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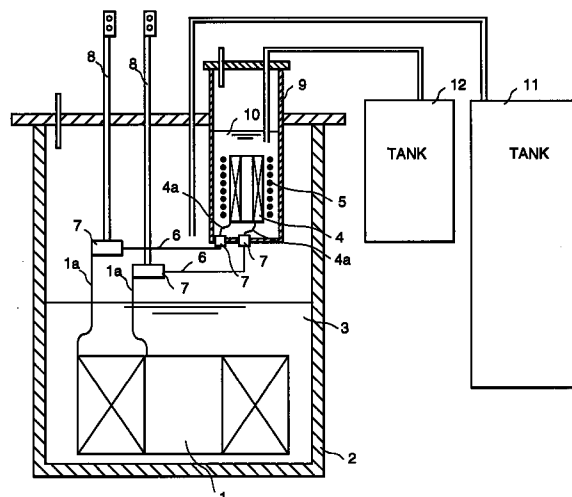
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(54) Method of manufacturing oxide superconducting magnet system, oxide superconducting magnet system, and superconductive magnetic field generating apparatus

(57) There is provided a method of manufacturing an oxide superconducting magnet system suitable to use an oxide superconductor in which parts of an oxide superconducting persistent current magnet comprising a superconducting magnet 1, a persistent current switch 4, and current leads 6 for superconductively connecting the superconducting magnet 1 and the persistent current switch 4 which are made of oxide superconducting materials are preliminarily formed in predetermined shapes and arrangement, connecting ends of the parts are come into contact with each other in connecting parts 7 and are simultaneously subjected to heat treatment for a partial melting followed by solidification to thereby make the parts including the connecting parts 7 superconductors, and after that, a cooling system of a predetermined construction necessary to operate the persistent current magnet is formed.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

The present invention relates to a method of manufacturing an oxide superconducting magnet system and an oxide superconducting magnet system in which an oxide superconductor which was found recently is applied.

For example, as disclosed in "Materia" Vol.34, No. 12, (1995), pp. 1378 to 1383, an oxide superconductor of a conventional technique is known to have the critical temperature and the critical magnetic field higher than those of a metal superconductor. It is known that the oxide superconductor has the remarkable advantage over a metal material from the point of view of the critical magnetic field especially at an extremely low temperature of 20K or lower. A strong magnetic field magnet using the property of the oxide superconductor has been being developed. A persistent current magnet employing the oxide superconductor which was experimentally manufactured is disclosed in "Japanese Journal of Applied Physics" (JJAP) Vol. 35, (1996), pp. 627 to 629.

On the other hand, in a system using a conventional metal superconductor which is at a practical stage, a method of leading liquid helium from a storage container to a cryostat via a transfer tube and immersing and cooling a superconducting coil and a persistent current switch in liquid helium by using natural convection is known. In recent years, a system in which the oxide superconductor is made in a wire state and a coil obtained by winding the oxide superconducting wire in a coil state is cooled by a regenerative refrigerator is disclosed in, for example, Japanese Patent Application Laid-Open No. 4-258103 (1992).

Furthermore, as the background of the present invention relating to the superconducting magnet, Japanese Patent Laid-open Nos. 64-4005 (1989), 9-18062 (1997), 2-16704 (1990), 1-298706 (1989), and 9-223623 (1997) are disclosed.

According to the conventional technique, however, since the oxide superconductor is made of ceramics, new problems such as a poor mechanical strength and complicated superconducting joint which do not occur in the metal superconductor were recognized and are an obstacle to practical use. Especially, the latter problem may be an obstacle to store magnetic energy in a persistent current mode which is one of the important factors of the superconductor, so that there is a problem in the manufacture.

On the other hand, the size of the experimental magnet disclosed in the literature is that of a clenched fist. The persistent current is at most 30A and the generated magnetic field is less than 1000 gauss. A thermal persistent current switch is used in the literature. It takes a long time of few hundreds seconds for the switching operation and a thermal design such as a method of

cooling the system is not fully examined. Consequently, it cannot be said that the magnet is considered as a practical large coil. The technique disclosed in the Japanese Patent Application Laid-Open No. 3-104042 is not a technique for cooling the persistent current magnet. A method of cooling a system employing a metal superconductor cannot be used as it is. Further, a method of cooling a persistent current magnet including a thermal persistent current switch using an oxide superconductor has never been reported, so that there is also a problem with respect to the cooling operation.

The problems of the cooling and manufacture will be described in detail hereinbelow.

When the oxide superconducting magnet can be used as a persistent current magnet, it can be considered that the oxide superconducting magnet is used for, for example, a superconducting magnetic energy storage (SMES), a nuclear magnetic resonance spectrometry (NMR), a magnetic resonance imaging apparatus (MRI) for medical application, a superconducting magnet for physical and chemical analysis and test, and the like. For example, validity of a strong magnetic field by a persistent current in the physical properties study using an NMR is naturally necessary for the study of magnetic field dependency of the material and is more important to a fact that the signal intensity is increased by the strong magnetic field.

(1) The signal intensity is proportional to H/T (H : magnetic field, T : temperature) and the larger H is, the better. Especially, the strong magnetic field is necessary to detect a signal of a nucleus having a small magnetic moment and a nucleus having a small natural abundance ratio. The study of a fine single crystal or the study under a high voltage come to be necessary recently and the strong magnetic field is also necessary to detect a signal of a very small amount of sample in this case.

(2) Since the width by perturbation of 2nd order of an electric quadruple interaction is inversely proportional to H , the larger H is, the narrower the width is and the signal intensity increases. (3) For the increase in H , a resonance frequency increases, Q of the circuit increases, and the sensitivity increases. (4) similarly, dead time of the pulse decreases and short T_2 can be measured. (5) Multiplexed signals can be separately measured in a low magnetic field.

In the field of life science, DNA as a gene of a living being is actively being studied and all the details of the genes of Homo sapiens would be made clear early in the 21st century. Protein is a biopolymer in which a number of amino acids are connected according to "design" drawn in DNA and is very important substance which has the responsibility to various life phenomena such as immunization. Protein displays a function indispensable to the life through the tertiary structure show-

ing how amino acids are folded and have the positional relations.

To know the tertiary structure of protein is a subject indispensable to clarify the life phenomenon. The body of a living being has more than one hundred thousands kinds of proteins and each of the proteins has a different tertiary structure. It is considered that the various tertiary structures are obtained by combination of about 1000 kinds of fundamental structures. If the fundamental structures of the proteins can be clarified, the proteins can be easily modified and designed according to an object. For example, the mechanisms of diseases such as cancer, infection, and hereditary disease would be more clarified and remarkable improvement in diagnostic and treatment techniques would be resulted. It is expected that development of medicines is accelerated. For instance, processes for screening substances which suppress toxicity of pathogenic proteins would be largely improved.

Further, it is expected that it can be applied to development in a bioreactor, a biodegradable plastic, a biosensor, and the like and can contribute to solve the food and environmental problems by creating plants having desired natures. An NMR apparatus employing the persistent current magnet by superconduction obtains information regarding structures of various compounds by using nuclear magnetic resonance occurring in atomic nuclei of certain kinds. As means for clarifying the structure of protein, X-ray crystallographic analysis, an electron microscope, and the like can be used. According to the methods, it is necessary to crystallize the proteins. On the contrary, the NMR has an advantage that it can be applied to a sample which is difficult to be crystallized, since measurement can be performed in an aqueous solution and operation for crystallizing the protein is unnecessary.

The upper limit of a detection frequency of a superconducting NMR apparatus used for clarifying the atom and molecule structures with high precision in the substance and material field and the organic and medical field is 750 MHz (17.6T) by the limit of the generation magnetic field. By allowing a very strong magnetic field exceeding the limit to be generated, a rapid progress in analysis of the structures of high molecular weight protein and the like can be expected. Development of the strong magnetic field magnet using the property of the oxide superconductor is therefore an urgent task. However, in order to use the oxide superconducting magnet as a practical superconducting magnet, it is necessary to realize the practically sufficient critical current of about hundreds to one thousand amperes the metal superconductor has already realized. Further, as a magnet system, it is necessary to improve the persistent current value and the magnetic field by more than one digit from the present state and also to increase the speed of the switching operation so as to be shorter than at least an order of few tens seconds. That is, the configuration of the cooling system has to be improved.

In the cooling operation of a system using a metal superconductor which is conventionally known, an immersing and cooling method is used in which liquid helium is introduced from a storage container to a cryostat via a transfer tube, a superconducting coil and a persistent current switch are immersed, and natural convection is used. With respect to the persistent current switch in such a case, for example, in case of a most general thermal persistent current switch, the operation is performed as follows.

(1) A magnet and a switch device are cooled by liquid helium and are made superconductive. (2) While the magnet is kept superconductive, the switch device is heated by a heater and is made in a normal conducting state, thereby making a resistor. (3) The superconducting magnet is excited by an external power source. (4) The switch device is cooled and is made superconductive. (5) The external power source is turned off. By the above operation, the magnet functions as a persistent current magnet.

