Development of cooling system for 66/6.9kV-20MVA REBCO superconducting transformers with Ne turbo-Brayton refrigerator and subcooled liquid nitrogen

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Introduction

We developed a turbo-Brayton refrigerator with Ne gas as a working fluid for a 3ϕ-66/6.9kV-2MVA superconducting transformer with coated conductors which was bath-cooled with subcooled LN2. The two-stage compressor and expansion turbine had non-contact magnetic bearings for a long maintenance interval. In the future, we intend to directly install heat exchanger into the GFRP cryostat of a transformer and make a heat exchange between the working fluid gas and subcooled LN_2.

In this paper we investigate the behaviour of subcooled LN_2 in a test cryostat, in which heater coils were arranged side by side with a flat plate finned-tube heat exchanger.

Summary

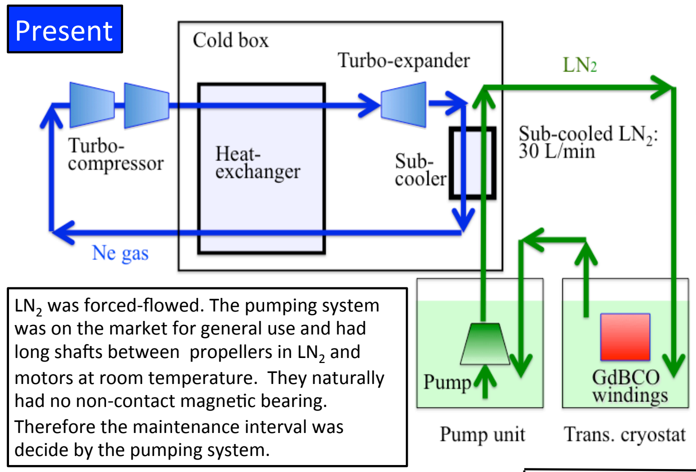
We built a test system to investigate the behaviour of subcooled LN_2 in a cryostat, in which a flat plate finned-tube heat exchanger for cooing and heater coils were arranged side by side in the LN_2 bath.

A He turbo-Brayton refrigerator was connected with the heat exchanger and He gas as a working fluid was introduced into the copper pipe of the heat exchanger.

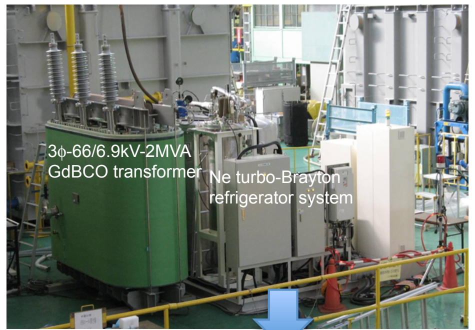
The pressure at the surface of LN_2 was atmospheric one. Just under the LN_2 surface, a stationary layer of LN_2 was created over the depth of 8 cm and temperature dropped from 77 K to 70 K with depth while, in the lower level than that, a natural convection current of LN_2 was formed and temperature was almost uniform at 66 K over around 1 m depth.

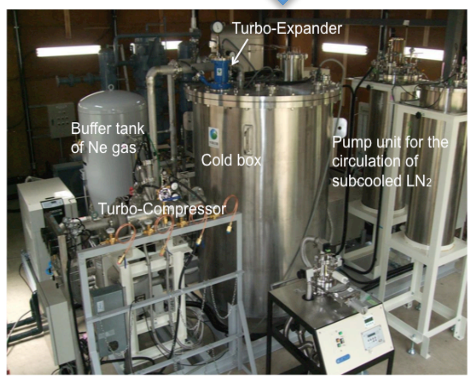
Construction of Test Cooling System

Present



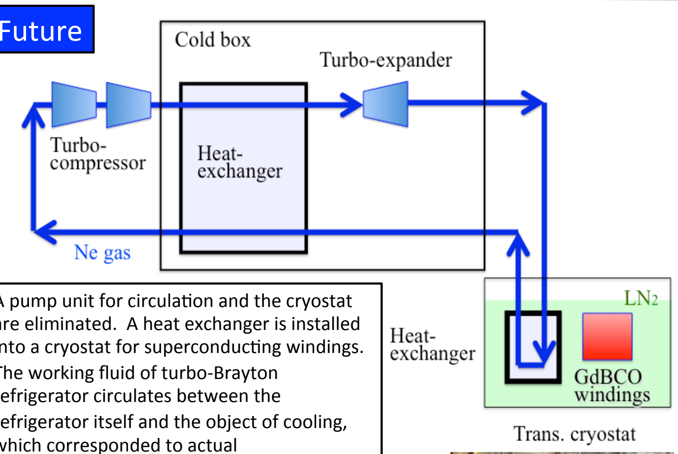
LN_2 was forced-flowed. The pumping system was on the market for general use and had long shafts between propellers in LN_2 and motors at room temperature. They naturally had no non-contact magnetic bearing. Therefore the maintenance interval was decide by the pumping system.





