§12. Electromagnetic and Structural Investigation of Inter-strand Resistance in CIC Conductor for Fusion Magnets

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It is obvious that inter-strand contact resistance distribution plays an important role for both ac loss and stability of cable-in-conduit conductors (CICCs) which have been introduced to the large scale fusion magnets. Our unique approach for investigating the distribution is based on the strand-trace measurement which have been performed by using special experimental device. The measurement technique uses simple four-terminal method to measure the strand resistance or the sum of the strand and inter-strand resistance included in a sliced CICC with 10mm in thickness in the conductor axial direction.

Figure 1 shows the sliced sample CICC designed for equilibrium field (EF) coil installed in JT-60SA. Epoxy resin is poured into the conduit to fill the void so that the strand movements during cutting are completely avoided. The sample is set on the holder which is able to control the operating temperature down to 120K, then a pair of probes move to each target strand cross section on both sliced sample surfaces. After the probes contact with specific pressure, power supply feed the current and output voltage which represents strand resistance or sum of strand resistance and inter-strand contact resistance is recorded on the electronic file. The above procedure is iterated with large number of combinations of strand cross sections on both surfaces. The combination of minimum voltage indicates the strand cross sections are identical strand which means the strand location on both surfaces is determined[1].

Experimentally obtained strand traces enable us to

$$\begin{bmatrix} L_{1,1} & M_{1,2} & \cdots & M_{1,216} \\ M_{2,1} & L_{2,2} & & \vdots \\ \vdots & & \ddots & \vdots \\ M_{216,1} & \cdots & \cdots & L_{216,216} \end{bmatrix} \begin{bmatrix} \frac{\partial i_1}{\partial t} \\ \vdots \\ \frac{\partial i_{216}}{\partial t} \end{bmatrix} = \begin{bmatrix} V_1 \\ \vdots \\ V_{216} \end{bmatrix} \quad \cdots \ (1)$$

investigate the strand movement during charging the coil by using theory of structural mechanics and the current imbalance by solving the electric lumped network modeling with calculated self and mutual inductances of strands. The inductance evaluation is performed by using Neumann equation which needs geometrical positions of segments of strands. The evaluation indicated that the maximum difference of inductance between strands was around 150 %. The equation 1 indicates the governing equation of transport currents in each superconducting strand without considering inter-strand contact resistance for simplicity. In order to take into account the inter-strand resistances, we need to measure the resistance distribution under the condition of 4.2K. It will be accomplished in the next several years due to the significance of the measurement.

Figure 2 shows the calculated transport current distribution flowing in each superconducting strands with their 3-dimensional locations[2]. To show the current imbalance intentionally, the changing rate of external magnetic field is 0.01T/s and the resultant inductive voltage and voltage from power supply are applied to both terminals of each strands. The result showed the relatively large current imbalance. In detail, the strands located around the center spiral carry negative current compared to which surrounding strands carry. In future work, we are going to measure the strand positions for getting longer traces and inter-strand contact resistance distribution in 4.2K for further calculation of current distribution even in the strong electromagnetic field based on the structural mechanics and electromagnetism.

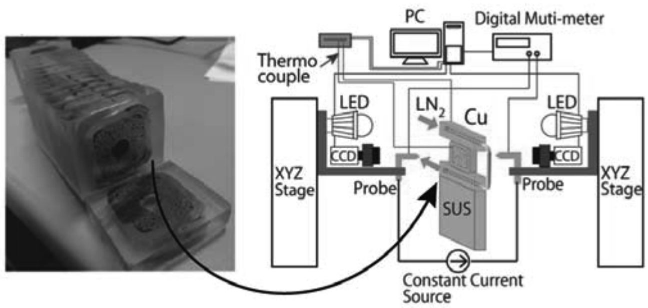

Fig. 1. Picture of sliced CICC samples (left) and schematic of measurement system (right)

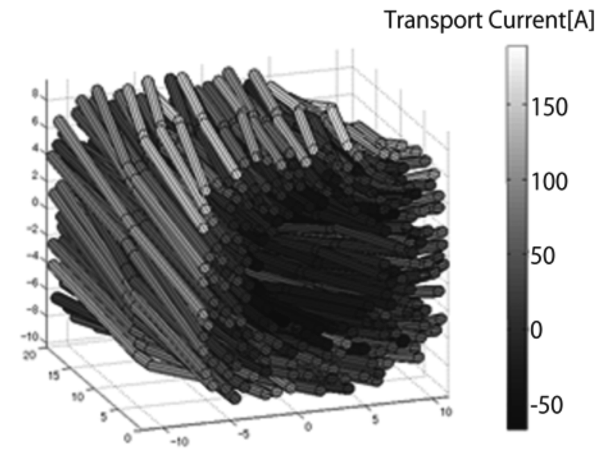

Fig. 2. Evaluated transport current distribution in 0.01T/s time variation of external magnetic field plotted on the measured strand 3-dimensional locations.

1)Yagai, T. et al. : IEEE Trans. Appl. Supercond. **17**(2007)2470
2) Yoshida, K.: Master Thesis of Sophia University (2015) .