In case of the metal superconductor, however, it is sufficient to increase the temperature of the superconductive part to at most 10 to 20K when a general thermal switch is turned off. On the contrary, in case of the oxide superconductor, since the critical temperature is as high as about 80 to 100K due to physical properties, it is necessary to increase the temperature much higher than the conventional technique in order to turn off the switch. There is a fear such that the magnet body is heated by heat conducted from the switch device which is heated to a high temperature and the superconduction is lost. In such a system where the critical temperature and the operating temperature are very different, it can be said that cooling system designing of a novel concept is requested.

On the other hand, there is a problem of formation of superconductive joint as a subject peculiar to the oxide superconductor. In case of the oxide superconductor, since it is made of sintered ceramics, there is a big problem in connecting and bending processes which are performed in the conventional metal superconductor. For example, in case of executing the bending process, distortion should be 0.2% or less. In case of performing the superconductive joint, for example, the jointing is performed by heat treatment such as heat treatment for a partial melting followed by solidification. In case of the oxide superconductor, however, this final heat treatment can be performed only once. It is therefore a problem that even when parts obtained by combining wires which are preliminarily subjected to heat treatment are collected, the superconductive joint cannot be performed.

SUMMARY OF THE INVENTION

It is, therefore, an object of the invention to provide a method of manufacturing an oxide superconducting magnet system which realizes a cooling system satisfying the function of the persistent current magnet while solving the problem from the viewpoint of manufacture peculiar to the oxide superconductor, and to provide an oxide superconducting magnet system and a superconducting magnetic field generating apparatus manufactured according to the method.

A method of manufacturing an oxide superconducting magnet system according to the invention achieving the object is characterized in that a superconducting magnet part, a persistent current switch part, and a current lead part for superconductively connecting the superconducting magnet part and the persistent current switch part, which are made of an oxide superconductor and construct an oxide superconducting persistent current magnet are preliminarily formed in predetermined shapes and arrangement, the jointing ends of each of the parts are come into contact with each other by connecting parts, a heat treatment for a partial melting followed by solidification is simultaneously performed to thereby make the parts including the connecting parts superconductive, and after that, a cooling system having a predetermined construction necessary for operating the oxide superconducting persistent current magnet is formed.

An oxide superconducting magnet system according to the invention achieving the object is manufactured by using the method of manufacturing the oxide superconducting magnet system according to any one of claims 1 to 7. It is also possible to manufacture an oxide superconducting magnet system having a persistent current magnet obtained in a manner such that each of a superconducting magnet part, a persistent current switch part, and a current lead part for superconductively connecting the superconducting magnet part and the persistent current switch part is constructed by an oxide superconducting wire and preliminarily formed in desired arrangement and shapes prior to a partial melting heat treatment for making each of the oxide superconductive wires superconductive, the jointing ends of each of the oxide superconducting wires are come into contact with each other by connecting parts which connect the parts in the above formed state, and after that, a heat treatment for a partial melting followed by solidification is simultaneously performed to make the parts including the connecting parts superconductive.

Further, a superconducting magnetic field generating apparatus according to the invention uses the oxide superconducting magnet system according to claim 8 or 9.

According to the invention, since a desired cooling system is formed after performing partial melting heat treatment to the parts constructing the oxide superconducting persistent current magnet, an oxide supercon-

ducting magnet system having no distortion in superconductive joint and having excellent cooling performance can be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram showing a superconducting magnet system of a first embodiment according to the invention;

Fig. 2 is a diagram showing a superconducting magnet system of a second embodiment according to the invention;

Fig. 3 is a diagram showing a superconducting magnet system of a third embodiment according to the invention;

Fig. 4 is a diagram showing a superconducting magnetic system of a fourth embodiment according to the invention;

Fig. 5 is a diagram showing a superconducting magnetic system of a fifth embodiment of the invention; and

Fig. 6 is a diagram for explaining a superconducting magnet system of a conventional technique.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the invention will be described hereinbelow with reference to the drawings.

(First embodiment)

An oxide superconducting magnet system (hereinbelow, simply called a superconducting magnet system) according to an embodiment of the invention will be described with reference to Fig. 1. That is, a method of manufacturing the superconducting magnet system according to the embodiment of the invention and a method of forming a cooling system structure will be described.

In Fig. 1, a superconducting magnet 1 constructed by a superconducting coil is wound with a silver sheathed 55 core tape-shaped wire using a $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor. A thermal persistent current switch 4 is non-inductively wound with a silver-10 weight % gold alloy sheathed 55 core tape-shaped wire using the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor. Each of current leads 6 for electrically and superconductively connecting the persistent current switch 4 and the superconducting magnet 1 is constructed by a 55 core tape-shaped wire sheathed by a silver alloy containing about 10 weight % of gold by using the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor.

All of the above elements (total four parts) are separately manufactured before partial melting/solidification heat treatment. Both ends 1a of the superconducting magnet 1 and both ends 4a of the persistent current switch 4 are butted against ends of the

current leads 6 by connecting parts 7, respectively, a heat treatment for a partial melting followed by solidification is performed at 880 °C for 30 minutes in an oxygen air current, thereby making a whole circuit comprising the elements (total eight parts) including the connecting parts 7 superconductive. Each of the connecting parts 7 serving as a superconductive connecting part is partially melted after the end faces of the tape-shaped multicore wires are held so as to be butted against each other so that the superconductive joint is certainly performed. After that, a manganin heater wire is wound around the persistent current switch 4, thereby forming a heater 5. In this manner, a persistent current switch part as a thermal switch is formed.

The superconducting magnet part of the embodiment corresponds to the superconducting magnet 1 and the ends 1a, the persistent current switch part corresponds to the persistent current switch 4, the ends 4a and the heater 5, and the current lead part corresponds to the current leads 6. The component elements including the connecting parts 7 can be also immersed in an epoxy resin for reinforcement after the heat treatment in accordance with necessity.

After that, while attention is carefully paid so that distortion of the superconducting magnet system is within a permissible distortion range when the superconducting magnet system shown in Fig. 1 is manufactured, the system is put in a stainless cryostat 2 and can be immersed and cooled in liquid helium as a refrigerant 3. The persistent current circuit is formed by connecting copper current leads 8 connected to an external power source and the connecting parts 7. It is desirable that the copper current leads 8 are detachable.

On the other hand, the persistent current switch 4 and the heater 5 are insulated from heat by a cryostat 9 as a cryostat for the switch part and are immersed and cooled in liquid helium serving as a refrigerant. Instead of liquid helium, liquid nitrogen, liquid hydrogen, liquid neon, or the like can be used. A refrigerant necessary to be supplied to the superconducting magnet part is supplied from a tank 11. A refrigerant necessary to cool the persistent current switch part is supplied from a tank 12. In the following description, the refrigerants 3 and 10 are described as liquid helium 3 and 10.

As shown in Fig. 1, the cryostat 9 housing the persistent current switch 4 in a heat insulating manner and the superconducting magnet 1 are housed in the cryostat 2 in a heat insulating manner. With such a construction, the influence of heat generated by the heater 5 can be avoided by the cryostat 9 and also by controlling a supply amount of the refrigerant 10. In case of forming the cooling system in which the persistent current switch part is housed in the cryostat 9 later, however, the oxide superconductor, having a low degree of freedom in processing as compared with a metal superconductor, has a problem in assurance of secure superconductive joint and very small distortion. In the embodiment, the following arrangement is used.

The external dimension and the strength of the connecting parts 7 electrically and superconductively connecting the persistent current switch 4 and the current leads 6 are larger than those of the ends 4a of the persistent current switch 4 and the current leads 6. Consequently, the connecting part 7 is preliminarily arranged so as to be supported (fixed) by a partition wall of the cryostat 9 as a part of the cooling system. With such a construction, even when the cooling system including the cryostat 9 is assembled in order to complete the superconducting magnet system, stress and deformation at the time of the assembly is absorbed by the connecting part 7, so that distortion occurring is reduced.

Another construction can be also used such that the connecting part 7 which is made superconductive and is reinforced by epoxy resin, filler, or the like is preliminarily arranged in the partition wall of the cryostat 9. Further, a construction such that other connecting parts obtained by covering and reinforcing the ends 4a of the persistent current switch 4 and the current leads 6 are provided in addition to the connecting part 7 and the other connecting parts are preliminarily arranged on the partition wall of the cryostat 9 can be also used. The connecting parts defined in the invention include the connecting parts 7 for superconductive joint and other connecting parts reinforced (or sheathed). It is more preferable that the connecting part is sheathed and reinforced by a heat insulating material.

(Comparative example)

Fig. 6 shows a comparative example. The comparative example relates to an oxide superconducting magnet system which is produced by using an oxide superconductor and by a method of forming a cooling system of a superconducting persistent current magnet according to a conventional technique.

The superconducting magnet 1 constructed by the superconducting coil is wound with a silver sheathed 55 core tape-shaped wire using the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor. The superconducting magnet 1 is housed in the stainless cryostat 2 and is immersed and cooled in the liquid helium 3. The thermal persistent current switch 4 is non-inductively wound with the silver-10 weight % metal alloy sheathed 55 core tape-shaped wire using the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor, and further, the manganin heater wire 5 is wound on the tape-shaped wire. The current leads 6 for superconductively connecting the persistent current switch 4 and the superconducting magnet 1 are constructed by the 55 core tape-shaped wires sheathed by a silver alloy containing about 10 weight % of gold. The superconducting magnet 1 and the persistent current switch 4 are superconductively connected via the current leads 6 and the connecting parts 7. The persistent current circuit is formed by being connected to an external power source via the copper current leads 8. The persistent current switch 4 is housed together with the superconducting

magnet 1 in the same cryostat 2 and the persistent current switch 4 is not particularly insulated from heat and is immersed and cooled in the same liquid helium 3.

