

SUPERCONDUCTING CABLE AND LIQUEFIED NATURAL GAS TRANSPORTATION SYSTEM

TECHNICAL FIELD

- 5 [0001] The present disclosure relates to a superconducting cable and a liquefied natural gas transportation system.

BACKGROUND ART

- [0002] A superconducting cable whose conductor is a superconducting cable wire, which
10 becomes superconducting at an extremely low temperature, has been commercialized as a cable capable of transmitting high current with small loss. To maintain the superconductivity of a superconducting material, it is necessary to maintain the superconducting material at an extremely low temperature.

- Patent Documents 1 and 2 disclose a superconducting cable which reduces heat leak
15 from outside by cooling a superconducting material with a cooling medium such as liquid nitrogen flowing around the superconducting material, and forming a vacuum space (vacuum layer) filled with a heat insulating layer around the superconducting material.

Citation List

- 20 Patent Literature

[0003]

Patent Document 1: JP2006-066382A

Patent Document 2: JP2015-153590A

- 25 SUMMARY

Problems to be Solved

- [0004] Thermal load of a superconducting cable is a sum of AC loss of a superconducting material and heat leak from outside. While AC loss occurs only when power is supplied,

heat leak is occurring on a constant basis, and heat leak can be reduced by increasing the vacuum degree of the vacuum layer. The vacuum layer is vacuumed in advance with a vacuum pump, and the vacuum pump is detached upon installation of the superconducting cable.

5 However, after using the superconducting cable for a long period of time, outgas is discharged from the heat insulating pipe of the superconducting cable, and the vacuum degree decreases. If the vacuum degree decreases, the heat leak amount increases considerably, which makes it necessary to perform complicated maintenance such as regular vacuuming.

[0005] In view of the above problem, an object according to an embodiment is to make it
10 unnecessary to perform complicated maintenance such as vacuuming to suppress heat leak into a superconducting cable.

Solution to the Problems

[0006] (1) A superconducting cable according to an embodiment includes: an outer tube;
15 an inner tube disposed inside the outer tube; a core portion which is disposed inside the inner tube and which includes a former and a superconducting member disposed on an outer periphery of the former; and a first heat insulating layer disposed on an outer periphery of the outer tube. An inside of the inner tube is filled with a cooling medium, and a space formed between the outer tube and the inner tube is filled with a liquefied natural gas.

20 [0007] With the above configuration (1), the cooling medium filling the inside of the inner tube cools the core portion, and the space formed between the outer tube and the inner tube is filled with liquefied natural gas having an extremely low temperature, and thus it is possible to reduce the heat leak amount to the core portion considerably. Thus, it is no longer necessary to provide a heat insulating structure by forming a vacuum layer, and thus it
25 is no longer necessary to perform maintenance such as regular vacuuming.

Further, since existing liquefied natural gas is used, which has been widely used as an energy source, it is unnecessary to provide a refrigerator for cooling natural gas. Furthermore, the first heat insulating layer disposed on the outer periphery of the outer tube

may be provided by diverting a heat insulating layer used to keep liquefied natural gas cool, which makes it possible to reduce the costs.

Furthermore, by reducing the heat leak amount, it is possible to reduce the refrigerating performance for cooling the cooling medium that is circulated in the superconducting cable as much as the reduced heat leak amount, and it is possible to reduce the amount of cooling medium that circulates the superconducting cable.

Further, by reducing the circulation amount of cooling medium, it is possible to reduce the costs of the cooling system including a cooling medium circulation pump.

[0008] (2) In an embodiment, in the above configuration (1), the core portion includes an electric insulating layer disposed on an outer periphery of the superconducting member.

With the above configuration (2), the electric insulating layer is disposed on the outer periphery of the superconducting member, and thereby it is possible to suppress generation of partial discharge from the superconducting member, and to suppress a decrease in the energy consumption efficiency.

[0009] (3) In an embodiment, in the above configuration (1) or (2), the superconducting cable further includes a second heat insulating layer disposed on an outer periphery of the inner tube.

With the above configuration (3), by providing the second heat insulating layer on the outer periphery of the inner tube, it is possible to further suppress heat leak into the inner tube.

