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(54) Superconducting coil and process for manufacturing the same, composite superconductor and process for manufacturing the same and superconducting apparatus.

(57) A superconducting coil (15) is formed by coating a composite superconductor (11) with a resin thereon and winding the coated superconductor. A coating film (7) of the resin is formed by a electrocoating method. The resin is selected from a group consisting of epoxy resins, acrylic resins, fluorine resins, phenolic resins and polybutadiene resins.

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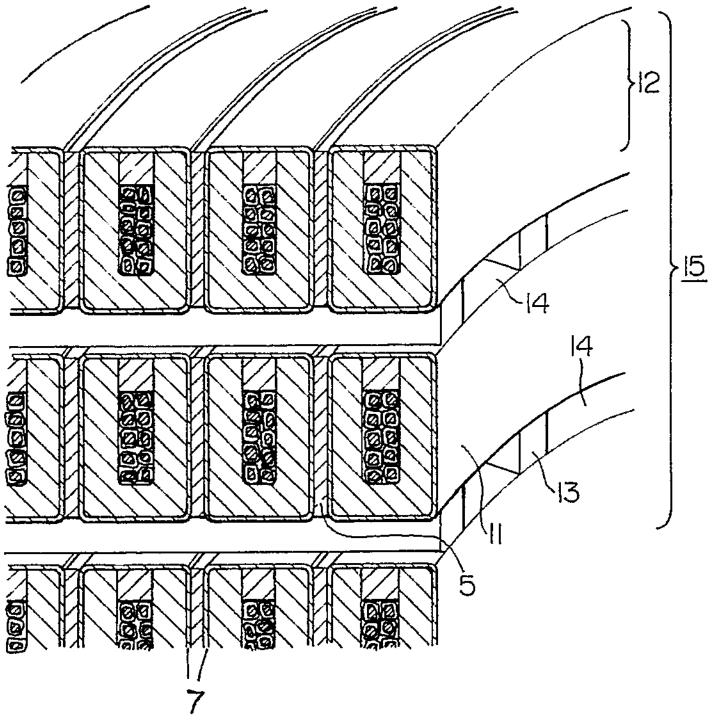
FIG.1



BACKGROUND OF THE INVENTION

The present invention relates to a superconducting coil and a process for manufacturing the same, a composite superconductor forming the superconducting coil and a process for manufacturing the same and a superconducting apparatus having the superconducting coil incorporated therein.

The composite superconductor generally comprises superconductors and normal conductors. The composite superconductor is formed into a round section wire, a square section wire, or a hollow wire, for example, by embedding superconductor wire elements having a diameter of 5 μm to 250 μm into a normal conductor formed of steel, alminium or other metals or an alloy of these metals.

As composite superconductor having an outermost portion around which a resin tape is wound has heretofore been known. However, the thickness of the resin tape is so thick that it functions only an insulating member since this composite superconductor is designed to be immersed in a liquid refrigerant.

Another composite superconductor which is coated with a copper oxide coating on the outermost surface thereof so that it can be immersed into a liquid refrigerant.

Further, a composite superconductor which is coated with a copper oxide coating on the outermost surface thereof is known as an example of a composite superconductor which is immersed into a liquid coolant is known (refer to JP-B-Sho 64-10887).

On the other hand, processes for coating the superconductor with a resin in lieu of tape by a dipping coating have been proposed (refer to JP-A-Hei 1-183008, Hei 1-251517, Sho 63-281316, Sho 64-7414, Sho 61-214305, Sho 64-19613).

A superconductor which are formed with a multiplicity of grooves and walls on the surface skin band of cooling area by cutting to increase the cooling area so that lowering of performance due to burn-out phenomenon is prevented has been proposed (refer to JP-A-Sho 55-56306).

SUMMARY OF THE INVENTION

It is an object of the present invention to realize a superconducting coil which is excellent in cooling performance, a composite superconductor and a process for manufacturing the same and a superconducting apparatus which are excellent in cooling performance.

It is another object of the present invention to realize a superconducting coil, a composite superconductor and a superconducting apparatus in which damage to the coating and short-circuiting will not occur.

It is a further object of the present invention to realize a superconducting coil and a composite superconductor which do not substantially require any waste liquid processing.

The above mentioned objects are accomplished by forming a thin resin coating on the surface of the composite superconductor and disposing spacers between the conductors.

A process to the present invention will now be described.

A technique using a copper oxide coating is characterized in that the outermost stabilizing portion of the composite superconductor is formed of copper and a copper oxide coating is formed on the surface of the outermost portion for enhancing the cooling performance. However, the metal surrounding superconducting wire elements which are structural members of the composite superconductor is limited to copper. A chemical treatment or electrolytic process using chromic acid, potassium permanganate and the like is used for forming a coating film. However, these process have a problem of processing of chemical waste liquids. Solution of this problem has been demanded in view of protection of environment.

Therefore, resin coating is more preferable. However a desired coating thickness cannot be obtained by conventional resin coating processes. In other words, conventional coating processes provide more thick coating film than that needed and partially ununiform coating film. These disadvantages are caused by dipping method. The dipping method would of course be an effective technique if these disadvantages would be eliminated.

The proposal to increase the cooled area has the possibility that raised portions formed on the cooling area may be partly omitted in use of an actual apparatus using the superconductor.

Due to poor heat conduction of the resin coating film, the thicker the coating film becomes, the higher the heat resistance of the coating film becomes, the more difficult it become to conduct the low temperature of a liquid refrigerant to the superconductor. However, if the coating film becomes too thinner, damages to the coating film and short-circuiting between the superconducting wires becomes liable to occur.

In accordance with the present invention, a thin coating film mainly formed of a high-molecular material is formed on the surfaces of composite superconductors including the cooling surfaces thereof and a cooling fluid is admitted between the cooling surfaces of the superconductors for stabilizing the cooling performance.

The present invention is realized by a combination of the formation of a thin resin coating on the surfaces of the composite superconductors and the interposition of spacers between the conductors.

The present invention will now be described.

(Superconducting coil)

A superconducting coil of the present invention is formed by winding composite superconductors which are coated with an insulating material therearound and wound. The insulating material is a resin. Further insulative spacer members are interposed between the composite superconductors coated with the resin.

A superconducting coil of the present invention is formed by winding composite superconductors which include combined plural superconducting wire elements and normal conductors. The composite superconductors are coated with a resin therearound and spacers are interposed between the resin coated composite superconductors.

A superconducting coil of the present invention is formed by winding composite superconductors coated with a resin while refrigerant paths are assured between the composite superconductors.

(Composite superconductor)

A composite superconductor of the present invention comprises composite superconducting wires coated with a resin, a part of the coated surface of the wires being additionally provided with an insulating member.

(Process for manufacturing a superconducting coil)

A process for manufacturing a superconducting coil includes winding composite superconductors which are coated with an insulating film on the surface thereof by an electrocoating method. If it is necessary to repair damaged portion of the insulating film occurred when the composite conductor is formed into the shape of coil, the electrocoating may be performed again after forming into the shape of coil.