The construction, operation, and effects of the embodiment of the invention will be described by comparing the embodiment with the comparative example.

The method of manufacturing the oxide superconducting magnet system shown in Fig. 1 will be first described. When the persistent current magnet in the oxide superconducting magnet system is constructed, manufacturing performance of the oxide superconductor and cooling performance determined by the physical properties (that is, the cooling system construction) have to be considered. In order to realize both of them, in the superconducting magnet system, according to a design in which the "shape and arrangement" necessary for the cooling system which is assembled afterwards and the "shape and arrangement" which assures the certain superconductive joint and the very small distortion are preliminarily considered, the superconducting magnet part, the persistent current switch part, and the current lead part are butted by wires which are not yet subjected to the partial melting heat treatment and are superconductively jointed by the partial melting heat treatment, thereby realizing the superconductive joint and forming a superconductive closed circuit (that is, the persistent current magnet) by all of the elements.

In other words, it is important to obtain the shape and arrangement similar to the shape of an actual system, that is, to design "geometrical shape and arrangement of the cooling system" in which unnecessary stress, deformation, and the like applied to the oxide superconductor or the like when the superconducting magnet system is finally constructed can be suppressed within a permissible range, namely, manufacturing performance is added prior to the partial melting heat treatment. Consequently, even when a desired cooling system is added after the partial melting heat treatment, the requests of the superconductive joint and the very small distortion are satisfied, the object of the manufacturing performance regarding the superconductive joint is achieved, and persistent current mode operation of the persistent current magnet can be stably performed. In other words, in the oxide superconducting magnet system manufactured as mentioned above, the practical persistent current mode operation of the oxide superconducting persistent current magnet can be realized for the first time.

Referring again to Fig. 1, the persistent current mode operation of the first embodiment will be described.

The superconducting magnet 1 was immersed and cooled in the liquid helium 3 and the persistent current switch 4 was similarly immersed and cooled in the liquid helium 10, thereby making the superconducting closed circuit superconductive. After that, the heater 5 was heated, the temperature of the persistent current switch 4 was increased to 90K in a few minutes, and the super-

conductive state was shifted to a normal conducting state. The amount of heat used was about 20W. The liquid helium 10 was evaporated as helium gas by the heating. In such a state, an external power source (not shown) is used, a current of 500A at maximum was supplied from the current lead 8 to the magnet 1 and the magnet was excited to a magnetic field of 15 tesla in about 10 minutes.

In this state, the liquid helium 10 of about 2 liters was injected from the tank 12 of about 2 liters and the persistent current switch 4 was cooled to 4.2K in about 50 seconds and was turned on. After that, the external power source was returned to zero in three minutes and the persistent current mode operation was set. Although a value of resistance of the persistent current switch in a normal conducting state is determined by a value of resistance of the alloy sheath, since a value of inductance varies according to the use and design of various coils, it is difficult to mention an optimum value of resistance. It is desirable that the value of resistance lies within a range about from 1 to few $\pm$ ohms. It is also desirable that the copper current leads 8 are pulled out to prevent heat invasion via the copper current leads 8 after the mode is shifted to the persistent current mode.

The superconducting magnet could operate in the persistent current mode in the structure of the first embodiment as mentioned above. In case of the comparative example shown in Fig. 6, however, even when the heater 5 was heated to turn off the persistent current switch 4, although the liquid helium 3 was evaporated, the temperature of the persistent current switch could not be sufficiently increased. The temperature of the persistent current switch was increased only after all of the liquid helium 3 was evaporated to the level at the bottom face of the switch. The time required to increase the temperature was about 50 minutes and the consumed liquid helium 3 reached the amount of 50 liters.

The external power source was intended to be turned on after confirming that the temperature of the switch increased to 90K. However, since the temperature at the upper end of the coil reached 40K, electricity was turned on only about 20A which is less than about 1/10 of the inherent critical current value I_c of the coil. The reason can be considered as follows. The superconducting magnet was above the liquid level, heat exchange with gas helium was performed, and the temperature increased. After that, liquid helium of 100 liters was injected from the tank 11 for about 20 minutes, the external power source was turned off after the liquid level was returned to the initial state, and the persistent current mode was set. In case of the comparative example, only magnetic field which is less than 1/10 of the case of the first embodiment could be generated.

According to the oxide superconducting magnet system of the first embodiment as mentioned above, after the elements of the superconducting closed circuit necessary for the persistent current mode operation are simultaneously subjected to the process of the partial

melting followed by solidification, the superconducting magnet is installed in the cryostat which houses the superconductive persistent current switch part in a heat insulating manner, thereby forming the cooling system in which the elements can be separately immersed and cooled in the refrigerant. Consequently, the operating speed of the persistent current switch 4 can be increased by more than 10 times as compared with the conventional technique. Further, the consumption of liquid helium at the time of temperature rising and cooling operation can be reduced by one digit, so that it is very effective from the economical point of view. Since the temperature is stabilized, there is also an effect that the magnetic field generated by the superconducting magnet 1 is improved.

By arranging a conventional metal persistent current magnet on the outside of the superconducting magnet system of the embodiment, the magnetic field largely exceeding 20T can be generated in the persistent current mode. Consequently, when the invention is applied to an NMR apparatus or the like, a resonance frequency of 1 GHz or higher can be detected, for example, in case of hydrogen atom, so that a remarkable far-reaching effect can be expected in fields such as medical and life science.

As mentioned above, in case of using the oxide superconductor, by applying the superconductive joint technique of the invention and the technique of cooling the superconducting magnet and the persistent current switch, the foregoing object is achieved. That is, the oxide superconducting magnet system of the invention is characterized in that each of "the superconducting magnet part, the persistent current switch part, and the current lead part for superconductively connecting the superconducting magnet part and the persistent current switch part" is constructed by a tape-shaped oxide superconducting wire which is wound and then subjected to the heat treatment for the partial melting followed by solidification, each part is preliminarily constructed before the heat treatment for the partial melting followed by solidification of the tape wire and is formed in accordance with desired arrangement and shape of a cooling system in which manufacturing performance of the superconducting magnet system is also considered, ends of the tape wires are butted to each other in the connecting parts of the above parts in such a state, and after that, the heat treatment for the partial melting followed by solidification is performed to the whole system to thereby make the system superconductive.

By constructing as mentioned above, all of the parts including the connecting parts are made superconductive and the superconductive closed circuit necessary for the persistent current mode operation can be formed. That is, the partial melting performed after the ends of the wires are butted to each other in the step of producing the superconductive joint system is effective to obtain high crystal orientation in the connecting parts.

It is consequently effective to obtain a high critical current density characteristic. Following to the step of manufacturing the jointing system, a cooling system structure indispensable to the superconducting magnet system is added. That is, according to the step of producing the superconducting cooling system, at least the persistent current switch part out of the superconducting magnet part and the persistent current switch part is insulated from heat, thereby holding each part at a desired temperature, enabling the temperature to be adjusted, and efficiently operating the oxide superconducting persistent current magnet.

There is provided a method of producing the oxide superconducting magnet system in which the problem of manufacturing performance peculiar to the oxide superconductor is solved and the problem of cooling performance caused by the physical properties can be also solved by the above producing steps. The superconducting tape may be deformed a little even after the heat treatment. For example, since distortion of 0.2% or less is permissible, for example, when a tape is preliminarily shaped in the shape of a product, the distortion is within the permissible range when the tape is actually assembled in the product. Generally, since the oxide superconductor is made of ceramics, the dimension is changed by the heat treatment. It can be said that the change of such a degree lies within the permissible range. When the cooling system is assembled later simply in a manner similar to the conventional technique, however, the distortion of 0.2% or more occurs, so that the producing method according to the invention is effective.

Regarding the problem of the high critical temperature limited by the physical properties, it is necessary to thermally insulate the magnet and the switch so that both of them stably operate. For example, like the superconducting magnet system of the embodiment, the persistent current switch part and the superconducting magnet part are housed in the cryostat which are thermally independent and are immersed and cooled by refrigerants, separately. When liquid helium is used as a refrigerant, there are consequently effects that the invention can contribute to the stability of the circuit and also can reduce the amount of consumption of liquid helium. As a refrigerant, liquid neon, liquid oxygen, liquid hydrogen, liquid nitrogen, or the like can be properly used according to use.

On the other hand, in the oxide superconducting magnet system, for the oxide superconductor (including wire) constructing the superconducting magnet, it is desirable to use silver or a silver alloy, for example, a silver alloy containing a very small amount like 0.01 to 1%, preferably, 0.1 to 0.5% by weight of magnesium, titanium, and nickel as an additive.

By using one of those materials, the tensile strength can be increased by more than three times as compared with pure silver. There is accordingly an effect that the superconducting system which withstands elec-

tromagnetic force and in which the covering material does not deteriorate by reaction with the oxide superconductor can be constructed.