[0010] (4) In an embodiment, in any one of the above configurations (1) to (3), the inner tube consists of a single inner tube, and is disposed inside the outer tube concentrically with the outer tube.

With the above configuration (4), by providing a single inner tube inside the outer tube so as to be concentric with the outer tube, it is possible to simplify the configuration of the inner tube.

[0011] (5) In an embodiment, in the above configuration (4), the core portion includes an electric insulating layer disposed on an outer periphery of the superconducting member, and a plurality of superconducting members and a plurality of electric insulating layers are disposed

on an outer periphery of the former alternately along a radial direction of the former.

With the above configuration (5), the core portion can be applied to direct transmission (bipolar transmission) or three-phase alternate transmission of a relatively small capacity, and the core portion can be reduced in size. Accordingly, it is possible to reduce the diameter of the superconducting cable.

[0012] (6) In an embodiment, in the above configuration (4), a plurality of core portions are disposed inside the inner tube, and the plurality of core portions are arranged along an axial direction of the inner tube.

With the above configuration (6), the plurality of core portions are disposed in a single inner tube, and thereby it is possible to obtain a superconducting cable that can be applied to direct power transmission (bipolar transmission) and three-phase AC transmission, while simplifying the configuration of the superconducting cable.

[0013] (7) In an embodiment, in any one of the above configurations (1) to (3), a plurality of inner tubes are disposed inside the outer tube, and the plurality of inner tubes are arranged along an axial direction of the outer tube.

With the above configuration (7), the plurality of inner tubes are disposed inside the outer tube, and thereby it is possible to obtain a superconducting cable that can be applied to direct power transmission (bipolar transmission) and three-phase AC transmission of a large capacity.

[0014] (8) In an embodiment, in the above configuration (7), the core portion is disposed inside each of the plurality of inner tubes.

With the above configuration (8), the plurality of core portions are disposed inside the plurality of inner tubes, and thereby it is possible to obtain a superconducting cable that can be applied to direct power transmission (bipolar transmission) and three-phase AC transmission of a large capacity.

[0015] (9) In an embodiment, in any one of the above configurations (1) to (8), the cooling medium is liquid nitrogen.

The temperature of liquefied natural gas is approximately minus 160 °C at a normal

pressure, and the temperature of liquid nitrogen is minus 196 °C at a normal pressure. Thus, by filling the outer side of the liquid nitrogen with the liquefied natural gas, it is possible to reduce the temperature difference between the liquid nitrogen and the outside air, thus reducing heat leak from outside. Furthermore, through gasification of the liquefied natural gas, the liquefied natural gas absorbs heat that the liquid nitrogen receives from the superconducting material, and thereby it is possible to suppress a temperature increase of liquid nitrogen.

[0016] (10) A liquefied natural gas transportation system according to an embodiment includes: the superconducting cable according to any one of the above (1) to (9); a liquefied natural gas supply source disposed on a first end side of the superconducting cable; a first pipe disposed between the liquefied natural gas supply source and a space formed between the outer tube and the inner tube of the superconducting cable; a consumer disposed on a second end side of the superconducting cable; and a second pipe disposed between the space and the consumer. The liquefied natural gas transportation system is configured to transport a liquefied natural gas to the consumer from the liquefied natural gas supply source, via the superconducting cable.

[0017] With the above configuration (10), with the outside of the cooling medium for cooling the core portion being filled with the liquefied natural gas having an extremely low temperature, it is possible to reduce the heat leak amount to the core portion considerably. Thus, it is no longer necessary to provide a heat insulating structure by forming a vacuum layer, and thus it is no longer necessary to perform maintenance such as regular vacuuming.

Further, liquefied natural gas that has gasified after absorbing leakage heat from outside is sent to a consumer on the terminating end of transportation, and can be used directly as an energy source at the consumer. Thus, it is possible to improve energy consumption efficiency.

Advantageous Effects

[0018] According to an embodiment, to suppress heat leak into a superconducting cable,

it is no longer necessary to perform complicated maintenance such as vacuuming. Further, by utilizing liquefied natural gas, which is an existing cold source, it is possible to improve energy consumption efficiency, and to perform transportation of liquefied natural gas at the same time.

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BRIEF DESCRIPTION OF DRAWINGS

[0019] FIG. 1 is a system diagram including a partial cross section, showing a liquefied natural gas transportation system that includes a superconducting cable according to an embodiment.