A process for manufacturing a superconducting coil of the present invention comprises the steps of winding composite superconductors into the shape of coil; and performing an electrocoating to form an insulating film on the surface of the coil.

(Process for manufacturing a composite superconductor)

A process of manufacturing a composite superconductor comprises the steps of combining a superconductor with a normal conductor; and electrocoating the entire surface of the combined conductor with a high-molecular resin.

When the electrocoating of the composite superconductor is successively performed, the applied voltage is 10 to 200 volts and the electrocoating time is 30 to 150 seconds.

(Way of combining into the composite superconductor)

A way of combining conducting wire elements with normal conductors includes ways as follows:

1. A plurality of superconducting wire elements are surrounded by a normal conductor.
2. Superconducting wire elements are disposed around a normal conductor.
3. A plurality of wires formed of a normal conductive material and a plurality of superconducting wire elements are stranded so that they coexist.

(Normal conductor)

A normal conductor having a low electric resistance is preferable since the normal conductor becomes a by-pass even if a superconductor is partially destroyed. Therefore, use of pure metal such as oxygen-free copper and silver is preferable.

(Superconductive material)

The materials of superconducting wire element are not particularly limited. Accordingly, intermetallic compounds such as Nb_3Sn and alloys such as NbTi may be used to cope with cryogenic temperatures (use of liquid helium). Even oxide ceramics system superconducting materials represented by Y-Ba-Cu-O may be used at temperatures above that of liquid nitrogen.

(Resin coating film)

Although preferable thickness of the coating film depends upon the service environment, thinner coating film is generally better. Preferable range is 1 to 30 μm. Uniform coating is preferable. The present inventors have found that an electrocoating method which will be described hereafter is most preferable to provide a preferable coating.

Specific example of high-molecular resin includes epoxy resins, acrylic resins, fluorine resins, phenolic resins and polybuthadiene resins. In particular, an excellent effect of the present invention is achieved when an epoxy resin is used.

(Superconducting apparatus)

A superconducting apparatus of the present invention comprises a superconducting coil which is formed by winding insulating material coated composite superconductors and is in contact with a liquid coolant. The insulating material forms a resin coating film. Spacings between the wound composite superconductors themselves are maintained by spacer members.

The liquid refrigerant includes liquid helium, liquid nitrogen, liquid oxygen and the like.

The superconducting apparatus of the present invention is designed to be cooled by boiling. Accordingly, all the portions between resin coated composite superconductors themselves excepting the spacer members should be areas to be cooled by the liquid refrigerant. That is, a structure in which the coated composite superconductors themselves directly contact with each other is eliminated so that the spacer members are necessarily interposed or liquid refrigerant flow paths are formed between the resin coated composite superconductors.

(Electrocoating)

Various methods such as spray coating, brush coating, dipping coating and electrocoating may be applicable as a high-molecular material coating method. The present inventors have found that use of the electrocoating is the most preferable to provide a thin and uniform coating.

The electrocoating method comprises the steps of; blending a high-molecular material such as an epoxy resin, acrylic resin in an aqueous solution; precipitating the resin on the surface of a piece to be coated which is formed of an electrically conductive material based on an electrophoretic principle; and baking the coated piece to form a firm insulating film thereon. This method makes it possible to coat an electrically conductive portion with a coating film having an uniform thickness.

The resin used for this coating method is blended in an aqueous solution. The blending ratio of water is about 70 to 80% by weight. This coating method is excellent in that the resin can be removed from the waste liquid by various filters and excellent in safety of working and environmental protection.

Such an electrocoating is generally performed in a batch manner. However, pieces to be coated according to the present invention are often linear and the length thereof is generally not less than several meters. Therefore, since conventional batch type processing can not coat the whole of linear piece to be coated, a process for electrocoating linear pieces was devised.

For repairing an omitted coating film caused on a part of a composite superconductor when it is wound in a coiled manner, electrocoating is suitably performed while the whole of the composite superconductor wound into a coil shape is immersed in an electrocoating bath.

When the composite superconductor is coated with an insulating film thereon, a high-molecular resin can be used as an insulating material and the whole or a part of the composite superconductor can be coated with a coating film having a given, thin and uniform thickness. Accordingly, a sufficient cooling thermal flow flux is assured so that a stable superconducting state may be attained depending upon an applied magnetic field.

It is necessary to provide a thin coating since the coating resin has a high heat resistance. Since the thickness of the resin film is substantially proportional to the breakdown voltage of an electric insulation, the thinner coating film provides the less insulation. However, in accordance with the present invention, spacer members are interposed. Accordingly, insulation is kept while flow paths of liquid refrigerant are assured and heat resistance is improved so that excellent boiling cooling can be expected.

As mentioned above, in accordance with the present invention a superconducting coil, a composite superconductor and a superconducting apparatus which are stable and excellent in cooling-performance can be provided. Since an uniform resin coating is formed by an electrocoating in the present invention, damage to coating and short-circuiting will not occur. Processes for manufacturing a superconducting coil and a composite superconductor of the present invention does not require a waste liquid processing.

If an epoxy resin is used for electrocoating in the present invention, new effects as will be described hereafter are achieved in addition to the above effects.

Omittion of coating film may readily occur due to scraping when the superconducting coil is formed and wound. However, the epoxy resin coating has an excellent adhesion to superconducting materials in comparison with the other resin coatings (for example, acrylic resins and fluorine resins) so that omittion is hard to occur. The epoxy resin is quickly dried and easy to be molded as general features and has advantages that it is easily available and inexpensive.

DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional in part and perspective view showing the structure of an embodiment of a superconducting coil of the present invention;

Fig. 2 is a perspective view showing the whole of the superconducting coil illustrated as the embodiment shown in Fig. 1;

Fig. 3 is a sectional view of a composite superconductor used for the embodiment of Fig. 1;

Fig. 4 is a flow chart showing a process for manufacturing the composite superconductor of the embodiment of Fig. 3;

Fig. 5A is a graph showing the relation between the heat flow flux of the superconducting coil and the temperature difference;

Fig. 5B is a graph showing the relation between the heat flow flux of the superconducting coil and the thickness of the coating film;

Fig. 6 is a sectional in part and perspective view of the composite superconductor of another embodiment of the present invention;

Fig. 7 is a sectional in part and perspective view showing the structure of the superconducting coil using the composite superconductor of Fig. 6; and

Fig. 8 is a sectional view of a superconducting apparatus having the superconducting coil of Fig. 1 incorporated therein.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[Embodiment 1]

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

Fig. 1 is a sectional in part and perspective view of a superconducting coil 15 comprising a plurality of stacked pancakes 12, each being formed by concentrically winding a high capacity linear composite superconductors each having a square section to provide inner diameter of a central hollow space of 200 mm and an outer diameter of about 500 mm. A perspective view of the superconducting coil 15 is shown in Fig. 2.