Further, in the superconducting magnet system using the oxide superconductor, as the oxide superconductor, a silver sheathed long $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_8$ superconductor having a flat shape in cross section is desirable. A multicore wire is more preferable. It is desirable to use a silver alloy containing 1 to 15 weight % of gold for a material covering the persistent current switch and the wire constructing the current lead. By using the silver alloy containing 1 to 15% of gold, the covering material can have high resistance and low heat conductivity. The resistance when the persistent current switch is off can be sufficiently held and the heat conductivity between the switch part kept at a high temperature and the superconducting magnet kept at a low temperature can be avoided. Thus, there is an effect that the superconducting magnet can stably operate.

The above is summarized. The method of manufacturing the oxide superconducting magnet system according to the invention is characterized in that, prior to performing the partial melting followed by solidification the superconducting magnet part, the persistent current switch, and the current lead part of the oxide superconducting persistent current magnet including the superconducting magnet part constructed by the tape-shaped oxide superconductive wire which is wound and then subjected to the heat treatment for the partial melting followed by solidification, the persistent current switch part, and the current lead part for superconductively connecting the superconducting magnet and the persistent current switch part, the parts are preliminarily formed as a system in the desired arrangement and shape, the ends faces of the tape wires are butted to each other in the connecting parts of the above parts, after that, the whole system is subjected to the process of the partial melting followed by solidification, and further, a desired cooling system construction is formed in the superconducting magnet system.

(Second embodiment)

An oxide superconducting magnet system of a second embodiment according to the invention will be described with reference to Fig. 2. Although the fundamental structure of the superconducting magnet system of the embodiment is substantially the same as that of the first embodiment, a method of cooling the superconducting magnet 1 is different. The superconducting magnet 1 as a superconducting coil is wound with a silver sheathed 55 core tape-shaped wire using a $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor. The superconducting magnet 1 is inserted into the stainless cryostat 2, laid in a vacuum, and cooled by the regenerative refrigerator 13.

Although a Gifford McMahon (commonly called "GM") refrigerator having two cooling stages is used

here as a regenerative refrigerator, a refrigerator having three cooling stages can be also used in order to increase the refrigerating ability at a low temperature. A pulse pipe refrigerator or the like can be also used. Although the pulse pipe refrigerator has the refrigerating ability lower than that of the GM refrigerator, it has an advantage of no vibration. By using the GM refrigerator or the pulse pipe refrigerator as a regenerative refrigerator in the superconducting magnet system, there is also an advantage that a low temperature can be easily obtained.

On the other hand, the thermal persistent current switch 4 is non-inductively wound with a silver-10 weight % gold alloy sheathed 55 core tape-shaped wire using the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor and the manganin heater wire 5 is further wound around the tape-shaped wire. Each of current leads 6 for electrically connecting the persistent current switch 4 and the superconducting magnet 1 is constructed by a 55 core tape-shaped wire sheathed by a silver alloy containing about 10 weight % of gold by using the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor. The superconducting magnet 1 is heat-conducted or cooled on a second cooling stage 14. The superconducting magnet 1 is superconductively jointed to the persistent current switch 4 via the connecting parts 7.

The persistent current circuit is connected to an external power source via the copper current leads 8. A low-temperature end 15 of the copper lead is heat conducted or cooled via the first cooling stage 16 and is connected to the superconducting magnet 1 via a current lead 17 using an oxide superconductor having a small heat conductivity. The first cooling stage 16 is also used for cooling a heat shield 18 of a cryostat 2. The heat shield 18 is formed in a cup shape of a thin copper and forms a double case with the cryostat 2. The heat shield 18 directly houses the superconducting coil 1 and an end of the opening is closely screwed into the first cooling stage 16. Preferably, the copper current leads 8 are detachable.

On the other hand, the persistent current switch 4 has a construction similar to that of the first embodiment. The persistent current switch 4 is heat insulated by a cryostat 9 and is immersed and cooled in liquid helium. Instead of the liquid helium 10 as a refrigerant, liquid nitrogen, liquid hydrogen, liquid neon, or the like can be used. Liquid helium necessary to be supplied to the superconducting magnet part is supplied from a tank 11. The refrigerant necessary to cool the persistent current switch part is supplied from a tank 12.

The effects of the embodiment of Fig. 2 will be described hereinbelow as compared with the comparative example.

In the example of Fig. 2, the superconducting magnet 1 was held at 15K by the regenerative refrigerator. On the other hand, the persistent current switch was immersed and cooled in liquid helium and was kept at 4.2K. Thus, the whole circuit was made superconduct-

tive. In this state, an external power source (not shown in the diagram) was used and a current of 300A at maximum was supplied from the copper current leads 8 to the magnet 1, and magnetization was performed to 9 tesla in about 10 minutes. In such a state, two liters of liquid helium was injected from the tank 12, the persistent current switch 4 was cooled to 4.2K in about 50 seconds, and the switch was turned on. After that, the external power source was returned to zero in about three minutes and a persistent current mode operation was set.

According to the second embodiment as mentioned above, the cooling system is formed in such a manner that the parts constructing the superconductive closed circuit necessary for the persistent current mode operation are simultaneously subjected to heat treatment for a partial melting followed by solidification, after that, the persistent current switch part and the superconducting magnet part are installed in the cryostats which are thermally independent, the persistent current switch part is kept at a desired temperature by the regenerative refrigerator, and the superconducting magnet part is immersed and cooled in the refrigerant. Thus, the operation of the thermal persistent current switch is facilitated and the consumption of the refrigerants can be reduced.

(Third embodiment)

An oxide superconducting magnet system of a third embodiment according to the invention will be described with reference to Fig. 3. Although the structure of the superconducting magnet system of the embodiment is substantially the same as that of the first embodiment, a method of cooling the persistent current switch 4 is different. In the diagram, in a manner similar to the first embodiment, the superconducting magnet 1 as a superconducting coil is wound with a silver sheathed 55 core tape-shaped wire using a $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor. The superconducting magnet 1 is inserted into the stainless cryostat 2 and immersed and cooled in liquid helium 3.

On the other hand, the thermal persistent current switch 4 is non-inductively wound with a silver-10 weight % gold alloy sheathed 55 core tape-shaped wire using the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor and the manganin heater wire 5 is further wound around the tape-shaped wire. Each of current leads 6 for electrically connecting the persistent current switch 4 and the superconducting magnet 1 is constructed by a 55 core tape-shaped wire sheathed by a silver alloy containing about 10 weight % of gold by using the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor. The superconducting magnet 1 and the persistent current switch 4 are superconductively jointed via the current leads 6 and the connecting parts 7. The persistent current circuit is connected to an external power source via the copper current leads 8. Preferably, the copper current leads 8

are detachable.

The persistent current switch 4 is heat insulated by a cryostat 9, heat-conducted or cooled via a second cooling stage 20 by a regenerative refrigerator 19, and is installed in a vacuum. A first cooling stage 21 of the refrigerator is used to cool a heat shield 22 of the cryostat 9. The heat shield 22 is formed in a cup shape of a thin copper, forms a double case with the cryostat 9, and directly houses the persistent current switch 4. An end of the opening is closely screwed into the cooling stage 21. Further, liquid helium necessary to be supplied to the superconducting magnet part is supplied from the tank 11. Instead of liquid helium, liquid nitrogen, liquid hydrogen, liquid neon, or the like can be also used as a refrigerant.

The effects of the embodiment will be described hereinbelow as compared with the comparative example.

In the example of Fig. 3, the superconducting magnet 1 was immersed and cooled in liquid helium. The persistent current switch 4 was heat conducted or cooled at about 10K by the regenerative refrigerator. In this state, after the temperature of the switch was increased to 90K in about 100 seconds by the heater 5, an external power source was turned on, and the superconducting magnet was excited to 10T. In such a state, when the temperature of the heater 5 reached about 20K in 10 minutes while cooling the switch 4 by the refrigerator 19, the external power source was turned off and the persistent current mode operation could be set. In order to improve usability of the system by increasing the cooling speed of the switch part, the construction as shown in Fig. 5 which will be shown hereinafter can be also used. With the construction of Fig. 5, it takes only few tens seconds to cool the switch part and there is an advantage that the switching operation is quickly performed.

In the superconducting magnet system of the third embodiment as mentioned above, the cooling system is formed in such a manner that the parts constructing the superconductive closed circuit necessary for the persistent current mode operation are simultaneously subjected to heat treatment for a partial melting followed by solidification, after that, the superconducted persistent current switch part and the superconducting magnet part are installed in the cryostats which are thermally independent, the persistent current switch part is kept at a desired temperature by the regenerative refrigerator, and the superconducting magnet part is immersed and cooled in the refrigerant. Thus, the operation of the thermal persistent current switch is facilitated and the consumption of the refrigerants can be reduced.

(Fourth embodiment)

An oxide superconducting magnet system of a fourth embodiment according to the invention will be described with reference to Fig. 4. Although the funda-

mental structure of the superconducting magnet system of the embodiment is similar to that of the second embodiment, a method of cooling both of the superconducting magnet 1 and the persistent current switch 4 is different. The superconducting magnet 1 as a superconducting coil is wound with a silver sheathed 55 core tape-shaped wire using a $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{Ox}$ oxide superconductor. On the other hand, the persistent current switch 4 is non-inductively wound with a 55 core tape-shaped wire sheathed by a silver alloy containing about 10 weight % of gold using a $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{Ox}$ oxide superconductor and a manganin heater wire 5 is wound around the tape-shaped wire. Each of the current leads 6 electrically connecting the persistent current switch 4 and the superconducting magnet 1 is constructed by a 55 core tape-shaped wire sheathed by a silver alloy containing about 10 weight % of gold using a $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{Ox}$ oxide superconductor.

