# §25. Simulation of Electromagnetic Behaviors of Lap Joints for Fusion Magnet Systems

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The joint between superconducting cable-in-conduit-conductors (CICC) is the key technology in magnetic confinement fusion apparatus and several hundreds of joints are involved in generally. In the Large Helical Device (LHD), there are 104 joints (44 joints in the helical coils and 60 in the poloidal coils). For the International Thermonuclear fusion Experimental Reactor (ITER), the number of joints are assumed be more than two hundred. DC resistance of the lap joint is typically designed less than several n-ohms and allowable joule loss is several watts. AC loss due to external field is also limited less than several watts. Reduction of AC loss and lower joint resistance are required simultaneously and those are conflicting trade-off. The lap joint had been examined under both self-field and external transverse field experimentally at Kagoshima Univ. [1), 2)]. In this study, we established the numerical model for the joint and analyzed numerically. In the simulation, modeling of contact resistances between parallel strands is important. Circuit constants were determined to reproduce the experimental results; those are the magnetic diffusion time constants and the DC joint resistance. The relation between the joint resistance and the AC loss were discussed. Constitution of the joint doesn't only influence on the joint resistance and the AC loss but also current distribution in the cable. Non-uniform current distribution (NUCD) among the strands is reported to result in the degradation of the stability. We also discussed about the current distribution with our numerical code and models and showed representative numerical results for NUCD in this report.

Figure 1 represents the numerical model of lap-joint. Experimental joint sample is made with two legs of Nb3$_S$n CICCs. The cable is multiply twisted by (2+1Cu) x 3 x 3 x 3 x 4, however we reduced it into the cable with 3 x 3 x4 superstrands (SSTs) as the numerical model. Here, the final twist pitch is 190 mm and copper sleeve and/or joint length is 250 mm in the experiment. We selected joint length as a parameter and three models are prepared; model-a) L$_J$=250 mm, b)125 mm and c) 62.5 mm. Figure 2 illustrates the XY plane projections of SST-tracks. In this figure, encounters of SSTs and the lap-joint–interface are not fair and joint resistances between individual SSTs in different leg must not be equal. Figure 3 shows the simulated results of the DC current distributions among 36 SSTs. Currents thorough individual SSTs are not even and remarkable NUCD occurs in the shorter joint case c).

Our conclusions are as follows. DC joint resistance is merely determined by the size, e.g. length of the lap-joint-interface. NUCD in the steady state depends on the distribution of contact points to the lap-joint-interface among the superstrands. NUCD is found enhanced for short joints, as at given twist pitch, the probability for single superstrands to reach the lap joint interface is lower. In contrast, The AC-losses from self-field and external magnetic field increases with the joint length. Both effects compete with each other and magnet operating condition will be decisive for optimizations. The model presented above may be found useful in joint design to find a good compromise.

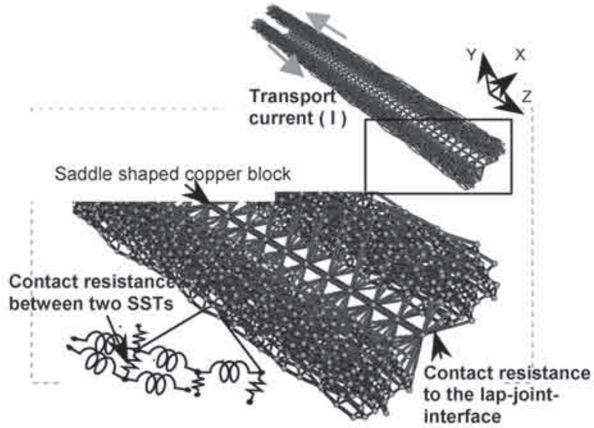

**Fig. 1** Numerical model of lap-joint. The saddle-shaped copper block is modeled into a single line. Identical voltages are applied to parallel SSTs. Tracks of SSTs have close relations to both mutual inductances and contact resistances. Contact resistances are described as transverse connections between SSTs.

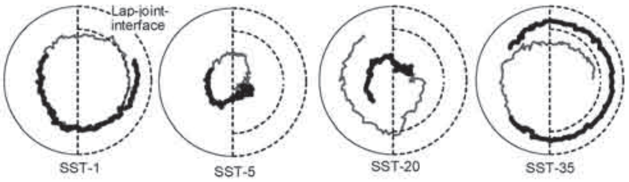

**Fig. 2** XY plane projections of SST-tracks. The SST in the area surrounded by two dashed arcs is expected to encounter the lap-joint-interface. The thick lines are extracted from Model-b. Both thick and thin lines are from Model-a. The tracks are determined by the twist-pattern. .

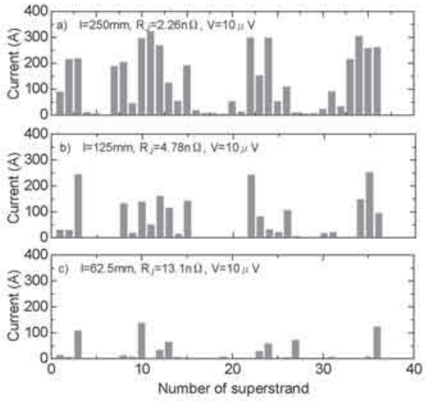

Fig. 3. DC current distributions among 36 SSTs.

Reference
1) Kawabata, S. et al., Presented at MT-18 (2003)
2) Seo, K., IEEE Trans. on Appli. Supercond. **15**, (2005) 1595