Feature Article: Refrigeration and Cryogenic Technologies
- The Development of Low Thermal Leak Peltier Current Leads for Superconducting Equipment

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The cost of cryocooling superconducting equipment will need to be reduced further in order to ensure its economic viability. Thus, the development of refrigerators with greater efficiencies and low temperature vessels with superior adiabatic characteristics has been progressing. Additionally, reducing conductor thermal loss from parts electrically connecting the power supply, which usually operate at room temperature, to parts operating at cryogenic temperatures becomes important when the cross-sectional area of the conductor increases.

It is the function of the current leads installed in a superconducting device to supply power to equipment (at cryogenic temperatures) derived from a power supply (at room temperature). Metallic copper is typically employed for the conductor owing to its high conductivity characteristics. However, despite this, the high thermal conductivity of high conductivity materials generally leads to greater thermal leakages, which become an issue for equipment with high current carrying capacities. Thus, the design of current leads addressing these conflicting characteristics is required.

One solution is to utilize a high temperature superconducting current lead in place of a conventional conductor. Current leads in contact with superconducting equipment operating at less than 10 K have temperatures of around 70 K, thus allowing the prospects of employing Bi-based high temperature superconductors as an alternative current lead conductors. Since Bi-based high temperature superconductors are a complex metal oxide, their thermal conductivities are much lower compared to copper and therefore thermal leakages due to heat transfer are greatly reduced. Furthermore, during operation, high currents can be transmitted without Joule heating and therefore exhibiting the ideal characteristics of current leads required for superconducting equipment. Higher current capacities requirements in recent years have seen the rise and development of current leads employing Y-based superconducting wires.

These superconducting current leads are however not suitable for applications such as superconducting cables that employ Y-based wires and practical equipment utilizing high temperature superconducting materials, since the temperature of the areas connecting current leads to equipment are close to room temperature. In order to address this, a Peltier current lead (PCL) has been developed with the current-carrying parts having a Peltier element sandwiched by copper conductors. The thermal conductivity of the Peltier element is small compared to that of the copper conductor thus minimizing thermal leakage due to heat transfer. When operational, although there is greater Joule heating compared to copper conductors, it is the Peltier effect that is responsible for transferring heat from the low temperature side to the high temperature side, thus minimizing the heat leak volume towards the low temperature side. Figure 1 shows the outline schematic structure of a PCL.
Since 2009, SWCC has made efforts in a joint research and development programme with Chubu University aimed at developing high current capacity PCLs. The research team has evaluated the performance characteristics of a PCL with a 200 m-class superconducting DC transmission test device (CASER-2), installed at Chubu University. The system is equipped with 23 PCLs connected to positive and negative poles, respectively. Several different copper leads were evaluated and comparisons made. Figure 2 shows the results from temperature distributions measured from PCLs and copper leads. The results from the PCLs established large temperature differences at both terminals of the Peltier element, confirming that the electrode with a temperature gradient lower than the Peltier element had a smaller thermal leakage towards the low temperature parts of the system. At the same time, the thermal leak volume per current lead was measured as 3.6 W for PCL compared to 4.3 W for a copper lead. Also, the thermal leak volume, which was calculated from the measured electrical resistance during operation, was confirmed as being sufficiently low with a value of approximately 32 W/kA.
Having evaluated the PCLs using CASER-2, a principle test involving 100 A-class PCLs was undertaken. Despite this, in order to realize practical PCLs the current carrying capacities still require improvement in accordance with specific equipment capacities. The fabrication of 200 A-class PCLs has been aimed towards the optimization of shape, orientations and connections of the elements, the results of which involve evaluating the current transmission characteristics and are shown in Figure 3. As the current carrying capacity increases the temperature of the element on the side of the lower temperature gradually declines because of the Peltier effect. Thus, evaluating the 200 A-class PCL confirmed its effective performance attributes with the minimum current value measured on the low temperature side shifting towards the high current region. This result paves the way for the future development of a PCL that is planned to have a current carrying capacity greater than 1 kA.

![Graph](image)

Fig. 3 PCL current application test results

The author considers that a reduction of thermal leaks from power supply parts is a significant issue to ensure the economic viability of advancing high power and large-scale superconducting equipment in the future. The development of a PCL is regarded as an important aspect in solving this issue. For the future the author would like to advance PCL product development aiming for enhanced performance of superconducting cables and equipment applications as well as compact power terminal parts by combining PCL with electric insulating technology.

References:

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