§13. Evaluation of Effects of Hall Currents on the Thermal Conductivity in a Composite Conductor of Aluminum and Copper

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Increase of resistivity of composite conductors made from aluminum and copper in the magnetic field is experimentally confirmed, and its theoretical explanation is also developed[1), 2)]. The increase of resistivity is cased by the opposite direction electric field which is induced by interaction between the external magnetic field and the Hall current that is induced by the difference of Hall voltage in the two material. The additional loss caused by the electric field is equal to the Joule heating of the Hall current. The influence of Hall current on the thermal conductivity, however, is not clearly understood. Since the influence of electric field on the thermal properties is small, it is considered that the decrease of the thermal conductivity caused by the Hall current is as small as the thermoelectric effect. The purpose of this research is to quantitatively examine the influence of Hall current in a composite conductor on the thermal conductivity for more precise analysis of the propagation of a normal-zone in the LHD helical coil conductor.

Setup of a sample of Cu-clad Al conductor (diameter of Al is 1.834 mm, and thickness of Cu is 0.128 mm) is shown in Fig. 1. Before the experiments, the magnetic field dependence of the average resistivity (ρ) has been estimated using literature data, and the difference of thermal conductivity (k) between with and without the Hall effect has been estimated. Under the condition that the temperature dependence of ρ and k can be ignored, the temperature rise (ΔT) at the center is given by

$$\Delta T = \rho I^2 L^2/(2kA^2) \qquad (1)$$

where I, L, A are the current, half length, and cross-sectional area of the sample, respectively. The Hall voltage is proportional to Hall coefficient (R_H), transverse magnetic field (B), I, and height of aluminum (h_{Al}). Since the Al wire is cladded with Cu, Hall current flows in the cross-section, and its joule loss is equivalent to extra resistivity, which is given by $\pi(R_H B)^2/(4R_{HC})$, where R_{HC} is the resistance of the Hall current loop. Since the magnetoresistivity of Cu is almost proportional to B, the increment of ρ with the Hall current is almost proportional to B, as shown in Fig. 2.

It is known that k and ρ of pure metals obey Weidemann Franz low (W-F-L) at very low temperature. Figure 2 shows the calculated k for RRR of Al of 1000. "without Hall effect" is the case where k is independent of Hall current. "with Hall effect" is the case where k and ρ obey the W-F-L. k without Hall effect is estimated to be three times as high as k with Hall effect at 7 T. Figure 3 shows the calculated temperature rise at the center of the conductor with the length of 0.40 m under the condition that the joule heating of the conductor is 50 mW constant. The temperature at both the ends are fixed to 4.2 K. If k is independent of Hall current, the temperature rise will be saturated at high field. If k and ρ obey the W-F-L, the temperature rise will be almost proportional to B.

1) Eckels, P. W. et al.: Cryogenics, 29 (1989) 748-752.
2) Kaneko, H. et al.: Cryogenics, 32 (1992) 1114-1120.

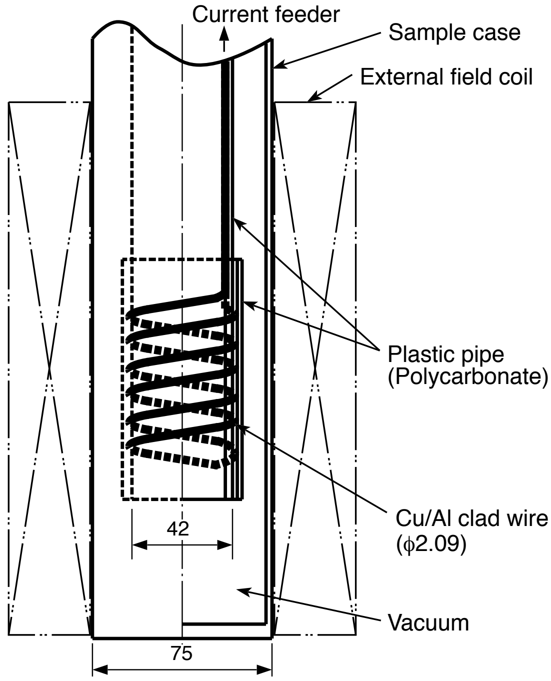

Fig. 1. Schematic drawing of a testing sample.

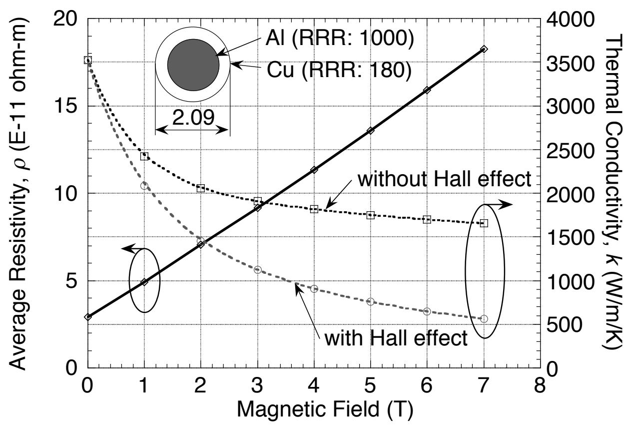

Fig. 2. Calculated average resistivity and thermal conductivity of Al-Cu round conductor.

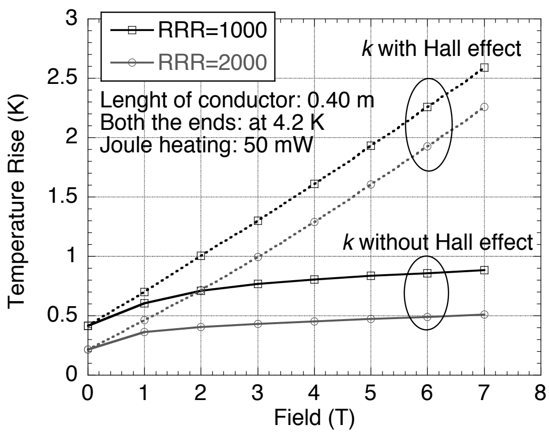

Fig. 3. Calculated temperature rise of Al-Cu conductor for joule heating of 50 mW for RRR of Al of 1000 and 2000.