§4. Analysis of Joint-resistance between Copper Sleeve and Strands in Cable-in-Conduit Conductor

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I. Introduction

Superconducting coils used for fusion reactors and SMES are formed from a Cable-in-Conduit-Conductor (CICC)[1]. The CICC is made of many twisted strands and has superior characteristics such as large current capacity, high mechanical strength, and so on. However, it has been observed that the critical current of CICC was lower than the expected one. One of the reasons is unbalanced current distribution caused by inhomogeneous contact resistances between a copper sleeve and strands at a joint called "wrap joint". We measured the contact resistance between the copper sleeve and each strand at a joint which simulated the wrap joint. The non-uniformity of contact resistances between the copper sleeve and the strands was observed.

II. Measurement of contact resistance between a copper sleeve and each strand

Table 1 shows the Specifications of a CICC sample with wrap joint[2]. Fig. 1 shows the schematic view of the measurement sample and circuit. A thin indium sheet was wrapped around the cable that the conduit was removed. The wrap of indium sheet simulated the solder coated in a real wrap joint. Then, the copper sleeve was installed on the cable with the indium sheet. We measured the contact resistance between the copper sleeve and each strand using the four-terminal method at the liquid helium temperature (4.2 K). The current was set to 6.0 A.

Fig.2 shows the contact resistance distribution between the copper sleeve and the strands. Zero resistance in Fig.2 means that we could not measure the contact resistance due to too small voltage. The number of strands with the zero resistance was 146 and the non-uniformity of the contact resistances was observed. This means that the strands with the zero resistance were in contact with the copper sleeve directly and the other strands didn't make contact with the copper sleeve directly. The high resistance was caused by the contact resistance between the strands.

In order to verify the validity of our measurement, we analyzed the contact condition between the copper sleeve and the strands using the data of strand paths measured in the other CICC sample[1]. We judged the contact condition by comparing the coordinates between the copper sleeve and each strand at each cross-section of the CICC sample. We evaluated the number of strands making contact with the copper sleeve in the wrap joint of 75mm in length. In the analysis, 150 strands made contact with the copper sleeve. The number of the strands is almost the same with the measured one, 146 strands. Therefore, the resistance distribution between the copper sleeve and the strands depended on the contact condition between the copper sleeve and the strands at the joint. This result means that such the non-uniformity of the contact resistances results in a non-uniform current distribution in a CICC.

III. Conclusion

We evaluated a contact resistance distribution between a copper sleeve and strands at the joint which simulated a wrap joint. The contact resistance distribution was inhomogeneous. This means that the current distribution in the wrap joint becomes unbalanced due to the non-uniform contact resistance distribution. Furthermore we analyzed the contact condition between the copper sleeve and the strands using the data of strands paths measured in the other CICC. The number of the strands which directly made contact with the copper sleeve in the analysis was nearly equal to that of experiment. The contact resistance distribution depended on the contact condition between the copper sleeve and the strands. Cable structure should be arranged to realize that all strands make contact with a copper sleeve to suppress inhomogeneous contact resistance distribution between a copper sleeve and strands.

1) Morimura, T. et al.: The Papers of Technical Meeting on "Application of Superconductivity", IEE Japan, (2013) ASC-13-018. (in Japanese)
2) Morimura, T. et al.: The 2013 Annual Meeting of the Institute of Electrical Engineers of Japan, (2013) 5-158. (in Japanese)

Table 1 Specifications of a CICC sample with wrap joint.

CIC conductor	number of strands	486
	strand diameter [mm]	0.89
	cable length [mm]	210.0
	cable shape [mm]	20.5×24.8
Copper sleeve	sleeve length [mm]	75.0
	sleeve shape [mm]	18.8×23.0
Indium sheet	thickness [μm]	50.0

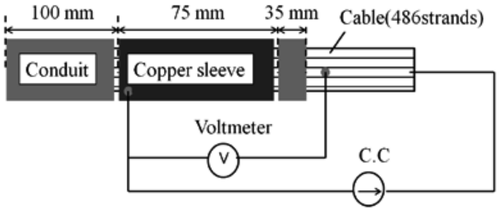

Fig.1 Schematic view of a measurement system.

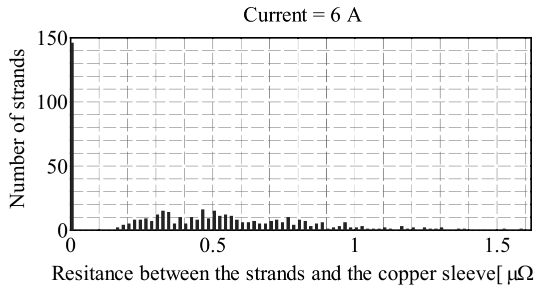

Fig.2 Resistance distribution between a copper sleeve and strands in a CICC sample.