The superconducting magnet 1, the persistent current switch 4, and the like are inserted into the stainless cryostat 2, put in a vacuum, heat-insulated from each other, and cooled by regenerative refrigerators 13 and 19. Although a Gifford McMahon (commonly called "GM") refrigerator having two cooling stages is used here as a regenerative refrigerator, a refrigerator having three cooling stages can be also used in order to increase the refrigerating ability at a low temperature depending on the use. A pulse pipe refrigerator or the like can be also used. Although the pulse pipe refrigerator has the refrigerating ability lower than that of the GM refrigerator, it has an advantage of no vibration.

The superconducting magnet 1 is heat conducted or cooled on a second cooling stage 14 of the regenerative refrigerator 13. The superconducting magnet 1 is superconductively jointed to the persistent current switch 4 by the connecting parts 7. The persistent current circuit is connected to an external power source via the copper current leads 8. Low temperature ends 15 of the copper lead are heat-conducted or cooled via a first cooling stage 16 and are connected to the superconducting magnet 1 via current leads 17 using an oxide superconductor having a small heat conductivity.

The first cooling stage 16 is also used for cooling a heat shield 18. The heat shield 18 is formed in a cup shape of a thin copper. The heat shield 18 directly houses the superconducting coil 1, the persistent current switch 4, and the like and an end of the opening is closely screwed into the first cooling stage 16. Preferably, the copper current leads 8 are detachable. The persistent current switch 4 is heat insulated or cooled via a second cooling stage 20 by the regenerative refrigerator 19 and is installed in the vacuum heat shield 18. The cryostat 2 and the heat shield 18 construct a double case which is preferable to form the heat insulation and vacuum.

The first cooling stage 21 of the refrigerator 19 is similarly used to cool the heat shield 18. Although there is no cryostat for housing the persistent current switch

part in a heat insulating manner, the persistent current switch part has a sufficient distance from the superconducting magnet 1 so that there are effects that the heat conductance is prevented and deterioration in performance by a magnetic field leaked from the magnet can be prevented.

On the other hand, in the embodiment, the connecting parts 7 (including connecting parts for covering and reinforcing the ends 1a of the superconducting magnet 1 or the current leads 6) are preliminarily supported and fixed to the second cooling stage 14 as a part of the cooling system, thereby reducing distortion occurring at the time of assembly.

The effects of the embodiment will be described hereinbelow by comparing with the comparative example.

In Fig. 4, the superconducting magnet 1 and the persistent current switch 4 are put in the same space but are heat-insulated in vacuum and are cooled to 15K by the regenerative refrigerators. In such a state, the heater 5 is heated and increased to 90K in about one minute. In this state, the superconducting magnet 1 is magnetized to 7T by an external power source. After that, the heater is turned off and the switch part is cooled. After confirming that it reached 20K in about 20 minutes, the external power source is turned off and the persistent current mode operation is set.

According to the superconducting magnet system of the fourth embodiment as mentioned above, the cooling system is formed in such a manner that the parts constructing the superconductive closed circuit necessary for the persistent current mode operation are simultaneously subjected to heat treatment for a partial melting followed by solidification, after that, the persistent current switch part and the superconducting magnet part are installed in the cryostats which are thermally independent, and the persistent current switch part and the superconducting magnet part are held at desired temperatures by the regenerative refrigerator. Thus, the operation of the system is facilitated and the consumption of the refrigerants can be reduced. In the superconducting magnet system, the persistent current switch part and the superconducting magnet part are installed in cryostats which are thermally independent and the temperature of the superconducting magnet part is held to a desired temperature, for example, to 20K by the regenerative refrigerator, thereby increasing the operating speed of the persistent current switch, facilitating the operation of the magnet system, and reducing the amount of refrigerant consumed by the system.

(Fifth embodiment)

A superconducting magnet system of a fifth embodiment according to the invention will be described with reference to Fig. 5. Although the fundamental structure of the superconducting magnet system of the present embodiment is substantially the same as that of the

third embodiment, a cooling accelerating means is added to the method of cooling the persistent current switch 4. In a manner similar to the first embodiment, the superconducting magnet 1 as a superconducting coil is wound with a silver sheathed 19 core tape-shaped wire using a $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor. The superconducting magnet 1 is inserted into the stainless cryostat 2 and immersed and cooled in liquid helium 3. On the other hand, the thermal persistent current switch 4 is non-inductively wound with a silver-10 weight % gold alloy sheathed 19 core tape-shaped wire using a $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor and the manganin heater wire 5 is further wound around the tape-shaped wire. A 55 core tape-shaped wire sheathed by a silver alloy containing about 10 weight % of gold by using the $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_x$ oxide superconductor is used as each of current leads 6 for electrically connecting the persistent current switch and the superconducting magnet and are superconductively jointed to the superconducting magnet 1 and the persistent current switch 4 in the connecting parts 7. The persistent current circuit is connected to an external power source via the copper current leads 8. Preferably, the copper current leads 8 are detachable.

The persistent current switch 4 is heat insulated by a cryostat 9, heat conducted or cooled via a second cooling stage 20 by a regenerative refrigerator 19, and is installed in a vacuum. A first cooling stage 20 of the regenerative refrigerator 19 is used to cool a heat shield 22. The heat shield 22 is formed thinly of aluminium, directly houses the persistent current switch 4, and an end of the opening is closely attached to the cooling stage 21. Further, liquid helium necessary to be supplied to the superconducting magnet part is supplied from the tank 11. Instead of liquid helium, liquid nitrogen, liquid hydrogen, liquid neon, or the like can be also used as a refrigerant.

In the embodiment, in order to increase the speed of cooling the persistent current switch, a refrigerant pipe 23 for forced cooling is arranged in addition to the above construction. As a refrigerant, low-temperature helium gas, liquid helium, liquid nitrogen, low-temperature nitrogen gas, liquid neon, low-temperature neon gas or the like can be used. It is preferable to arrange the refrigerant pipe 23 around the switch when the persistent current switch is small and to arrange the refrigerant pipe 23 in the switch when the persistent current switch is large. It is preferable to use a material having a good heat conductivity such as copper.

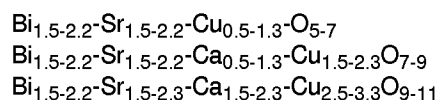
The effects of the embodiment will be described hereinbelow as compared with the comparative example.

In the persistent current switch cooled by the regenerative refrigerator of the fifth embodiment as mentioned above, auxiliary cooling operation by using a refrigerant can be performed when at least the persistent current switch part is cooled and the speed of cooling the persistent current switch is increased, thereby

enabling the switching operation to be facilitated. In the superconducting magnet system, the persistent current switch part includes at least a switch for thermally increasing or decreasing temperature, thereby more finely adjusting the operating speed of the switch. In this case, in order to further facilitate the operation of the switch, an external magnetic field can be also applied to the switch part.

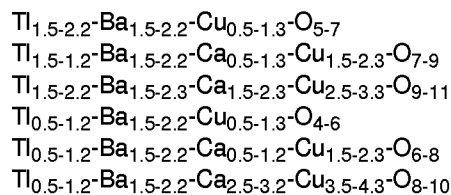
It is preferable that the oxide superconductor of the embodiment is a long silver sheathed $\text{Bi}_2\text{Sr}_2\text{Ca}_1\text{Cu}_2\text{O}_8$ superconductor having a flat shape in cross section. More preferably, it is a multicore wire. There are following Bi-Sr-Ca-Cu-O superconductors.

Bi-Sr-Ca-Cu-O group

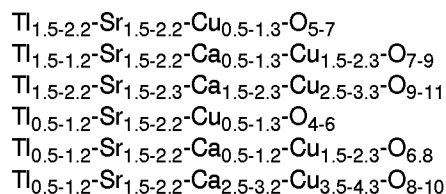


As other superconducting materials, the following superconducting materials and the like can be used.

