Vapour cooled 2G HTS current leads

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Abstract. Novel current leads having a rated current of 200 A and based on 2G HTS wire by SuperPower has been designed, manufactured and successfully tested with ramping currents up to 250 A. Flexible design of the current leads allows addition of HTS tapes and brass or copper stripes to adjusting a current capacity up to 1000 A.

1. Introduction

Superconducting magnets in bath helium cryostats require the low boil-off current leads stable to stray magnetic field. High magnetic field systems are supplied by relatively high currents which result in high helium evaporation rates. The theoretical optimum of the heat leak per current (Q/I) for copper leads is 1.04 W/kA for vapour-cooled leads [1]. The heat leaks less than 70 mW/kA have been achieved for 13 kA current leads based on Bi-2223 HTS tapes (known as the first generation wire). In this case the cooling of the leads was done by forced gas flow with a rate about 1 g/s [2]. The heat leak of the same order of magnitude has been achieved by several groups on current leads based on Bi-2223 HTS tape in Ag-Au matrix when the hot end of the lead had been cooled by liquid nitrogen (for instance, [3]). But there are a little of experimental data on HTS current leads operated at self cooling conditions without liquid nitrogen interception. This work presents a design and test results of the current leads working on the self cooling conditions without liquid nitrogen interception and utilizing the Coated Conductor which is known as the second generation (2G) of HTS wire. The heat leakage to the helium bath measurement technique is described in details.

2. HTS tape

The HTS tape is a coated conductor (CC) made by SuperPower by IBAD MgO and MOCVD processes. The main properties of the CC are shown in table 1.

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Table 1. The main properties of the CC

| Characteristic               | Value       |
|-----------------------------|-------------|
| Substrate layer             | Hastelloy® C276 |
| total thickness             | 0.096 mm    |
| Total Copper Stabilizer thickness | 0.04 mm    |
| tape width                  | 4.1 mm      |
| critical current $I_c$ (at 77K): | 78 A        |

3. Current leads design

The basic considerations of current lead design and calculation technique of main parameters are discussed in our previous paper [4]. The current lead consists of three sections (normal, mixed and HTS) whose are thermally, mechanically and electrically connected in series. The primary parts of the current lead are shown on the figure 1.

![Figure 1. The primary parts of the current lead.](image)

The normal section consists of the brass stripes soldered on the copper washers to intensify the heat exchange with helium gas. The temperature of the hot top point of the normal section is equal to the room temperature. The temperature of the cold (bottom) point is about 100 K which is close to the HTS critical temperature. In the mixed section the HTS tapes are soldered to the brass stripes. The temperature of the cold end of the mixed section is about 50 K. The third part is HTS section, it consists of two 2G HTS tapes. The stainless steel tube uses as a structural support throughout the current lead. The overall length of the lead is 600 mm. Figure 2 shows the photo of the current lead.

![Figure 2. The photo of the leads.](image)
4. Heat leak measurement technique
The helium gas flow rate at room temperature was measured by gas flow meter AALBORG GFM-37A with response time 0.8 sec. Thus, the differential (liters per time) flow rate was measured. Taking into account that evaporation of 1 litter of liquid helium at 4.2 K corresponds to 750 litters of gas at room temperature (23 C) the liquid helium boil-off rate has been calculated. The assumption that helium gas had the room temperature was based on the long length of gas line (about 10 m) between cryostat and flow meter. Then boil-off rate was recalculated to the heat leakage.

5. Experimental results and discussion
The current leads have been mounted to the insert for helium vessel and extended with two 30 cm long technical copper bars with overall cross section of 70 mm². Electrical circuit was closed by copper bar shunted by 3 HTS tapes near the cold contacts through pressed indium contacts as shown on figure 3.

![Figure 3. The photo of the insert.](image)

Two charcoal TVO sensors (calibrated by RTI) have been placed to one of the current lead. The former on the cold terminal and the later on the upper end of HTS section.

The initial boil-off rate of the vessel (without current leads) was measured to correspond to 180 mW. After adding the current leads the static heat leak has been increased to 280 mW that corresponds to additional heat leak concerned with current leads of 50 mW per lead at zero current. Current was kept constant during the experiment until boil-off rate and temperatures measured by TVO sensors arrived some constant value. Variation of boil-off rate during current transport is shown on figure 4.

During the experiment the temperature of the cold connector varied from 4.5 to 6.7 K. This fact indicates that in real cryostat NbTi or Nb3Sn bus bar could be utilized for connection the leads with superconducting magnet. Long time stable operation during of the leads at currents up to 200 A has been registered. Moreover the current leads have been tested at current 250 A during 20 min. Additional heating concerning with electrical bridge has been measured to be 2 mW at 200 A.

The additional static heat leak concerned with the leads at rated current 200 A was 127 mW per lead which corresponds to specific heat leak equal to 0.635 W/kA. This value is 1.65 times lower then theoretical minimum for non superconconducting current leads but much higher than specific heat leaks for liquid nitrogen cooled current leads. Relatively high heat leak of the lead is concerned with heat transport through 0.04 mm thick copper stabilization layer of the HTS tapes. The further minimization of heat leakage is possible by utilization the HTS tapes with more thin copper stabilization layer or without one.
Figure 4. Variation of boil-off rate during current transport.

Variation of the temperature of the hot part of HTS section during current transport is shown on figure 5. The temperature of the warm end of HTS section has 44 K at 200 A.

Figure 5. Variation of the temperature of the hot part of HTS section
6. Conclusions
A pair of helium vapour cooled current leads utilizing the 2G HTS wire has been manufactured and tested. The experiment reveal that current lead is stable for thermocycling and long time operation at currents up to 200 A. The static heat leak trough the lead of 127 mW at 200 A has been achieved. The further minimization of heat leakage is possible by utilization the HTS tapes with more thin copper stabilization layer. Moreover, flexible design of the lead allows addition of HTS tapes and brass or copper stripes to adjusting a current capacity up to 1000 A.

References

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