The superconducting coil 15 of the present embodiment is formed by stacking 12 pancakes.

The superconducting coil 15 is manufactured according to following steps. The process for manufacturing the high capacity composite superconductor 11 will now be described with reference to Fig. 3.

A superconducting wire element which is a bundle of 1060 filaments formed of NbTi having a diameter 50 μm is inserted into an oxigen-free copper pipe, from which the wire is extruded for drawing working. Thereafter, 10 molded strands, which are formed by being subjected to aging heat treatment are inserted into a recess of a stabilized block 2 of oxygen-free copper having a π-shaped section which is formed by hot extrusion. Then, the stranded wires 1 are pressed by a lid 3 and fixed by a solder 4. The sectional dimension of the superconductor 11 in such a condition is 12.6 mm x 26.8 mm. The superconductor is then coated with an insulating film 7 over an entire of the outer periphery thereof. An electrocoating method is used for applying the insulting film 7.

In order to apply the coating method for wire material to be coated, treating bathes, one for each step of a process shown in Fig. 4 are aligned. The material to be coated is successively subjected to coating treatment.

Dimensions of the material to be coated and coating conditions are shown in Table 1.

Epoxy cation electrocoating material (for example, Aqua No. 4200 manufactured by Nippon Yushi Co., Ltd.) is used as an electrocoating paint.

Table 1

<table>
<tr><th colspan="3">Items</th><th>Parameters</th></tr>
<tr><td colspan="3">1. Dimension of superconductor</td><td>12.6 mm × 26.8 mm</td></tr>
<tr><td colspan="3">2. Thickness of insulating film</td><td>1.5 µm</td></tr>
<tr><td colspan="3">3. Speed of winding up of conductor</td><td>not less than 0.2 m/min</td></tr>
<tr><td rowspan="4">4. Coating conditions</td><td rowspan="2">4.1 Electrolytic coating</td><td>Applied voltage</td><td>10 V</td></tr>
<tr><td>Time</td><td>150 sec.</td></tr>
<tr><td rowspan="2">4.2 Baking</td><td>Heating temperature</td><td>175°C</td></tr>
<tr><td>Heating time</td><td>25 min.</td></tr>
</table>

An electrocoating apparatus which will be described hereafter is used.

The length of a baking electric furnace is 5 m in view of conductor winding up speed and heating time. As electrocoating conditions, the conditions of Table 1 excellent in smoothness are applied in consideration of independently determined thin film coating conditions.

The length of degreasing and washing baths in a direction of passing of a piece to be coated which are used at steps shown in Fig. 4 is 0.3 m. The spacing of 0.1 m is provided between the baths and a spacing of 0.5 m is provided for an air blowing station. The length of an electrocoating bath is 0.5 mm. A spacing of 0.1 m is provided between the electrocoating bath and a washing bath at next step is 0.1 m. Pure water contained in the electrocoating liquid is dropped in the spacing to preliminarily wash the coated conductor to remove residual electrocoating liquid which has formed no coating film. The washing bath is 0.5 m in length. The water in the bath is stirred by using a circulating pump. After washing the conductor with water, the range of air blowing for removing water droplets is 0.3 m, and the range of temperature gradient up to a baking furnace temperature of 175°C is 0.3 m.

Each bath is double-structured. A sponge-like seal member is disposed at each of outlet and inlet for preventing leakage of liquid therefrom to the inside of an inner treatment bath. The liquid leaked in spite of such a provision is recovered into an outer bath and is circulated by the circulating pump.

In each treatment bath, the level of the treating liquid is maintained above the upper side of a piece to be coated by using the discharging pressure of the circulating pump so that the treating liquid normally covers the superconductor.

Roller electrodes are disposed in front of the degreasing bath for conducting a current to the piece to be coated.

When the high capacity composite superconductor 11 which is thus formed by such a process is wound in an annular shape having the above mentioned dimensions, the insulator 5 made of FRP (glass fiber reinforced epoxy resin) having a section of 0.2 mm x 25 mm is disposed on the side of the superconductor with which the other superconductor contacts as shown in Fig. 3. The insulator 5 is disposed since the electric resistance of the insulating film 7 coated over the outer periphery of the superconductor 11 is so low that insulation between the superconductors is insufficient if the coating thickness is low. As a result of this, the insulator 5 functions as a spacer member.

The superconducting coil 15 is thus formed by stacking 12 these pancakes 12. At this time, spacers 13, each formed of bar-like insulator radially extending from the inner radial side to outer radial side thereof are disposed between adjacent pancakes 12 to provide spacings through which liquid helium passes 14.

The superconducting coil 15 which is formed by the above mentioned steps is immersed in liquid helium at an atomospheric pressure so that helium boiling characteristics is measured for evaluating the heat conduction characteristics thereof. Boiling characteristics is measured for different film thicknesses as shown in Fig. 5A. Comparison of a curve (i) of uncoated specimen with a curve (ii) of a specimen coated with a 1.5 μm thick insulating film of the present embodiment shows that a slight increase in temperature difference (between the conductor temperature T_{cond} and the helium temperature T_{He}) increases a minimum value of heat flow flux : q_{min} by about 0.18.

A curve (iii) represents the heat conduction characteristics of a specimen coated with a 5 μm thick coating film according to the electrocoating method. qmin = 0.24 w/cm^2 was obtained at a temperature difference equivalent to a critical temperature Tc of superconduction.

Curves (iV) and (V) represent heat conduction characteristics of specimen coated with 17 μm and 40 μm thick coating films, respectively.

Not less than 1 μm coating film thickness provides a stable coating film according to electrocoating method. Although preferable range of the coating film thickness of the composite superconductor is 1 μm to 30 μm in the present embodiment, it is preferable that the heat flow rate be higher and that the coating film thickness be 5 μm to 20 μm in view of and manufacturing conditions and process control.

Based on the heat conduction characteristics, an effective heat flow flux q_e used for the design of superconductor is determined as shown in Fig. 5B. A way of determining q_e relies upon Madoc's equi-area law (The Institute of Electrical Engineers of Japan Daigaku-Koza, Superconductivity engineering, revised page 105, 1988 published by the Institute of Electrical Engineers of Japan). A value q_e increases with an increase in the thickness of the coating film. When the thickness exceeds 18 μm, the heat resistance in the coating film becomes predominant so that q_e decreases with an increase in thickness. Measuring is conducted under conditions that the superconductor is formed of a niobium and titanium alloy, the strength of applied magnetic field was 8 Tesla; the ratio of conducting current to critical current is 0.5. It is understood from Fig. 5B that a value of coating film thickness (about 18 μm) gives a maximum q_e and that a higher q_e value is preferably obtained if the thickness is 5 to 20 μm.

Although use of epoxy resins in the present embodiment is described in detail, use of acrylic resins, fluorine resins, phenol resins and polybutadiene resins may provide equivalent effects.

