§11. Thermal Analysis on Current Leads for Large Scale Superconducting Applications

Kawahara, T., Watanabe, H., Hamabe, M.,
Yamaguchi, S. (Chubu Univ.)

Fusion energy is expected as a new clean energy without CO_2 emission. For the nuclear fusion, plasma should be confined by large superconducting magnets, for which large current is fed by huge bus lines. For such large current transmission, superconducting distribution systems seem to be effective. And also, future large energy generation by fusion systems would require highly effective transmission systems for actual use of electric power. Thus, we should develop high performance superconducting systems with low thermal loss.

For short distribution systems, dominant heat leak comes from current leads at the terminals. We have developed a Peltier current lead (PCL) for the thermal insulation on the current lead[1)]. In the PCL, the Peltier modules are inserted in the current lead. On the current lead, main heat sources are Joule heat and conduction heat from the outside. Thermoelectric materials can pump out the heat from the low temperature part by the Seebeck effect and also insulate the conduction heat by the low thermal conductivity (Fig. 1). We develop a simulation code to calculate the heat leak of the PCL and optimize the shape of them. We used thermal balance equations for the heat leak estimation including the Seebeck effect[1)], where the temperature distribution and the heat leak were calculated by the developed code.

The resistivity of thermoelectric materials is larger than that of the copper lead, and the Seebeck coefficient is only large near room temperature. Therefore, the combination of the thermoelectric elements at the higher temperature side and the copper lead set on the other side represents the usual configuration in the PCL. The temperature distribution was calculated using thermal balance equation as shown in Fig. 2[2)]. In this figure, the temperature distribution is plotted as a function of the form factor IL/A multiplied by the current I. Given the small thermal conductivity, a large temperature difference is observed on the thermoelectric elements and then a relative small temperature difference is observed on the copper current lead, where the short copper lead can be used in the PCL compared to a whole copper current lead (CCL). With this configuration, the heat leak of the PCL is 31.6 W/kA. Thus, we can achieve an approximate 40% reduction in heat load in comparison with the copper current lead.

Now we combine the multi-stage configuration on the copper part in the PCL[3)]. Fig. 3 shows the heat load split to on the current lead at the higher and lower temperatures. The heat load at the higher temperature part of the current lead decreases as the mid-stage temperature increases, and the heat load at the lower temperature part of the current lead also increases. Although the total heat load is the same, the COP of the cryo-cooler changes with temperature, and the total electric power required for the cooling is dependent on the mid-stage temperature.

We have succeeded in developing the simulation code of PCL with the multi stage structures for the use of large current applications. It seems to be useful for the optimization of the heat leak of total systems. When we combine the low heat leak terminals and cryogenic double pipe systems, we can obtain the high performance total systems and they can fit to internet data centers and future transmission systems with sustainable energies.

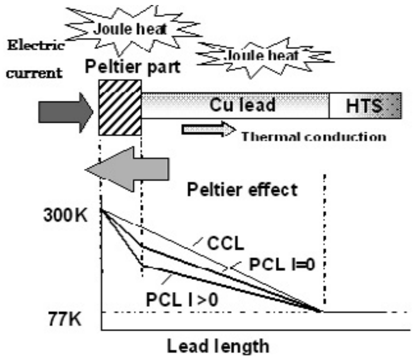

Fig. 1. Temperature profiles of a CCL and a PCL.

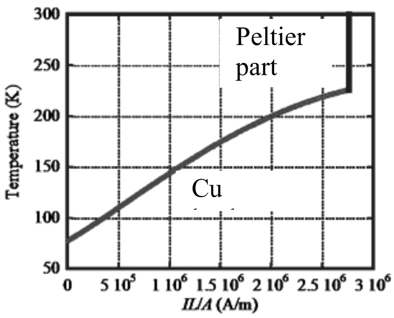

Fig. 2. Temperature distribution on the current lead. Positions are normalized by the current, length and cross-section of current lead, which are form factors.

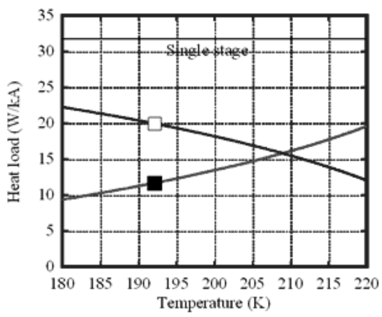

Fig. 3. Mid-stage Temperature dependence of the heat loads. Filled squares denote the heat load on the upper current lead, and open ones denote that on the lower current lead. Single stage case is also plotted.

1) S. Yamaguchi *et al.*: Rev. Sci. Instrum. **75**, 207 (2004).
2) T. Fujii *et a*l., AIP Conference Proceedings, **1218**, pp. 561-568 (2010).
3) T. Kawahara *et al.*, CEC-ICMC 2011, Spokane, USA, C2PoC-07, (2011).