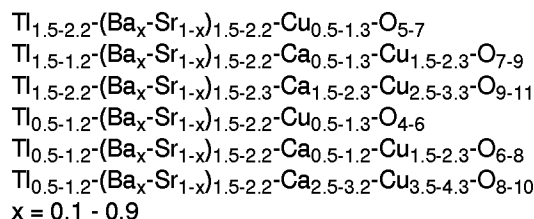
Tl-Ba-Ca-Cu-O group



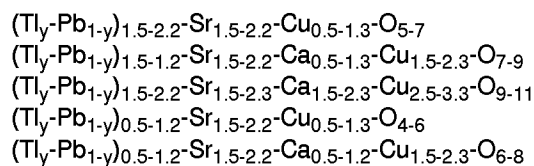
Tl-Sr-Ca-Cu-O group

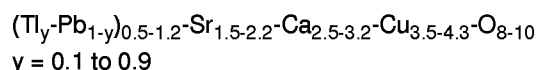


Tl-Ba-Sr-Ca-Cu-O group

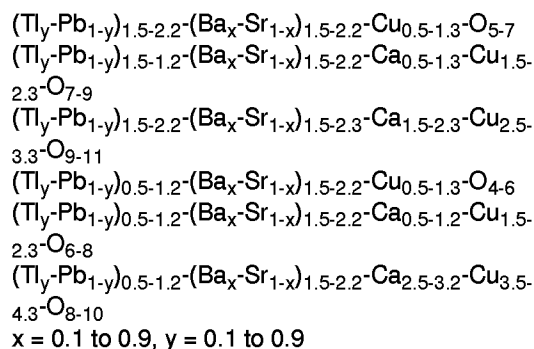


Tl-Pb-Sr-Ca-Cu-O group

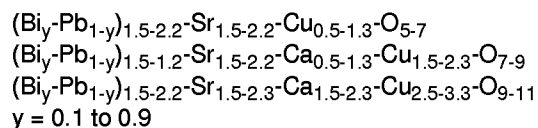




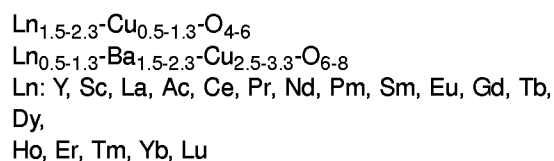
Ti-Pb-Ba-Sr-Ca-Cu-O group



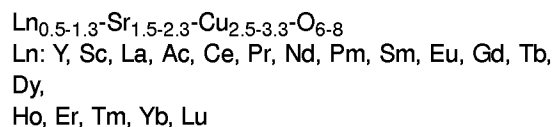
Bi-Pb-Sr-Ca-Cu-O group



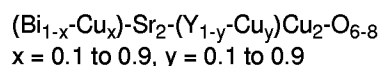
Ln-Ba-Cu-O group



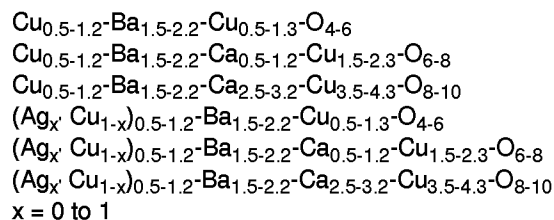
Ln-Sr-Cu-O group



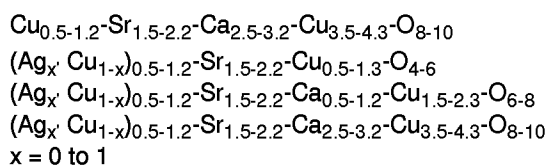
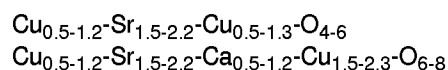
Bi-Sr-Y-Cu-O group



Ba-Ca-Cu-O group

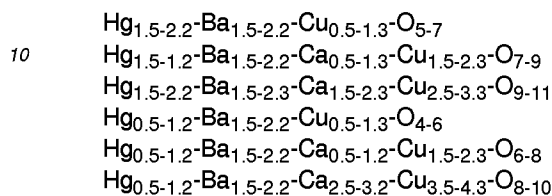


Sr-Ca-Cu-O group



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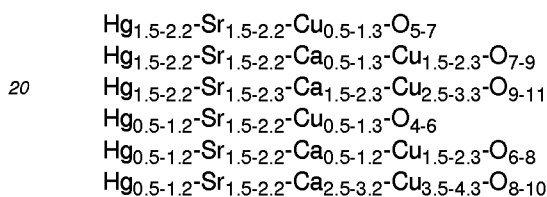
Hg-Ba-Ca-Cu-O group



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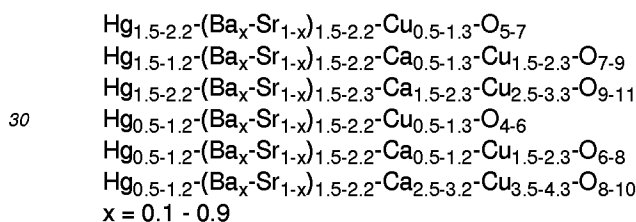
Hg-Sr-Ca-Cu-O group



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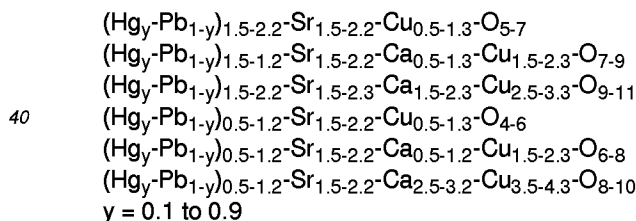
Hg-Ba-Sr-Ca-Cu-O group



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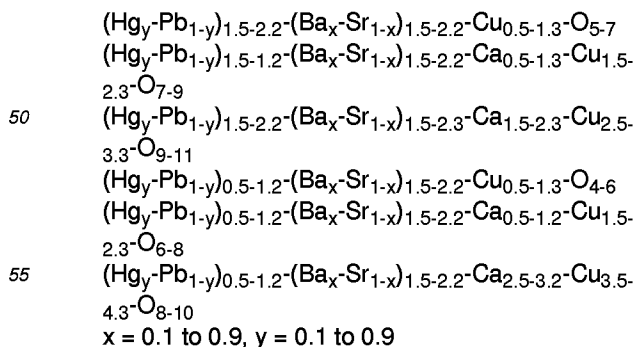
Hg-Pb-Sr-Ca-Cu-O group



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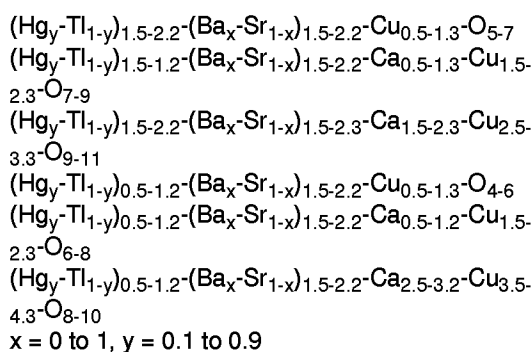
Hg-Pb-Ba-Sr-Ca-Cu-O group



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Hg-Tl-Ba-Ca-O group



In the group containing mercury, by substituting rhenium (Re) for a part (the atomic ratio of 0.1 to 0.5) of the mercury site, composition of crystal phases is facilitated. Further, there are advantages such that the critical magnetic field is improved.

By forming a desired cooling system after the partial melting heat treatment of the invention, the problems from the view point of manufacture such as joint and distortion can be solved and there is an effect that the oxide superconducting magnetic system in which the persistent current mode operation can be stably performed can be provided.

By applying the magnetic field generating apparatus using the oxide superconducting magnet system of the invention to an analyzing apparatus, a nuclear magnetic resonance spectrometry apparatus, a strong magnetic field generating apparatus, a magnetic separating apparatus, a superconducting magnetic energy storage, and the like, a practically useful system can be built and there is also an effect that the invention widely contributes to the society.

Claims

1. A method of manufacturing an oxide superconducting magnet system, wherein a superconducting magnet part, a persistent current switch part, and a current lead part for superconductively connecting said superconducting magnet part and said persistent current switch part, which are made of oxide superconducting materials and construct an oxide superconducting persistent current magnet are preliminarily formed in predetermined shapes and arrangement, jointing ends of each of said parts are come into contact with each other by connecting parts, a heat treatment for a partial melting followed by solidification is simultaneously performed to thereby make said parts including said connecting parts superconductors, and after that, a cooling system having a predetermined construction necessary for operating said oxide superconducting persistent current magnet is formed.

2. The method according to claim 1, wherein in said

cooling system of the predetermined construction, said persistent current switch part and said superconducting magnet part are installed in cryostats which are thermally independent and are respectively immersed and cooled in refrigerants supplied to said cryostats.

3. The method according to claim 1, wherein said cooling system of the predetermined construction is installed in a cryostat which houses both of a switch part cryostat housing said persistent current switch part in a heat insulating manner and said superconducting magnet part in a heat insulating manner, and

said persistent current switch part is immersed and cooled in a refrigerant supplied to said switch part cryostat and said superconducting magnet part is immersed or cooled by a refrigerant or is cooled and held at a desired temperature by a regenerative refrigerator.

4. The method according to claim 1, wherein said cooling system of the predetermined construction is installed in a cryostat which houses said persistent current switch part and said superconducting magnet part in a heat insulating manner, and

said persistent current switch part is cooled and held by a regenerative refrigerator to a desired temperature and said superconducting magnet part is immersed or cooled by a refrigerant or is cooled and held at a desired temperature by a regenerative refrigerator.

5. The method according to any one of claims 1 to 4, wherein said cooling system having the predetermined construction for cooling said persistent current switch part has auxiliary cooling means for accelerating the speed of cooling said persistent current switch part.

6. The method according to claim 1, wherein said connecting part is arranged so as to be supported by a part of said cooling system.

7. The method according to claim 3 or 4, wherein said regenerative refrigerator is a GM refrigerator or a pulse pipe refrigerator.

8. An oxide superconducting magnet system manufactured by using the method of manufacturing the oxide superconducting magnet system according to any one of claims 1 to 7.