10 FIG. 2 is a lateral cross-sectional view of a superconducting cable according to an embodiment.

FIG. 3 is a lateral cross-sectional view of a superconducting cable according to an embodiment.

15 FIG. 4 is a lateral cross-sectional view of a superconducting cable according to an embodiment.

DETAILED DESCRIPTION

[0020] Embodiments of the present invention will now be described in detail with reference to the accompanying drawings. It is intended, however, that unless particularly
20 specified, dimensions, materials, shapes, relative positions and the like of components described in the embodiments shall be interpreted as illustrative only and not intended to limit the scope of the present invention.

For instance, an expression of relative or absolute arrangement such as “in a direction”, “along a direction”, “parallel”, “orthogonal”, “centered”, “concentric” and “coaxial” shall not
25 be construed as indicating only the arrangement in a strict literal sense, but also includes a state where the arrangement is relatively displaced by a tolerance, or by an angle or a distance whereby it is possible to achieve the same function.

For instance, an expression of an equal state such as “same” “equal” and “uniform”

shall not be construed as indicating only the state in which the feature is strictly equal, but also includes a state in which there is a tolerance or a difference that can still achieve the same function.

Further, for instance, an expression of a shape such as a rectangular shape or a cylindrical shape shall not be construed as only the geometrically strict shape, but also includes a shape with unevenness or chamfered corners within the range in which the same effect can be achieved.

On the other hand, an expression such as “comprise”, “include”, “have”, “contain” and “constitute” are not intended to be exclusive of other components.

10 [0021] FIGs. 1 to 4 show a superconducting cable 10 (10A, 10B, 10C, 10D) according to some embodiments.

In FIGs. 1 to 4, the superconducting cable 10 has a dual-tube structure including an outer tube 12 and an inner tube 14 disposed inside the outer tube 12. A core portion 20 (20a, 20b, 20c) is disposed inside the inner tube 14, and the core portion 20 (20a, 20b, 20c) includes a former (wire core) 16 and a superconducting member 18 disposed on the outer periphery of the former 16. A heat insulating layer 22 (first heat insulating layer) is disposed on the outer periphery of the outer tube 12. The inside of the inner tube 14 is filled with a cooling medium 'r'. The space formed between the outer tube 12 and the inner tube 14 is filled with liquefied natural gas LNG.

20 [0022] With the above configuration, the inside of the inner tube 14 is filled with the cooling medium 'r' and the space formed between the outer tube 12 and the inner tube 14 is filled with liquefied natural gas LNG having an extremely low temperature, and thereby it is possible to reduce the heat leak amount to the core portion 20 considerably. Thus, it is no longer necessary to provide a heat insulating structure by forming a vacuum layer, and thus it is no longer necessary to perform maintenance such as regular vacuuming.

Further, since existing liquefied natural gas is used, which has been widely used as an energy source, it is unnecessary to provide a refrigerator for cooling natural gas. Furthermore, the heat insulating layer 22 disposed on the outer periphery of the outer tube 12

may be provided by diverting a heat insulating layer used to keep liquefied natural gas cool (e.g. rigid polyurethane foam, glass wool, etc.), which makes it possible to reduce the costs.

[0023] Furthermore, by reducing the heat leak amount, it is possible to reduce the refrigerating performance for cooling the cooling medium 'r' that is circulated in the superconducting cable 10 as much as the reduced heat leak amount, and it is possible to reduce the amount of cooling medium that circulates the superconducting cable 10.

Further, by reducing the circulation amount of cooling medium, it is possible to reduce the costs of the cooling system of the cooling medium 'r' including a cooling medium circulation pump.

[0024] In an embodiment, as shown in FIGs. 1 to 4, the core portion 20 includes an electric insulating layer 24 disposed on the outer periphery of the superconducting member 18.

According to this embodiment, with the electric insulating layer 24 disposed on the outer periphery of the superconducting member 18, it is possible to suppress generation of partial discharge from the superconducting member 18, and to suppress a decrease in the energy consumption efficiency of the superconducting cable 10.

Further, normally, an electric insulating layer is disposed also between the former 16 and the superconducting member 18. The electric insulating layer is not shown in FIGs. 1 to 4.