It is necessary that the applied voltage and the electrocoating time fall in the ranges 10 to 200 volts and 30 to 150 seconds, respectively if each of these resins is formed into the above-mentioned thickness. For example, if the thickness of the insulator film is changed to 10 μm and 30 μm, the applied voltage is changed to 50 V (electrocoating time: 150 seconds) and 200 V (150 seconds), respectively.

Even if the coating film 7 covering the superconductor 11 is formed of enamel and a dip coating method in which a superconductor is immersed into a high-molecular material solution and then pulled out for curing is used for applying the insulating film, similar result is obtained.

[Embodiment 2]

Another embodiment of manufacturing the superconducting coil will now be described with reference to Fig. 2. The linear composite superconductor 11 which is manufactured in Embodiment 1 is concentrically wound to manufacture pancakes 12, each having, for example, an inner diameter of 200mm and an outer diameter of 500 mm.

The superconducting coil 15 comprises one or plurality of stacked pancakes 12. The thickness of an annular plate forming each pancake is 26.8 mm. The number of stacks of the superconductor is 12. Bar-like spacers 13 radially extending from the inner to outer side are disposed between the adjacent pancakes 12 so that spacings 14 through which liquid helium passes. After the pancakes are subjected to degreasing treatment of the process shown in Fig. 2, they are subjected to electrocoating treatment under conditions of applied voltage of 20 volts for 60 seconds and then sequentially subjected to steps of washing with water, air blowing and baking. Although heating temperature is 175°C which is same as that for the composite superconductor of the baking condition, after temperature is measured and has reached 175°C, the temperature is kept for 25 minutes since the pancakes have a heat capacity.

According to such a treating method, the resin is selectively deposited to a portion of the insulating film which is damaged on forming the pancakes and through which normally conductive material is exposed resulting in that pancakes for superconducting coil having a damage-free insulating film can be manufactured.

It is, of course, that the above-mentioned electrocoating of insulating film can be achieved for each of the pancakes 12 formed of a composite superconductor which has not been subjected to electrocoating, or alternatively for an assembled superconducting coil.

[Embodiment 3]

The other embodiment of the present invention will be described. When concentric pancakes are manufactured by winding the superconductcr 11 coated with the insulating film 7 used in the embodiment 1, an insulator 5 for preventing the superconductor 11 from contacting with the other superconductor is preliminarily wound around the superconductor 11 as shown in Fig. 6. Thereafter, the pancakes are concentrically formed in the present embodiment. The insulator 5 is a polyimide tape is having a width of 15 mm in the present embodiment. If the insulator 5 is adhered to the superconductor 11 with an adhesive and the like when the insulator 5 is wound around the superconductor 11, subsequent working become easier.

A sectional in part and perspective view of a superconducting coil formed of the above mentioned superconductor 11 is shown in Fig. 7. In the present embodiment, the boiling characteristics of the superconductor substantially corresponds to the curve (iii) in Fig. 5A when the insulating film 7 is 5 μm in thickness. According to the present embodiment, the surface area of the insulator 5 covering the superconductor 11 is lower than that of the embodiment 1 and the migration of the boiling liquid is possible in a direction of thickness of the pancake 12.

[Embodiment 4]

A boiling type superconducting device which uses the superconducting coil 15 of the embodiment 1 is exemplarily shown in Fig. 8.

The superconducting coil 15 in which spacings 14 through which liquid helium passes are formed between the pancakes 12 is immersed in liquid helium 17. The superconducting coil 15 is supported by a support 16 and is connected to current terminals 19.

A helium container 21 containing liquid helium 17 is provided with a liquid helium charging and discharging port 24 at the upper side thereof. The helium container 21 is surrounded by a heat shielding plate 22 on the outer peripheral side thereof. The heat shielding plate 22 is surrounded by a vacuum container 23 on the outer side thereof. Vacuum adiabatic chambers 20 are defined between the helium container 21 and the heat shielding plate 22; the heat shielding plate 22 and the vacuum container 23. A support 16 for supporting a compression load is provided on the lower side of each chamber. A support 18 is provided to support a tensile load on the upper side thereof.

Application of the electrocoating method according to the embodiment which has been described in detail makes it possible to coat the insulator which stabilizes the cooling performances of the composite superconductor and superconducting coil with a coating film having a thickness of 1 to 30 μm which is excellent in cooling efficiency. Damages of the coating film caused by working of the superconducting coil and pancakes may be selectively repaired by electrocoating the superconducting coil or pancakes again so that defects-free superconducting coil and pancakes can be manufactured.

The electrocoating method is most safe among various coating methods and the manufacturing cost is low since the ratio of water in the coating material is about 75%.

Although Mb_3Sn is used as a superconductive material for liquid helium in the above mentioned embodiments, the present invention is not limited to only this material and may be applicable to any other superconductive materials and liquid refrigerant. If a superconductor comprising, for example, perovskite superconducting wires which are surrounded by a stable metal such as silver and then coated with a resin is used together with an insulator and spacer members, a liquid refrigerant at a temperature equal to or above the temperature of the liquid nitrogen may be used.

Claims

1. A process for manufacturing a composite superconductor, comprising the steps of:
   combining superconductors (1) with normal conductors (2); and
   electrocoating the entire surface of the combined conductor (11) with an epoxy resin (7).

2. A process for manufacturing a composite superconductor according to Claim 1 in which the applied voltage is 10 to 200 volts and the electrocoating time is 30 to 150 seconds when the electrocoating of the composite superconductor (11) is successively performed.

3. A process for manufacturing a superconducting coil, comprising the steps of:
   coating the surface of a composite superconductor (11) with an epoxy resin (7);
   forming a superconducting coil (15) by winding the coated composite superconductors; and
   then conducting an electrocoating of the coil (15) with an epoxy resin (7) again for repairing a

damaged portion of an insulating film caused on working of the composite superconductor (11) into a coil (15).

4. A process for manufacturing a superconducting coil, comprising the steps of;
forming a coil (15) by winding composite superconductors (11); and
thereafter conducting an electrocoating of the surface of the coil with an epoxy resin.

5. A composite superconductor, comprising: composite superconducting wires (11) which are coated with an epoxy resin (7) and insulating members (5) which are additionally provided on a part of the coated surfaces of the wires.

6. A composite superconductor according to Claim 5 in which the epoxy resin (7) is applied by an electrocoating.

7. A composite superconductor according to Claim 5 in which the thickness of the coating film is 1 to 30 μm.

8. A superconducting coil which is formed by winding composite superconductors (11) coated with an epoxy resin (7) therearound.

9. A superconducting coil according to Claim 8 in which the thickness of the coating film of the epoxy resin (7) ranges from 1 to 30 μm.

10. A superconducting coil which is formed by winding composite superconductors (11) coated with an epoxy resin (7) therearound and said superconductors including a plurality of superconducting wire elements (1) and normal conductors (2).

11. A superconducting coil according to Claim 10 including composite superconductors (11) in which the plurality of superconducting wires elements (1) are surrounded by the normal conductors (2) therearound.

