Current dependence of heat leak on the terminals in the superconducting DC transmission and distribution system of CASER-2

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Abstract. Superconductivity can solve the energy problems in the world as energy saving technologies. In particular, superconducting direct current (DC) transmission and distribution (T&D) systems is promising, as it can be easily extended to large scale energy transmission systems for energy sharing. We are developing cryogenic systems for effective cooling of superconducting T&D systems. In the cooling experiments with the 200 m-class superconducting DC T&D system at Chubu University (CASER-2), we have estimated the performance of the system. For example, our superconducting cable is connected to the outside at the terminals using Peltier current leads (PCLs). The PCL is composed of a thermoelectric material and a copper lead. Small thermal conductivity and large thermopower of the thermoelectric modules can effectively insulate the heat leak to the low temperature end. We measured the temperature along the current leads and the heat leak at the terminals. As current leads have an optimal shape factor, the optimum operation current exists. The current dependence of the system performance is discussed.

1. Introduction

The energy problems should be solved urgently for the future world. Superconductivity has a high potential as an energy saving technology, which comes from its zero direct current (DC) resistance. Therefore, superconducting transmission and distribution (T&D) systems are promising and such large scale T&D systems help the smart use of unstable natural energies by the energy sharing. The actual use of applied superconducting systems requires high performance cryogenics, because superconductivity can be archived only at the low temperature.

Chubu University has developed 20 m-class superconducting DC transmission device (CASER-1) [1] and 200 m-class superconducting DC T&D system (CASER-2). Using these facilities, we have studied several cooling technologies such as low heat leak cryogenic pipes, high performance terminal systems and so forth to obtain the pragmatic performance of actual superconducting systems [2][3].
High performance current leads are required for the applied superconductivity [4][5]. For examples, the gas cooled current leads opened the commercial use of superconducting magnet systems [6]. We have developed the Peltier current lead (PCL) as a low heat leak current lead [7][8][9], which is used in the terminals of CASER-2. In this paper, we discuss about the performance of PCL in CASER-2. In the actual use of superconducting T&D systems, the current feeding is changed by the power demanded. Therefore we measured the heat leak under the different currents feeded and discuss the current dependence of the heat leak.

2. Experiments in CASER-2

2.1. CASER-2 specifications
Figure 1 shows the pictures of CASER-2 and its specifications. The transmission power of CASER-2 is 40 MW and the length is approximately 200 m. There is an undulation of 2.7 m and a turn with the minimum radius of 2 m, which can emulate actual conditions of transmission lines in the field. We have already finished the 3rd cooling experiment for cryogenics and a superconducting state. As an example, we show the temperature along the cryogenic pipe and the electric field induced in the cable in the first few days in the first cooling experiment (figure 2). Within a week, the whole system was cooled down to the liquid nitrogen temperature and superconducting cables went into the superconducting state, where the electric field on the cable was zero.

![Figure 1. Specification of CASER-2.](image1)

2.2. Experiments for current lead
We also estimated the performance of the terminals. The terminals in applied superconducting systems connect between the superconductors and outer systems set in the room temperature. Since there is large conduction heat, the reduction of the heat leak on the terminals is one of the key technologies for high performance superconducting systems. Therefore we use the PCL for the thermal insulation on the current lead. In particular, as the T&D systems should carry large current for power transmission, the effect of the improvements of the current lead will be large. During the cooling experiments, we can easily observe the difference in the performance between the PCL and the copper current lead (CCL). The large heat leak of the CCL generates ice on the outside of the flange of the cryostat as shown in figure 3 (a), where two kinds of PCLs were used. One is the home made PCL including CCL (figure 3 (a)), and another is a commercial one made by SWCC (figure 3 (b)).

![Figure 2. First cooling experiment in CASER-2.](image2)
The schematic structure of the PCL is shown in figure 3 (c). The PCL is composed of a thermoelectric material and a copper lead. Small thermal conductivity and large thermopower of thermoelectric modules can effectively insulate the heat leak to the low temperature end [7][10][11].

We measured the temperature at the three different positions on the current lead as T1, T2 and T3. The slope of the temperature distribution can roughly tell us the amount of the conduction heat on the current lead. The temperature of the liquid nitrogen (T4) is also measured for the heat leak to the superconducting system. The feeding current for the superconducting cable is in the range between 0 to 1.2 kA. As the stabilization of the system required long time, we selected this current range for the heat leak measurements.

3. Results and discussion

Firstly, we will show the temperature distribution on the current lead without feeding a current in figure 4. The large temperature difference on the BiTe modules is observed both for n- and p-type. The mild slope of the temperature distribution on the copper pert in the PCL means the small heat leak on the current lead. Contrary, the CCL has a large slope of the temperature distribution, which was caused by the large heat leak and the iced lead on the flange was observed as figure 3 (a). Therefore,

Figure 4. Temperature distribution on the current lead. Those for PCL with n- and p-types, and also copper lead are plotted.

Figure 5. Current dependence of the heat leak on the terminals. Squares and circles are for Terminals A and B, respectively.
the temperature difference between T1 and T2 is one of the parameters for the performance of the terminals. This temperature difference increases as the feeding current increases at the lower current and have some maximum at the optimum current around 800 A. This is the optimum condition for the actual shape of the current lead.

Next we show the feeding current dependence of the heat leak on the terminals in figure 5. Above 800 A, the steep increase of the heat leak was observed. Therefore, the optimum condition for the current lead seems to be around 800 A. There is a small difference of the heat leak between the terminals A and B, because of the difference of the shape factor of the current lead for the optimum current. Since the over current condition caused the large heat leak, the further optimum design of the current lead such as thermoelctric parameters, thermal configurations and so forth will be required. On the other hand, below its optimum current, we reduced the heat leak effectively on the terminals, which lead to enhance the performance of the superconducting T&D systems.

4. Summery
The 200 m-class superconducting DC T&D system of CASER-2 was successfully constructed and we have performed several cooling experiments to show the capability of the superconducting power transmission systems. Such large power applications, we should consider the current dependence of the system performance. We measured the temperature distribution on the current lead to estimate the performance of the terminals and also measured the temperature variation of the liquid nitrogen in the terminals. We observed the optimum current for the systems and successfully insulate the heat which comes from the outside of the system.

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