[0025] In an embodiment, as shown in FIGs. 1 to 4, a heat insulating layer 26 (26a, 26b, 26c) (second heat insulating layer) is disposed on the outer periphery of the inner tube 14 (14a, 14b, 14c). As the heat insulating layer 26, a laminated body of polyethylene film can be used.

According to this embodiment, by providing the heat insulating layer 26 (26a to 26c) on the outer periphery of the inner tube 14 (14a to 14c), it is possible to further suppress heat leak into the inner tube.

[0026] In an embodiment, as shown in FIG. 1, the former 16 may be a solid member. Alternatively, the former may have a pipe shape, where a hollow section 28 is formed inside as shown by two-dotted line. The hollow section 28 of a pipe-shaped former can also be

used as a flow passage of cooling medium.

In an embodiment, if the former 16 is to be used merely as a support member for the superconducting member 18, the former 16 may be made of a non-conductive material such as resin. If the former 16 is to have a function as a branch path of electric current in case of malfunction, the former 16 may be made of a normal conductive metal material such as copper and aluminum.

Further, as a solid former 16, a plurality of metal wires having an insulating coating such as enamel may be bound together.

[0027] In an embodiment, as in the superconducting cable 10 (10A, 10B) shown in FIGs. 1 and 2, the inner tube 14 includes a single inner tube, and the single inner tube 14 is disposed concentrically with the outer tube 12, inside the outer tube 12.

The superconducting cable 10 (10A) shown in FIG. 1 includes a single core portion 20 having one former 16 and one superconducting member 18 inside one inner tube 14.

The superconducting cable 10 (10B) shown in FIG. 2 includes a single core portion 20 having one former 16 and a plurality of superconducting members 18 inside one inner tube 14.

[0028] According to these embodiments, by providing a single inner tube 14 inside the outer tube 12 so as to be concentric with the outer tube 12, it is possible to simplify the configuration of the inner tube 14. According to this embodiment, in the superconducting cable 10 (10A) shown in FIG. 1, the core portion 20 has a single-layer superconducting member 18, and can be used for direct power transmission (unipolar transmission).

In the superconducting cable 10 (10B) shown in FIG. 2, the core portion 20 has a three-layer superconducting member 18 (18a, 18b, 18c), and can be used for three-phase AC transmission.

Further, in a case where the core portion 20 has a two-layer superconducting member 18, it can be used for direct power transmission (bipolar transmission).

[0029] In an embodiment, as in the superconducting cable 10 (10B) shown in FIG. 2, the core portion includes a plurality of electric conducting members 18 (18a, 18b, 18c) and a plurality of electric insulating layers 24 disposed on the outer periphery of the former 16,

alternately along the radial direction of the former 16.

According to this embodiment, the core portion 20 can be applied to direct transmission (bipolar transmission) or three-phase alternate transmission of a relatively small capacity, and the core portion 20 can be reduced in size. Accordingly, it is possible to reduce the diameter
5 of the superconducting cable 10.

In the superconducting cable 10 (10B) shown in FIG. 2, the core portion 20 has a three-layer superconducting member 18 (18a, 18b, 18c), and thus can be used for three-phase AC transmission.

[0030] In an embodiment, like the superconducting cable 10 (10C, 10D) shown in FIGs. 3
10 and 4, a plurality of core portions 20 (20a, 20b, 20c) are disposed inside the inner tube 14, and the plurality of core portions 20 (20a to 20c) are arranged along the axial direction of the inner tube 14. In these embodiments, the plurality of core portions 20 (20a, 20b, 20c) including the former 16 and the superconducting material 18 are disposed independently from one another.

15 The superconducting cable 10 (10C) shown in FIG. 3 includes, inside a single inner tube 14, three independent core portions 20 (20a to 20c) each of which includes a former 16 and a superconducting material 18.

[0031] According to this embodiment, the plurality of core portions 20 (20a to 20c) are disposed in a single inner tube 14, and thereby it is possible to obtain a superconducting cable
20 that can be applied to direct power transmission (bipolar transmission) and three-phase AC transmission, while simplifying the configuration of the superconducting cable 10.