12. A superconducting coil according to Claim 10 in which the superconducting wire elements (1) are disposed around said normal conductors (2).

13. A superconducting coil according to Claim 10 in which the plurality of normal conductors (2) and superconducting wire elements (1) coexist with each other.

14. A superconducting coil according to Claim 10 which is formed by winding the composite superconductors (11) coated with an epoxy resin (7) therearound while refrigerant paths are assured between the composite superconductors (11).

15. A superconducting coil according to Claim 14 in which a superconducting material forming the composite superconductors (11) is an intermetallic compound.

16. A superconducting coil according to Claim 14 in which a superconducting material forming the composite superconductors (11) is an oxide ceramics.

17. A superconducting coil according to Claim 14 in which the superconducting material forming the composite superconductors (11) is an alloy.

18. A superconducting coil according to Claim 10 in which said normal conductor (2) is formed of a pure metal.

19. A superconducting coil according to Claim 10 in which the thickness of the epoxy resin coating film (7) is in a range of 1 to 30 μm.

20. A superconducting coil, comprising:
coils which are formed by winding composite superconductors (11) coated with an epoxy resin

thereon; and
insulative spacer members (13) disposed between the coils (15) for supporting said coils.

21. A superconducting coil according to Claim 20 in which the thickness of the epoxy resin coating film (7) is in a range of 1 to 30 μm.

22. A superconducting coil, comprising:
a coil which is formed by winding composite superconductors (11) coated with an epoxy resin (7) thereon and including a plurality of superconducting wire elements (1) and normal conductors (2); and
insulative spacer members (13) between said coils for supporting said coils (15).

23. A superconducting coil according to Claim 22 in which the plurality of superconducting wire elements (1) are surrounded by the normal conductors (2).

24. A superconducting coil according to Claim 22 in which the superconducting wire elements (1) are disposed around said normal conductors (2).

25. A superconducting coil according to Claim 22 in which the plurality of normal conductors (2) and superconducting wire elements (1) coexist with each other.

26. A superconducting coil according to Claim 22 which is formed by winding the composite superconductors (11) coated with an resin (7) therearound while refrigerant paths are assured between the composite superconductors (11).

27. A superconducting coil according to Claim 26 in which a superconducting material forming the composite superconductors (11) is an intermetallic compound.

28. A superconducting coil according to Claim 26 in which a superconducting material forming the composite superconductors (11) is an oxide ceramics.

29. A superconducting coil according to Claim 26 in which the superconducting material forming the composite superconductors (11) is an alloy.

30. A superconducting coil according to Claim 22 in which said normal conductor (2) is formed of a pure metal.

31. A superconducting coil according to Claim 22 in which the thickness of the epoxy resin coating film(7) is in a range of 1 to 30 μm.

32. A superconducting apparatus comprising wound composite superconductors (11) which are coated with an epoxy resin (7) and are in a contact with liquid refrigerant via said epoxy resin coating, spacings between the wound superconductors themselves being maintained by spacer members (13).

33. A superconducting apparatus according to Claim 32 in which the superconducting wire elements (1) of the composite superconductor (11) are formed of a material selected from a group consisting of alloys and intermetallic compounds.

34. A superconducting apparatus according to Claim 32 in which the superconducting wire elements (1) of the composite superconductors (11) are formed of oxide ceramics and the liquid refrigerant is a liquid nitrogen.

35. A process for manufacturing a composite superconductor, comprising the steps of:
combining superconductors (11) with normal conductors (2); and
coating the combined conductor with a high-molecular resin (7) on the entire surface thereof.

36. A process for manufacturing a composite superconductor according to Claim 35 in which said high-molecular resin is selected from a group consisting of epoxy resins, acrylic resins, fluorine resins, phenolic resins, and polybutadiene resins.

37. A process for manufacturing a composite superconductor according to Claim 35 in which the applied voltage is 10 to 200 volts and the electrocoating time is 30 to 150 seconds when the electrocoating of the composite superconductor (11) is successively performed.

38. A process for manufacturing a superconducting coil, comprising the steps of:
coating the surface of a composite superconductor (11) with an insulating film (7);
forming a superconducting coil (15) by winding the coated composite superconductors (11); and
then conducting an electrocoating of the coil (15) with an insulating film again for repairing a damaged portion of the insulating film (7) caused on working of the composite superconductor (11) into a coil (15).

39. A process for manufacturing a superconducting coil, comprising the steps of;
forming a coil by winding composite superconductors (11); and
thereafter conducting an electrocoating of the surface of the coil (15) with an insulating film (7).

40. A composite superconductor comprising composite superconducting wires (11) which are coated with a resin (7) and insulating members (5) which are additionally provided on a part of the coated surfaces of the wires.

41. A composite superconductor according to Claim 40 in which the resin (7) is applied by an electrocoating.

42. A composite superconductor according to Claim 40 in which the thickness of the coating film (7) is 1 to 30 μm.

43. A superconducting coil, comprising:
coils which are formed by winding composite superconductors (11) coated with a resin (7) thereon; and
insulative spacer members (13) disposed between the coils (15) for supporting said coils (15).

44. A superconducting coil according to Claim 43 in which the thickness of the resin coating film (7) is in a range of 1 to 30 μm.

45. A superconducting coil, comprising:
a coil (15) which is formed by winding composite superconductors (11) coated with a resin (7) thereon and including a plurality of superconducting wire elements (1) and normal conductors (2); and
insulative spacer members (13) between said coils for supporting said coils.

46. A superconducting coil according to Claim 45 including composite superconductors (11) in which the plurality of superconducting wire elements (1) are surrounded by the normal conductors (2) therearound.

47. A superconducting coil according to Claim 45 in which the superconducting wire elements (1) are disposed around said normal conductors (2).

48. A superconducting coil according to Claim 45 in which the plurality of normal conductors (2) and superconducting wire elements (1) coexist with each other.

49. A superconducting coil according to Claim 45 which is formed by winding the composite superconductors (11) coated with a resin (7) therearound while refrigerant paths are assured between the composite superconductors (11).

50. A superconducting coil according to Claim 49 in which a superconducting material forming the composite superconductors (11) is an intermetallic compound.

51. A superconducting coil according to Claim 49 in which a superconducting material forming the composite superconductors (11) is an oxide ceramics.

52. A superconducting coil according to Claim 49 in which the superconducting material forming the composite superconductors (11) is an alloy.

53. A superconducting coil according to Claim 45 in which said normal conductor (2) is formed of a pure metal.

54. A superconducting coil according to Claim 45 in which the thickness of the resin coating film (7) is in a range of 1 to 30 μm.

55. A superconducting apparatus comprising wound composite superconductors (11) which are coated with a resin and are in a contact with liquid refrigerant via said resin coating, spacings between the wound superconductors themselves being maintained by spacer members (13).