9. An oxide superconducting magnet system having a persistent current magnet obtained in a manner such that each of a superconducting magnet part, a persistent current switch part, and a current lead part for superconductively connecting said super-

conducting magnet part and said persistent current switch part is constructed by an oxide superconducting wire and preliminarily formed in desired arrangement and shape prior to a partial melting heat treatment for making each of said oxide superconductive wires superconductive, ends of each of said oxide superconducting wires are come into contact with each other by connecting parts for connecting said parts in said formed state, and after that, a heat treatment for a partial melting followed by solidification is simultaneously performed to said parts including said connecting parts to thereby make them superconductors.

10. A superconducting magnetic field generating apparatus using the oxide superconducting magnet system according to claim 8 or 9.

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FIG. 1

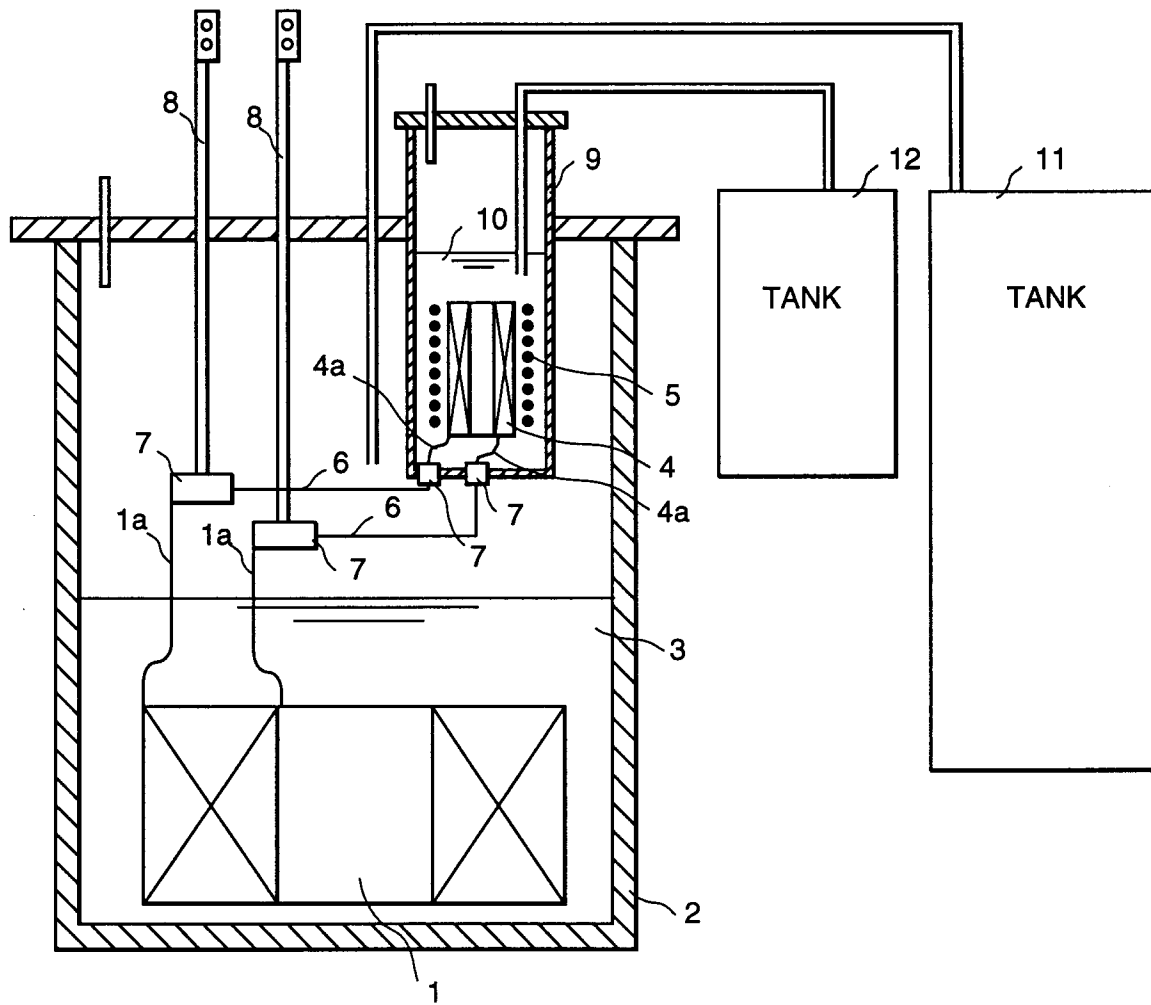


FIG. 2

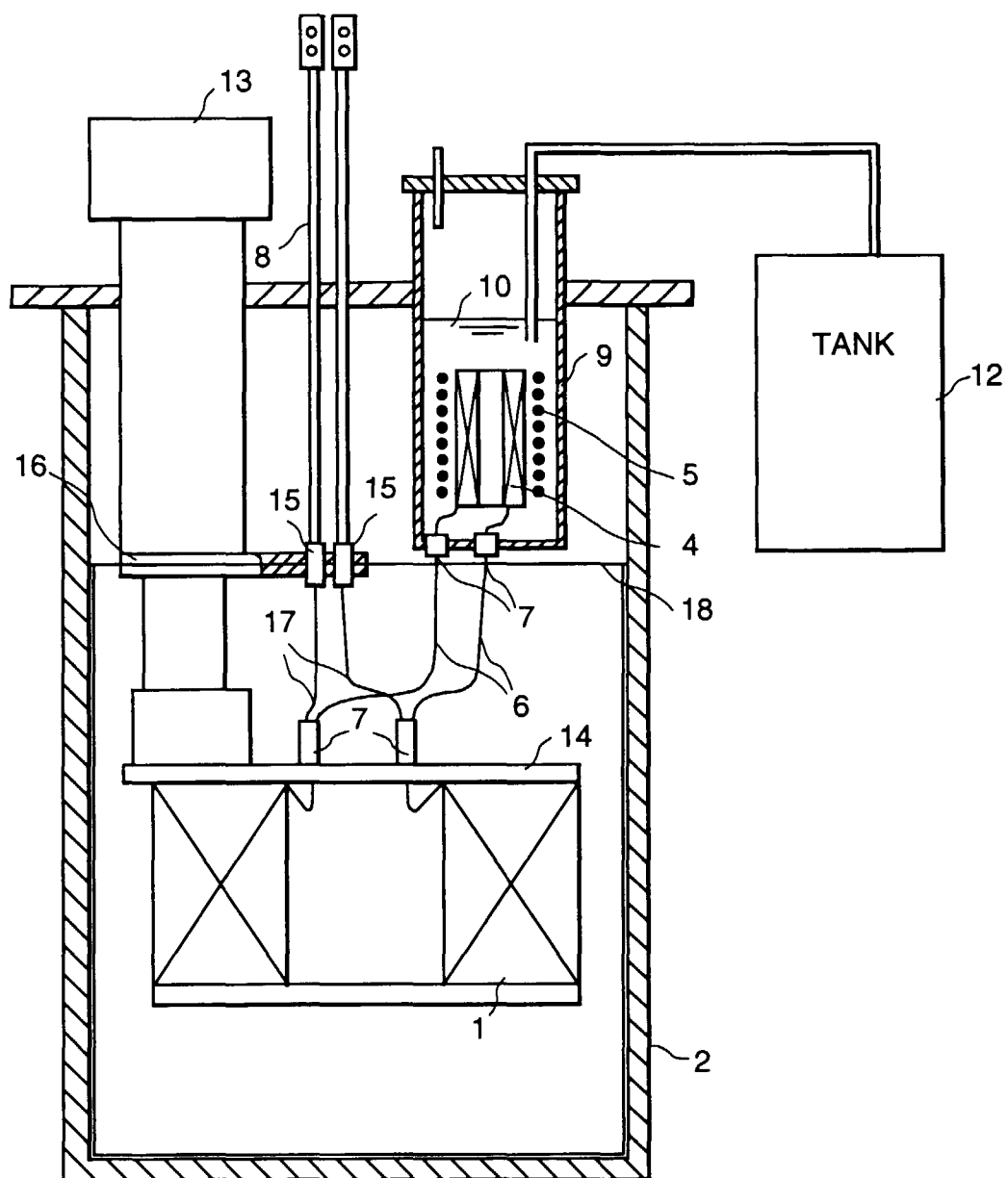


FIG. 3

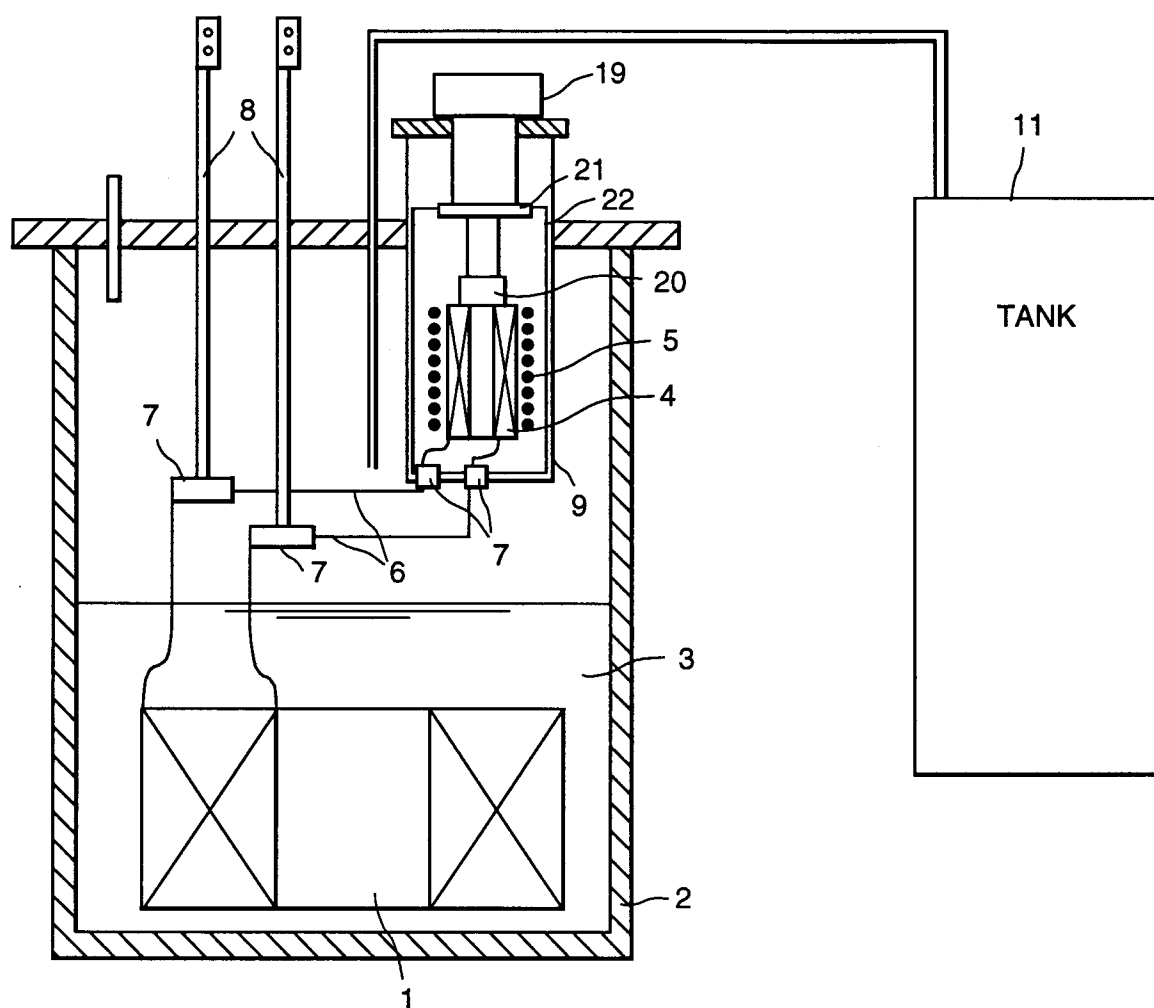


FIG. 4

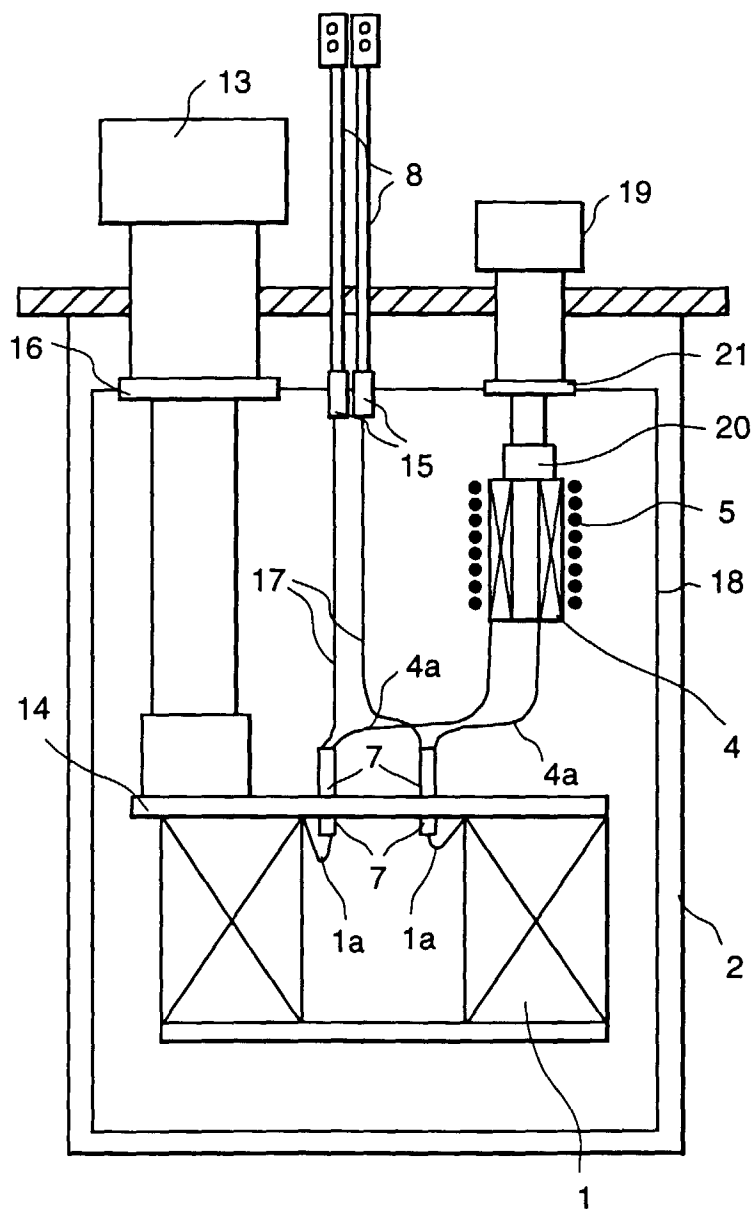


FIG. 5

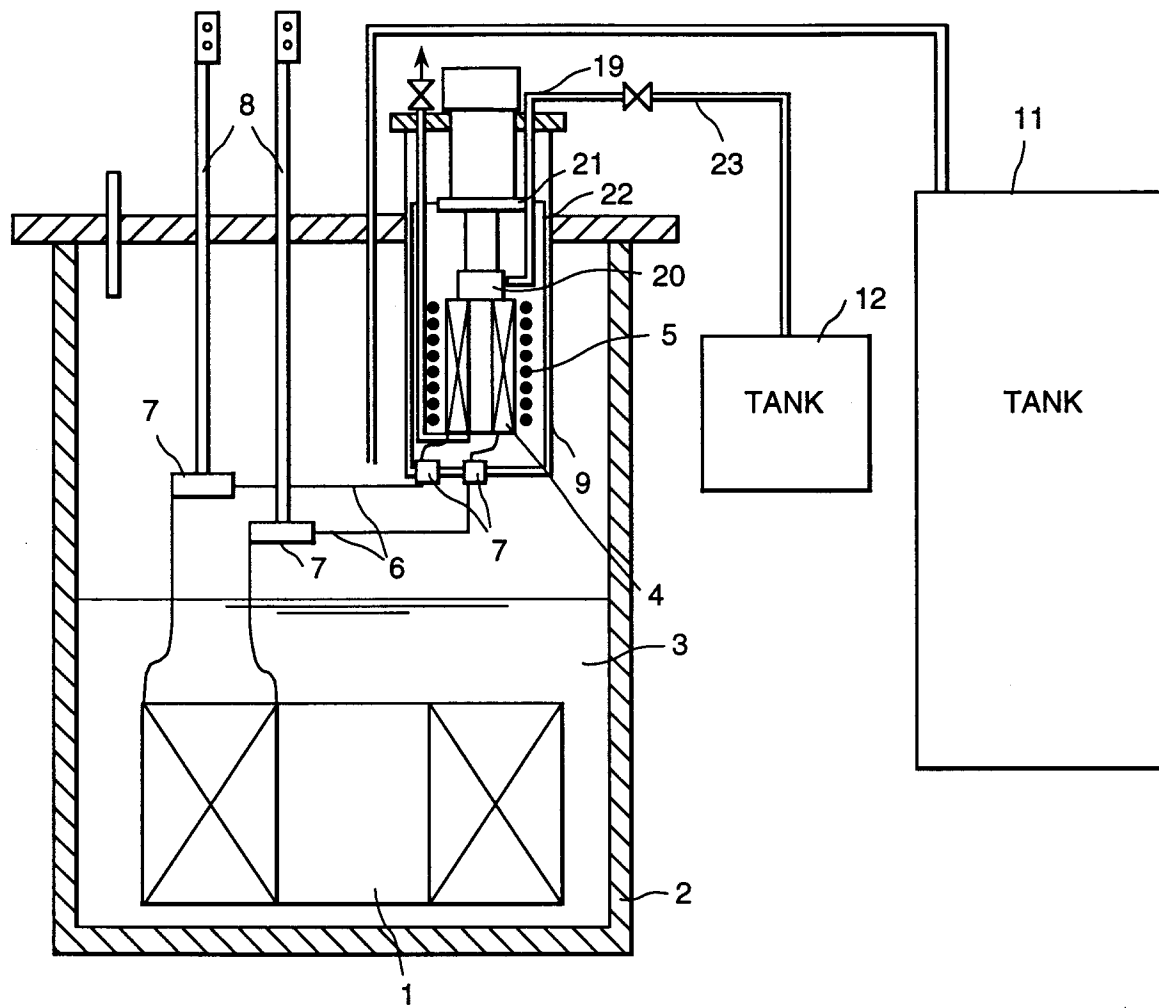


FIG. 6