[0032] In an embodiment, like the superconducting cable 10 (10D) shown in FIG. 4, a plurality of inner tubes 14 (14a, 14b, 14c) are disposed inside the outer tube 12, and the plurality of inner tubes 14 (14a, 14b, 14c) are arranged along the axial direction of the outer
25 tube 12.

According to this embodiment, with the plurality of inner tubes 14 (14a to 14c) disposed inside the outer tube 12, it is possible to obtain a superconducting cable that can be applied to direct power transmission (bipolar transmission) and three-phase AC transmission of a large

capacity.

[0033] In an embodiment, like the superconducting cable 10 (10D) shown in FIG. 4, independent core portions 20 (20a to 20c) are disposed inside the plurality of inner tubes 14 (14a, 14b, 14c), respectively.

5 The superconducting cable 10 (10D) shown in FIG. 4 includes, inside each of the three inner tubes 14 (14a to 14c), a single independent core portion 20 including a former 16 and a superconducting material 18.

According to this embodiment, with the independent core portions 20 (20a to 20c) disposed inside the inner tubes 14 respectively, it is possible to obtain a superconducting cable
10 that can be applied to direct power transmission (bipolar transmission) and three-phase AC transmission of a large capacity.

[0034] In an embodiment, like the superconducting cable 10 (10D) shown in FIG. 4, heat insulating layers 26 (26a to 26c) are disposed on the outer periphery of the plurality of inner tubes 14 (14a, 14b, 14c), respectively. Accordingly, it is possible to suppress heat leak into
15 each inner tube even further.

[0035] In an embodiment, like the superconducting cable 10 (10A to 10D) shown in FIGS. 1 to 4, liquid nitrogen is filled inside the inner tube 14 as a cooling medium 'r'.

The temperature of liquefied natural gas LNG is approximately minus 160 °C at a normal pressure, and the temperature of liquid nitrogen is minus 196 °C at a normal pressure.
20 Thus, by filling the outer side of the liquid nitrogen with the liquefied natural gas LNG, it is possible to reduce the temperature difference between the liquid nitrogen and the outside air, thus reducing heat leak from outside. Furthermore, through gasification of the liquefied natural gas, the liquefied natural gas absorbs heat that the liquid nitrogen receives from the superconducting material 18, and thereby it is possible to suppress a temperature increase of
25 liquid nitrogen.

[0036] As shown in FIG. 1, the liquefied natural gas transportation system 30 according to an embodiment is a transportation system that transports liquefied natural gas by utilizing the superconducting cable 10 (10A to 10D).

In FIG. 1, a liquefied natural gas supply source 32 is disposed on the first end side of the superconducting cable 10, and a pipe 34 (first pipe) connecting the liquefied natural gas supply source 32 and a space formed between the outer tube 12 and the inner tube 14 of the superconducting cable 10 is provided.

5 Furthermore, a consumer 36 is disposed on the second end side of the superconducting cable 10, and a pipe 38 (second pipe) connecting the consumer 36 and a space formed between the outer tube 12 and the inner tube 14 of the superconducting cable 10 is provided.

[0037] In the above configuration, liquefied natural gas LNG is transported from the liquefied natural gas supply source 32 to the consumer 36 via the superconducting cable 10.

10 While being transported through the superconducting cable 10, the liquefied natural gas LNG absorbs leakage heat from inside of the superconducting cable 10, and thus it is possible to maintain the inside of the inner tube 14 at an extremely low temperature.

[0038] With the above configuration, with the outside of the cooling medium 'r' for cooling the core portion 20 being filled with the liquefied natural gas LNG having an
15 extremely low temperature, it is possible to reduce the heat leak amount to the core portion 20 considerably. Thus, it is no longer necessary to provide a heat insulating structure by forming a vacuum layer, and thus it is no longer necessary to perform maintenance such as regular vacuuming.

Further, since existing liquefied natural gas is used as a cold source, it is unnecessary to
20 provide a refrigerator for cooling natural gas. Furthermore, the heat insulating layer 22 disposed on the outer periphery of the outer tube 12 may be a heat insulating material used to keep liquefied natural gas cool, which makes it possible to reduce the costs.

Further, liquefied natural gas that has gasified after absorbing leakage heat from outside is sent to a consumer on the terminating end of transportation, and can be used directly as an
25 energy source at the consumer. Thus, it is possible to improve energy consumption efficiency.

