§4. A Proposal for Prevention of Current Imbalance by Peltier Current Lead

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In order to reduce heat flux to low temperature magnet system, Peltier current lead (PCL) was proposed by S. Yamaguchi et al and the experiment had been performed [1]. The experimental result proves the principle and saves the consumption of the electric energy. PCL is composed of the pair of p-type and n-type thermoelectric semiconductors, which work as a heat pump. Current imbalance is one of the serious problems in large-scale magnets, and the current-lead-resistance method was proposed by S. Yamaguchi et al [2] and the experiment had been done and proven its principle [3]. This method uses the resistance of the current lead strand to improve the current imbalance, and it is quite effective even in large magnets. In this report, we propose the combination of both two ideas. The schematic structure is shown in Fig. 1.

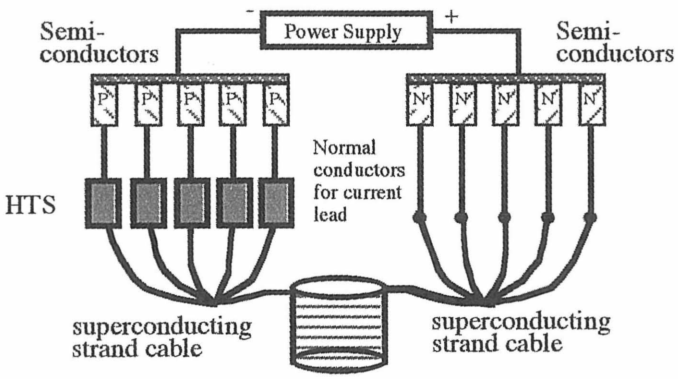

Fig. 1. Schematic structure of the proposed Peltier current lead to improve current imbalance.

Each strand of the magnet and current lead are connected to the semiconductor individually. The resistance of semiconductors is high as compared with the metals, therefore, the current imbalance is improved and the semiconductor works as a PCL to reduce the heat flux to the low temperature system [4]. The generalized Ohm's law is given by

$$\mathbf{E} = \eta \mathbf{J} + \alpha\, \mathrm{grad}T \qquad (1)$$

where **E** is electric field, **J** is current density, η is resistivity, α is thermopower and T is temperature.

Therefore, we should consider the thermoelectric effect, and the circuit equation of the two wire model magnet is given by

$$L_1 \frac{dI_1}{dt} + M \frac{dI_2}{dt} + R_1 I_1 + \alpha_1 \Delta T_1 = V_{ex} \qquad (2)$$

$$L_2 \frac{dI_2}{dt} + M \frac{dI_1}{dt} + R_2 I_2 + \alpha_2 \Delta T_2 = V_{ex} \qquad (3)$$

where I_1 and I_2 are the currents in the two wires (strands), L_1 and L_2 are the self-inductance of the two wires, M is the mutual inductance, R_1 and R_2 are the resistance of the two semiconductors, α_1 and α_2 are the thermoelectric power of two semiconductors, ΔT_1 and ΔT_2 are the temperature differences of two semiconductors ends and V_{ex} is the external source voltage.

The current ratio of I_1 and I_2 is calculated from Eqs. (2) and (3), and is given by

$$\frac{I_1}{I_2} = \{iR\,(V_{ex0} - \alpha_1 \Delta T_1) + (-M\,V_{ex0} + L_2(V_{ex0} - \alpha_1 \Delta T_1 + M\,\alpha_2\,\Delta T_2)\,\omega\} \,/\, \{iR\,(V_{ex0} - \alpha_2 \Delta T_2) + (-M V_{ex0} + L_1\,(V_{ex0} - \alpha_2\,\Delta T_2\,) + M\,\alpha_1\,\Delta T_1\,)\,\omega\,\} \qquad (4)$$

If the condition of

$$\alpha_1 = \alpha_2 \qquad (5)$$

$$\Delta T_1 = \Delta T_2 \qquad (6)$$

is satisfied, the equation (4) will be an usual equation and is given by

$$\frac{I_1}{I_2} = \frac{R + i\omega(L_2 - M)}{R + i\omega(L_1 - M)} \qquad (4')$$

This idea is valid both for the superconducting magnets and cables, and if we use HTS conductor, PCL is only method to reduce the heat leak to the low temperature system. In the next step, we hope to perform the experiment.

Reference

1) S.Yamaguchi, et al, Proc. 16th Int. Cryogenic Eng. Conf./Int. Cryogenic Mat. Conf. (ICEC16/ICMC) part-2, pp. 1159-1162, 1997.
2) S. Yamaguchi et al, Cryogenics, vol. 36, pp. 661-665, 1996.
3) S. Yamaguchi et al, Cryogenics, vol. 38, pp. 875-880, 1998.
4) S. Yamaguchi et al, Applied Superconducitvity Conf., LFD-07, Palm springs, Cal., USA, 1998.