# §16. AC Loss and Stability of Large-scale Superconducting Magnet for Fusion

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i) Introduction

The JT-60 Super Advanced (JT-60SA) of Japan Atomic Energy Agency is a fusion experiment designed to contribute to the early realization of fusion energy by providing support to the operation of ITER. The superconducting magnet system in JT-60SA consists of 18 toroidal field (TF) coils, 4 stacks of central solenoid (CS) modules and 6 plasma equilibrium field (EF) coils. The CS consists of a stack of four electrically independent modules to allow control of the plasma shape. The type of the joint between the conductors of the CS is butt joint. The butt joint was developed during ITER-EDA CS model coil program and adopted by ITER as one of the candidate joint for CS. New tools for the butt joint were developed for the JT-60SA CS and qualification samples of the butt joint were fabricated. The butt joints are located at the coil outer diameter and are embedded within the winding pack to supplying the magnetic flux to the plasma. When a time-varying magnetic field is applied to the butt joints, an AC loss occurs, and temperature at the joint rises due to the AC loss. The loss is the main origin of instability in the butt joint. The butt joint is a compact joint, but it has a limited stability because of poor helium cooling. Therefore, to protect this coil system from quench, it is necessary to understand the AC loss of the butt joint.

In this study, the AC loss in the butt joint of the CS under a time-varying external magnetic field is measured. The AC losses at the butt joint in the CS are estimated by using a FEM simulation software. The FEM simulation software is used COMSOL Multiphysics®.

ii) Experimental and Analytical results

The analytical model of the butt joint is showed in Fig. 1. The strands area is defined as multiplicative model of copper and $Nb_3Sn$. The volume of multiplicative model is calculated from the component ratio of the copper and $Nb_3Sn$. The AC loss of the steel spacer and SHe is ignored, because these electrical conductivities are small. The relative magnetic permeability of the multiplicative model is 1. The electrical conductivities of the multiplicative model have anisotropy. The electrical conductivity of the copper (copper sheet and sleeve) and the resistance of the butt joint with increasing magnetic field at 4.2 K are shown in Fig. 2. From this figure, the electrical conductivity of the copper and the resistance of the butt joint depend on the magnetic field. The contact resistance between the copper sheet and conductor in Fig. 1 is calculated from the current value when the 1 V was applied to the butt joint. These results are used in this analytical model. Fig. 3 shows the analytical and experimental AC loss results. The experimental data are also plotted in the figure. From the figure, the analytical results agreed with the measured data, and hence we think the analytical model shown in Fig. 1 can present the actual phenomena.

iii) Conclusion

The AC losses of the butt joint of the CS conductor for JT-60SA are measured and analyzed under a time-varying magnetic field. According to the measured results, the AC loss of the butt joint became the smallest of all joints (the butt joint, the pancake joint, the terminal joint, and the prototype joint) [1]. We think that we could succeed to design and make the stable joints. We numerically analyzed the AC loss of the butt joint, and the numerical results well agreed with the experimentally measured data.

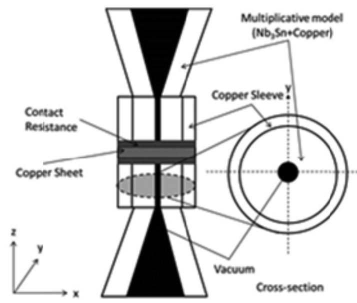


Fig. 1. Analytical model for AC loss.

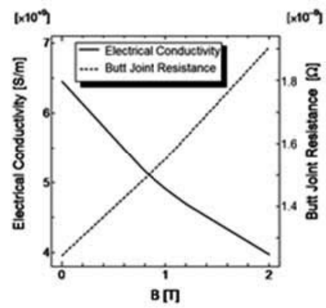


Fig. 2. Dependence of the copper's electrical conductivity and the butt joint resistance under the magnetic field.

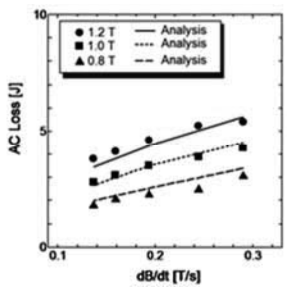


Fig. 3. AC loss of the analytical and experimental results.

1) Nakamura, K. et al. : IEEE Trans. Appl. Supercond. Vol. 23 (in press).