56. A superconducting apparatus according to Claim 55 in which the superconducting wire elements (1) of the composite superconductor (11) are formed of a material selected from a group consisting of alloys and intermetallic compounds and liquid refrigerant is a liquid nitrogen.

57. A superconducting apparatus according to Claim 55 in which the superconducting wire elements (1) of the composite superconductor (11) are formed of oxide ceramics and the liquid refrigerant is a liquid nitrogen.

FIG.1

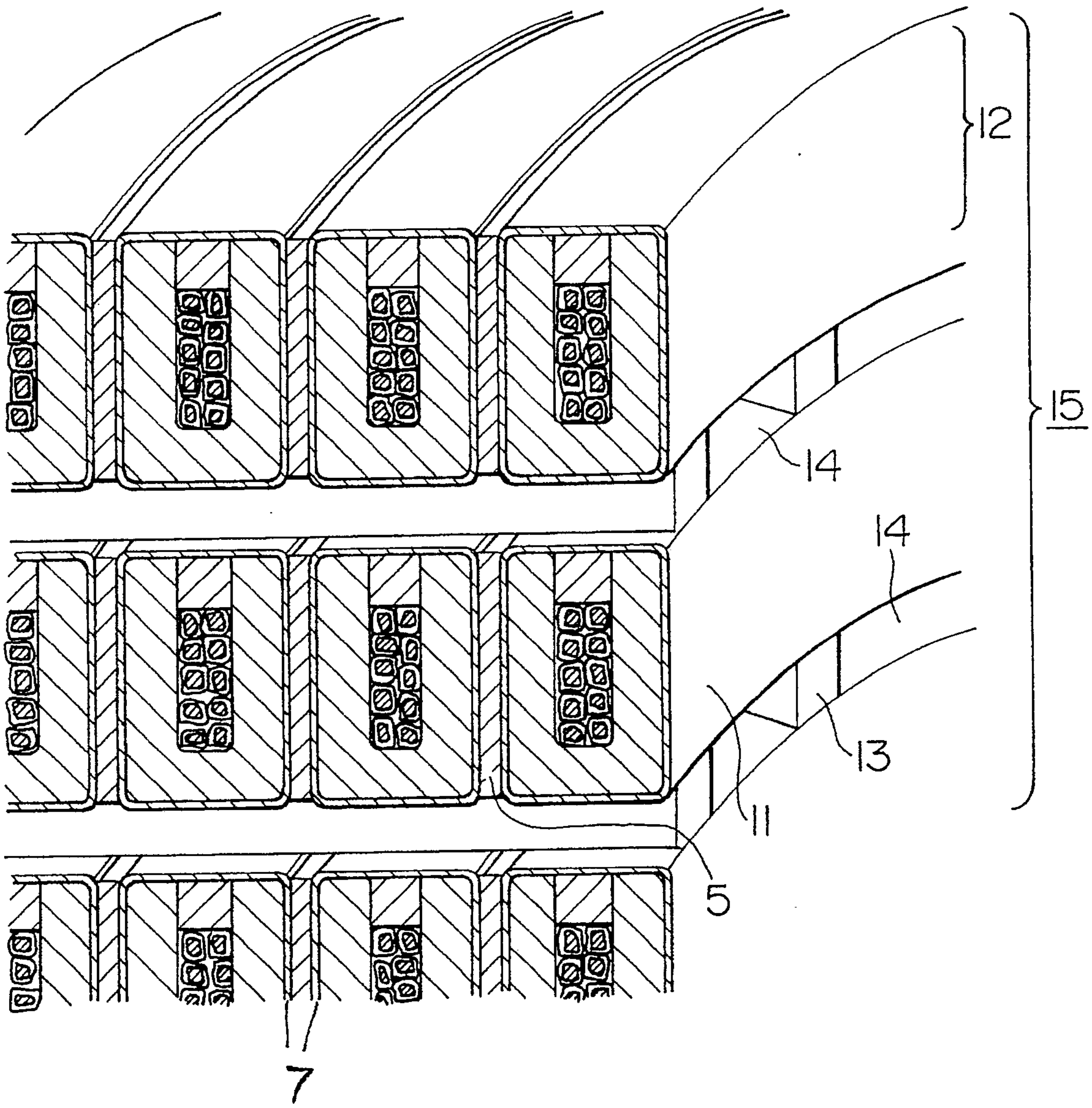


FIG. 2

