§16. Development of Thermal Analysis Code for Peltier Current Lead

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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 small 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, where gas cooling effects are included as conventional gas-cooled leads are known as a high performance current lead for superconducting magnet systems.

We used thermal 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. Gas cooling is expressed by the heat exchange ratio f between cold gas and the current lead. f = 0 means the no heat exchange, which is conduction cooling. f = 1 means that the cold gas can exchange the heat with the current lead in the equilibrium condition, which is self cooling. For f = 1, the gas comes from only the current lead, however the cold gas can come from the other parts of the systems. For example, it might be transmission lines themselves for the transmission applications or the motor shafts for the car applications. Therefore, we also consider f > 1, which is an over-gas condition. In these calculations, we optimize the shape of the current lead for the current of 100 A and 200 A. For thermal strain analysis, we used a commercial finite element analysis program of ANSYS[2)].

The simulation code can calculate the temperature distribution on the current lead as shown in Fig. 2. Small thermoelectric parts of Peltier modules can effectively have large temperature difference. We used three different modules, and optimized shape factors depend on the thermoelectric properties, then the simulation code can be used for the optimization.

We will also discuss about improvement by the gas-cooled configuration on the PCL using the numerical simulation. We call this new configuration as GC–PCL. For the conventional Cu current lead (CCL), the heat leak is 42.5 W/kA. By using PCL, it is reduced to 28.5 W/kA for p-type without gas cooling. In f = 1, gas cooling can reduce the heat leak to 17.9 W/kA, which is a 37% reduction. For f = 2 and 3, approximately a 50% reduction can be obtained on the heat leak.

Finally, we show the thermal strain on the interface of the current lead. Small thickness of Peltier modules causes large stress by the edge effects, since the current leads are attached on the cryostat. These effects seem to be larger at larger current. In the case of 200 A, the compression at the corners can be observed in Fig. 3.

We have succeeded in developing the simulation code of PCL for the use of large current applications. It seems to be useful for the optimization of the heat leak of total systems. The numerical analysis of thermal strain also supports that the one dimensional analysis developed in this projects is useful for the thermal optimization.

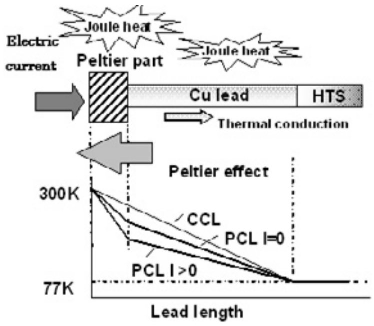

Fig. 1. Temperature profiles of a CCL and a PCL.

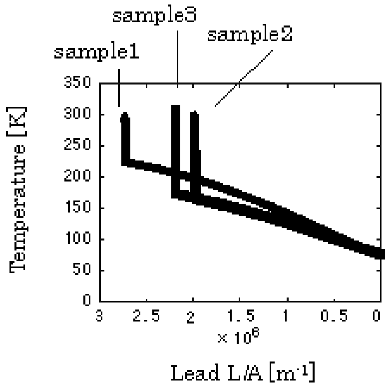

Fig. 2. Temperature profiles at 100A for f=0.

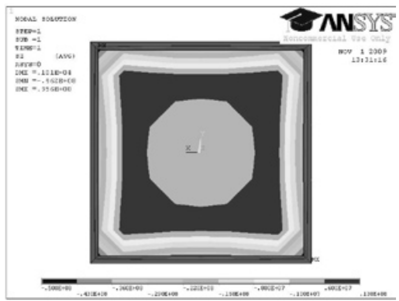

Fig. 3. Strain on the current lead interface at I =200 A.

1) S. Yamaguchi et al.: Rev. Sci. Instrum. **75** (2004) 207.
2) http://www.ansys.com