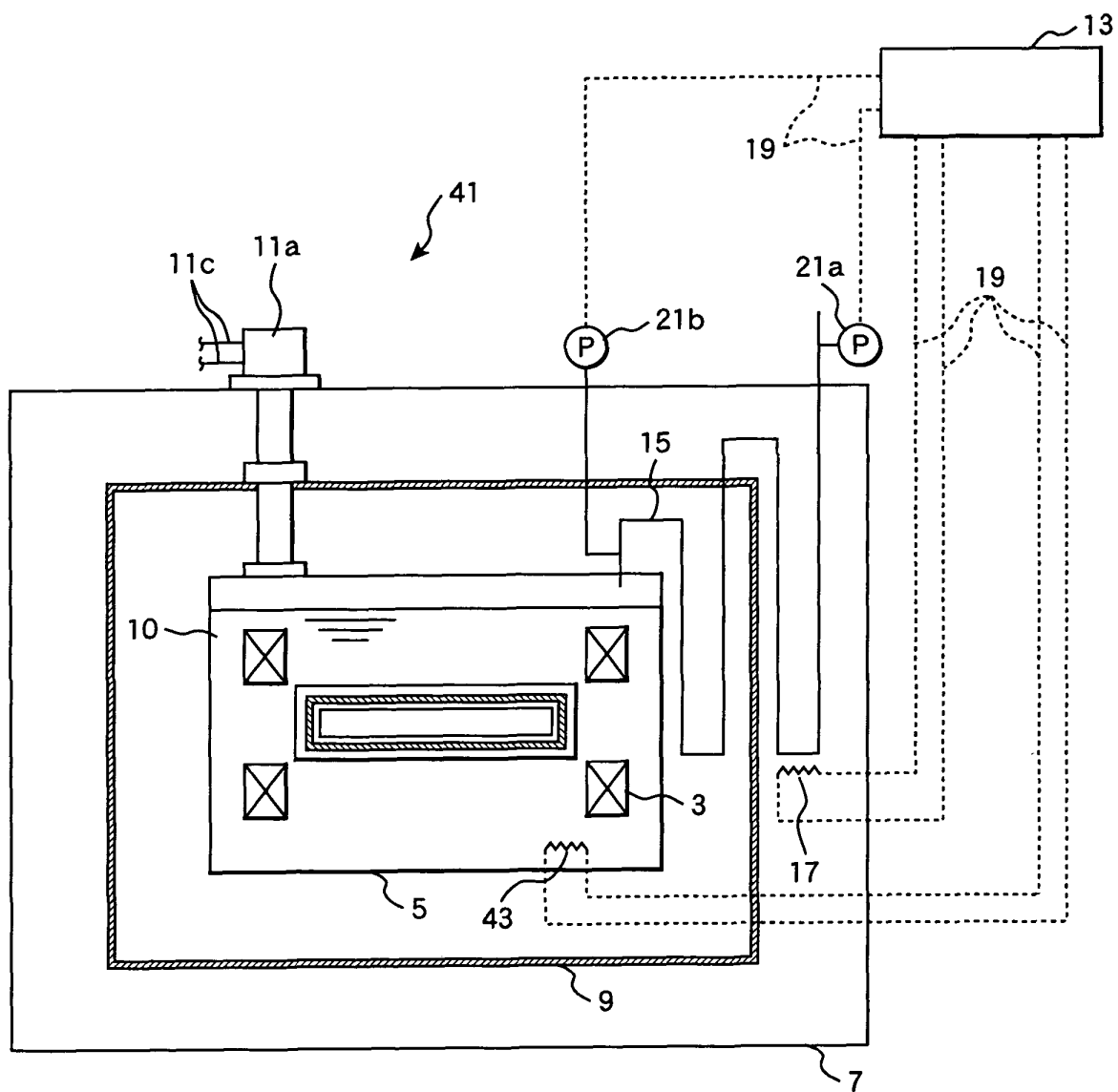


FIG. 8