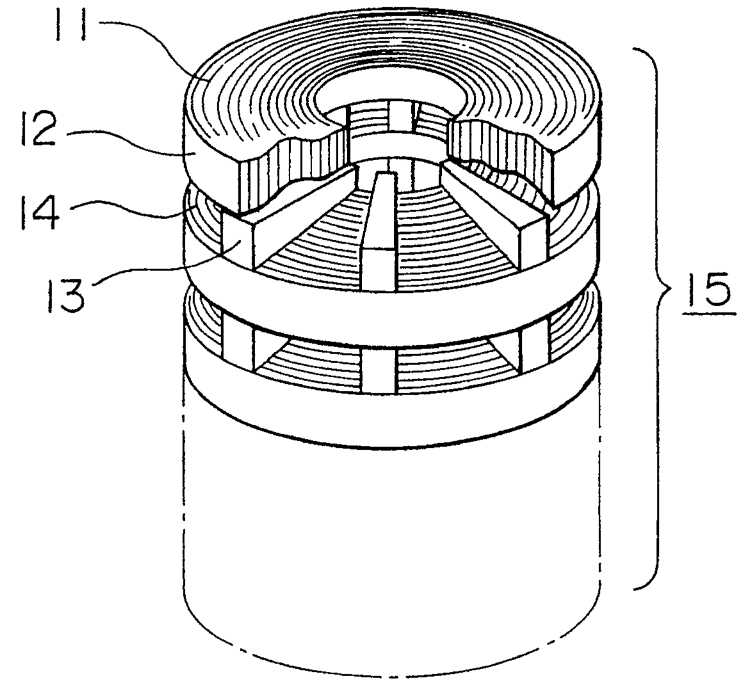


FIG. 3

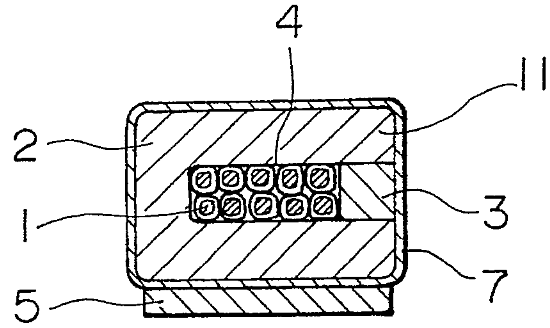


FIG. 4

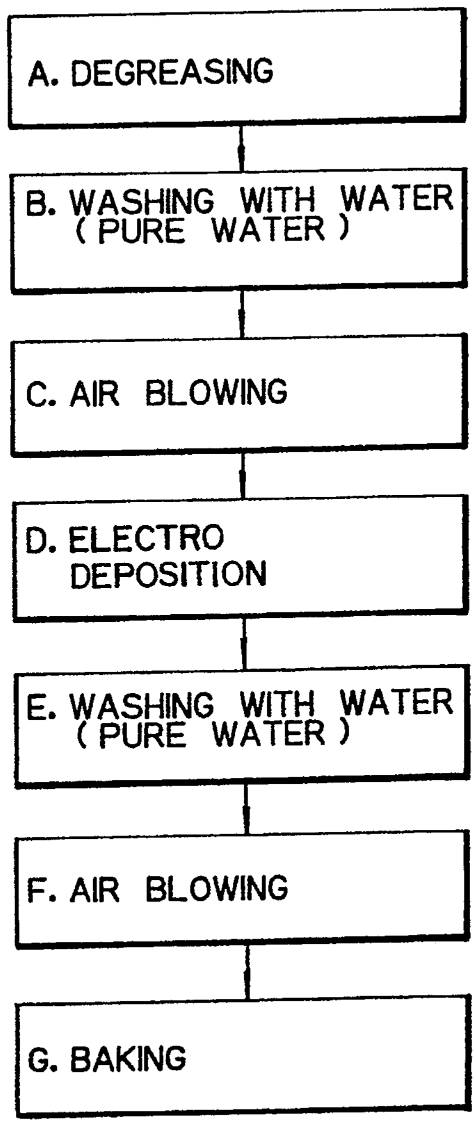

A. DEGREASING
B. WASHING WITH WATER
(PURE WATER)
C. AIR BLOWING
D. ELECTRO
DEPOSITION
E. WASHING WITH WATER
(PURE WATER)
F. AIR BLOWING
G. BAKING

FIG. 5A

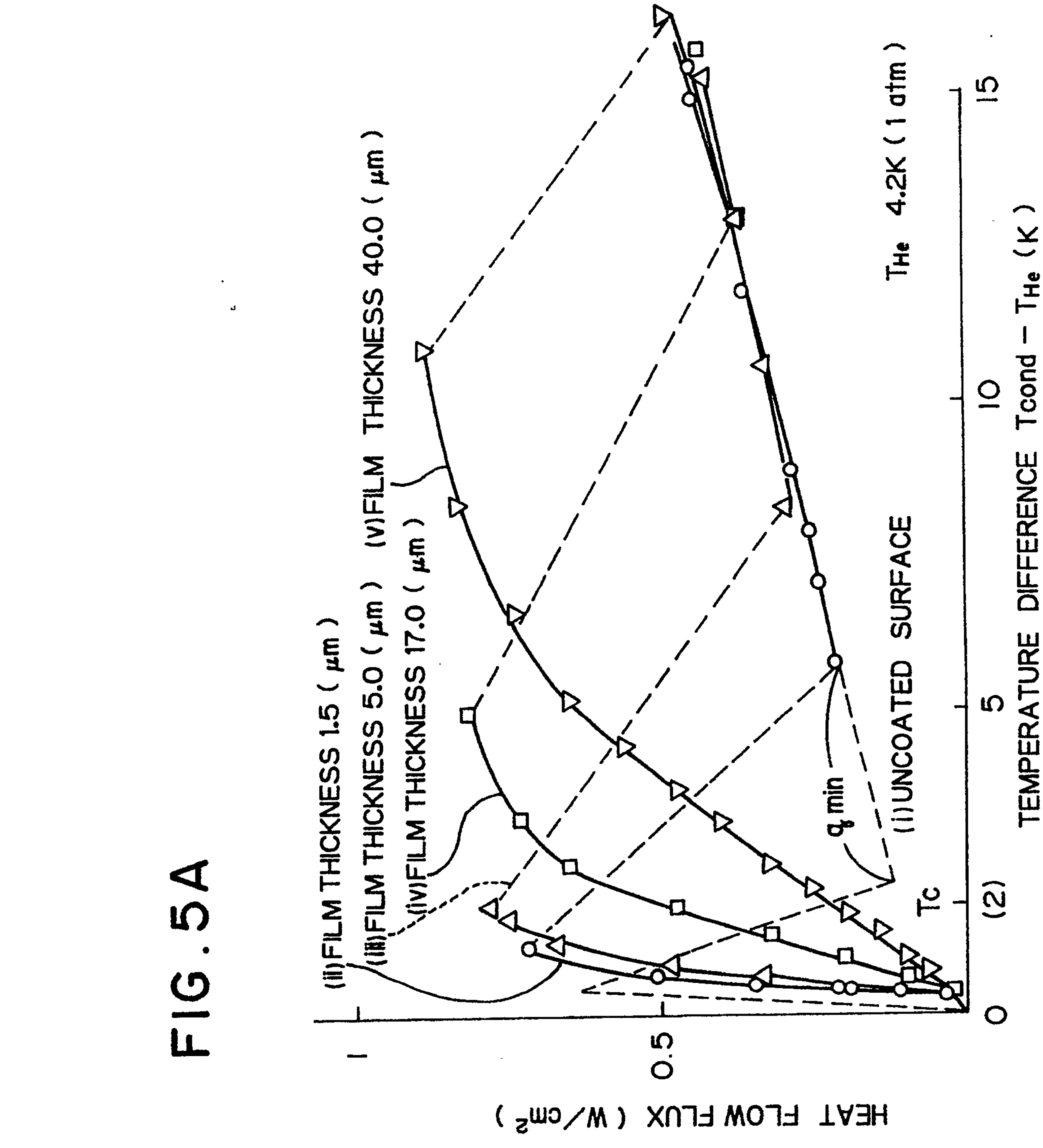

(ii) FILM THICKNESS 1.5 (μm)
(iii) FILM THICKNESS 5.0 (μm)
(iv) FILM THICKNESS 17.0 (μm)
(v) FILM THICKNESS 40.0 (μm)
(i) UNCOATED SURFACE
q min
Tc
THe 4.2K (1 atm)
HEAT FLOW FLUX (W/cm²)
TEMPERATURE DIFFERENCE Tcond − THe (K)
0
0.5
1
(2)
5
10
15