[0039] In an embodiment, the liquefied natural gas supply source 32 and the consumer 36 include a storage tank of liquefied natural gas.

In an embodiment, as shown in FIG. 1, the pump 40 is disposed in the pipe 34, and the liquefied natural gas LNG stored in the storage tank of the liquefied natural gas supply source 32 is transported by the pump 40 to the storage tank of the consumer 36 via the superconducting cable 10. Natural gas that has gasified from leakage heat from outside or heat received from the cooling medium 'r' is discharged to the storage tank at the consumer 36, and can be utilized directly as an energy source.

[0040] In an embodiment, as the cooling medium 'r', an extremely low-temperature medium such as liquid helium, liquid hydrogen, and liquid oxygen can be used, besides liquid nitrogen.

Industrial Applicability

[0041] According to an embodiment, it is possible to suppress heat leak into a superconducting cable with liquefied natural gas, and make it unnecessary to perform complicated maintenance such as vacuuming. Further, by utilizing liquefied natural gas, which is an existing cold source, it is possible to improve energy consumption efficiency, and to perform transportation of liquefied natural gas at the same time.

Description of Reference Numeral

[0042]

10 (10A, 10B, 10C, 10D) Superconducting cable

12 Outer tube

14 (14a, 14b, 14c) Inner tube

16 Former

18 (18a, 18b, 18c) Superconducting member

20 (20a, 20b, 20c) Core portion

22 Heat insulating layer (first insulating layer)

24 Electric insulating layer

26 (26a, 26b, 26c) Heat insulating layer (second heat insulating layer)

	28	Hollow section
	30	Liquefied natural gas transportation system
	32	Liquefied natural gas supply source
	34	Pipe (first pipe)
5	36	Consumer
	38	Pipe (second pipe)
	40	Pump
		LNG liquefied natural gas
	r	Cooling medium

CLAIMS

1. A superconducting cable, comprising:
an outer tube;
5 an inner tube disposed inside the outer tube;
a core portion which is disposed inside the inner tube and which includes a former and a superconducting member disposed on an outer periphery of the former; and
a first heat insulating layer disposed on an outer periphery of the outer tube,
wherein an inside of the inner tube is filled with a cooling medium, and a space formed
10 between the outer tube and the inner tube is filled with a liquefied natural gas.
2. The superconducting cable according to claim 1,
wherein the core portion includes an electric insulating layer disposed on an outer
periphery of the superconducting member.
15
3. The superconducting cable according to claim 1 or 2,
further comprising a second heat insulating layer disposed on an outer periphery of the
inner tube.
- 20 4. The superconducting cable according to any one of claims 1 to 3,
wherein the inner tube consists of a single inner tube, and is disposed inside the outer
tube concentrically with the outer tube.
5. The superconducting cable according to claim 4,
25 wherein the core portion includes an electric insulating layer disposed on an outer
periphery of the superconducting member, and
wherein a plurality of superconducting members and a plurality of electric insulating
layers are disposed on an outer periphery of the former alternately along a radial direction of

the former.

6. The superconducting cable according to claim 4,
wherein a plurality of core portions are disposed inside the inner tube, and
5 wherein the plurality of core portions are arranged along an axial direction of the inner tube.
7. The superconducting cable according to any one of claims 1 to 3,
wherein a plurality of inner tubes are disposed inside the outer tube, and the plurality of
10 inner tubes are arranged along an axial direction of the outer tube.
8. The superconducting cable according to claim 7,
wherein the core portion is disposed inside each of the plurality of inner tubes.
- 15 9. The superconducting cable according to any one of claims 1 to 8,
wherein the cooling medium is liquid nitrogen.
10. A liquefied natural gas transportation system, comprising:
the superconducting cable according to any one of claims 1 to 9;
20 a liquefied natural gas supply source disposed on a first end side of the superconducting cable;
a first pipe disposed between the liquefied natural gas supply source and a space formed between the outer tube and the inner tube of the superconducting cable;
a consumer disposed on a second end side of the superconducting cable; and
25 a second pipe disposed between the space and the consumer,
wherein the liquefied natural gas transportation system is configured to transport a liquefied natural gas to the consumer from the liquefied natural gas supply source, via the superconducting cable.