A turbo-Brayton refrigerator with neon gas as a working fluid and a cooling capacity of 2kW at 65K was developed. An expansion turbine and a two-stage turbine compressor with non-contact magnetic bearings were adopted.

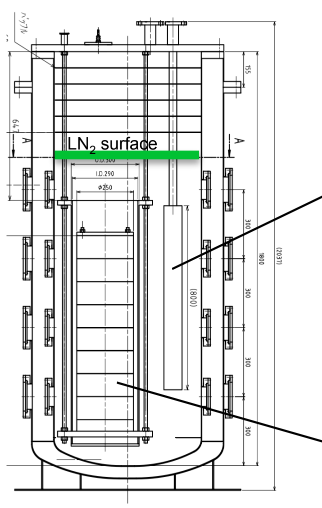
Future

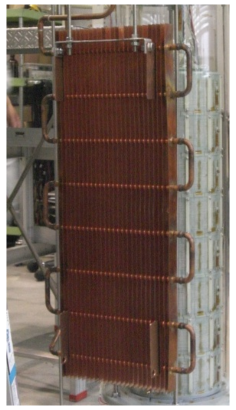


A pump unit for circulation and the cryostat are eliminated. A heat exchanger is installed into a cryostat for superconducting windings.

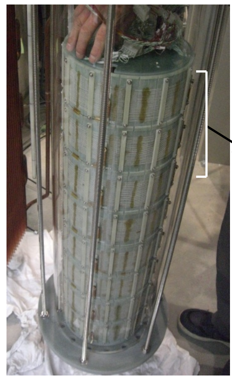
The working fluid of turbo-Brayton refrigerator circulates between the refrigerator itself and the object of cooling, which corresponded to actual superconducting machines and devices.

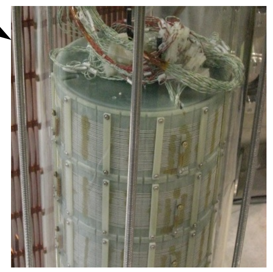
Test cryostat





Flat plate finned-tube heat exchanger





Heater coils

In a new test cooling system in this study,

1) He turbo-Brayton liquefier/refrigerator made by Linde Co. with a liquefying capacity of 230 liter/hour was used for convenience.
   It had a cooling capacity of over 1.6 kW at 5 to 77 K .
2) Flat plate finned-tube heat exchanger : A copper pipe with an outer diameter of 12.7 mm, a thickness of 1 mm and a length of about 5 m was bended into a repeated U-shape and many pieces of copper-fin-plates with a thickness of 0.4 mm were attached by silver soldering.
3) Manganin heater wire was wound on a GFRP bobbin into a single-layer solenoid with a diameter of 250 mm and a height of 100 mm and then the eight heater coils were stacked in a line.

Experiment

1) LN_2 at 77 K was first transferred into the test cryostat.
   500 liter of LN_2 was held.
   Surface level of LN_2 was 1.32 m.
2) By operating the He turbo-Brayton refrigerator and flowing He gas into the copper pipe of the heat exchanger, LN_2 was cooled down to a subcooled state.
   Preessure at the surface was atmospheric one.
3) Temperature of the He gas at the inlet of the heat exchanger was controlled so that the temperature of LN_2 did not decrease to less than 63.3 K.
4) By overcooling, freezing LN_2 clung between the fins of the heat exchanger.
5) By heating with heater coils, temperatures started to rise up.
   When all the heater coils generated heat evenly and the total heat power was less than 1 kW, no bubble was observed. In that case, a rising current of LN_2 in the cooling channel surrounded by a glass pipe became visible even if no bubble appeared.
6) When the uppermost and lowermost coils generated heat power of 200 W per each, bubbles were produced. However bubbles rose up by several cm from the top of the heater coils and then re-condensed and disappeared by cooling by circumambient subcooled LN_2.
7) Just under the LN_2 surface, a stationary layer of LN_2 was created over the depth of 8 cm and temperature dropped from 77 K to 70 K with depth while, in the lower level than that, a natural convection current of LN_2 was formed and temperature was almost uniform at 66 K over around 1 m depth. The boundary plane was visible.