FIG.5B

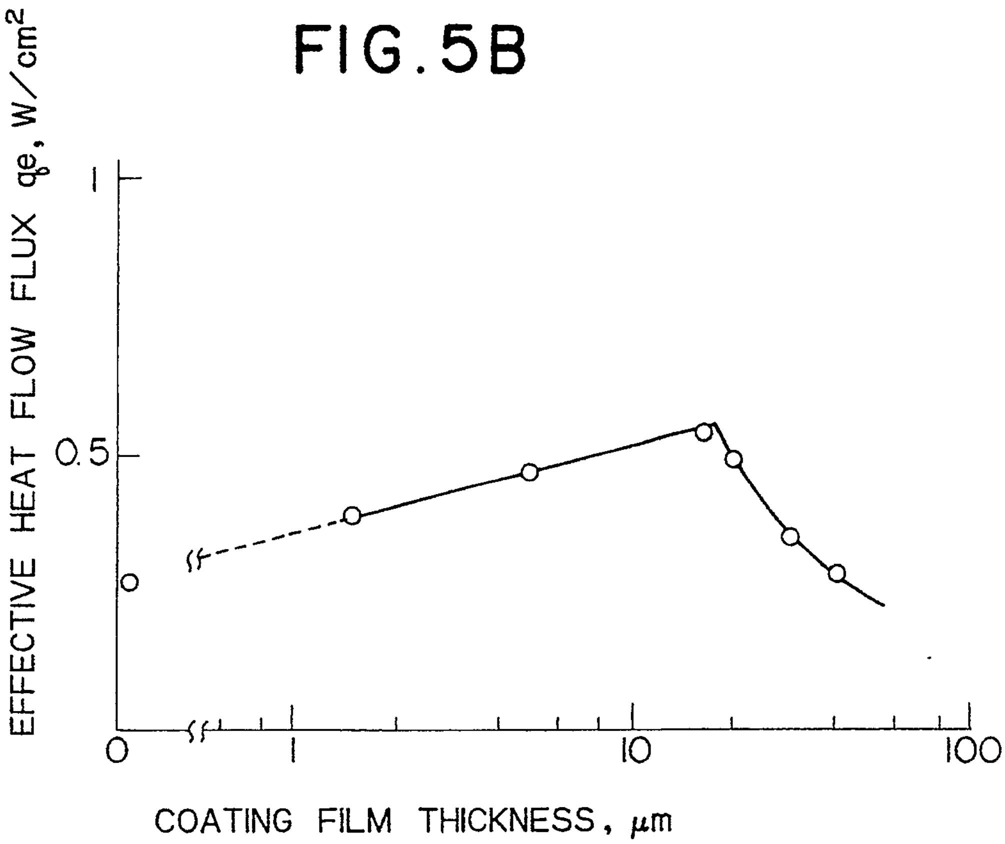

EFFECTIVE HEAT FLOW FLUX qe, W/cm²
1
0.5
0
1
10
100
COATING FILM THICKNESS, μm

FIG.6

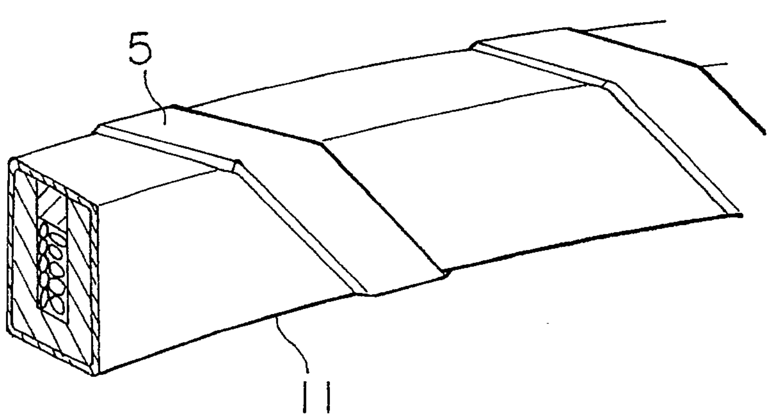

5
11

FIG. 7

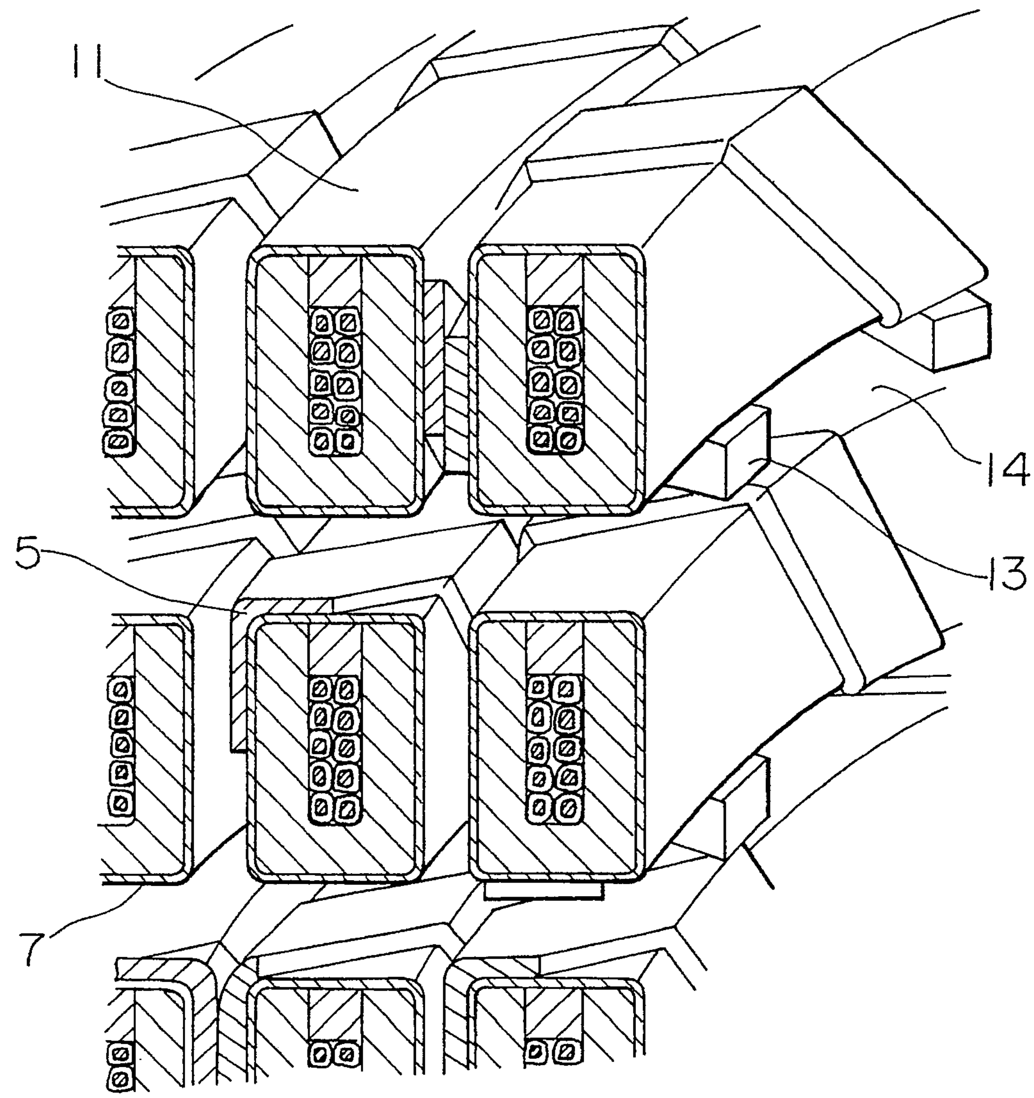


FIG. 8