§16. Evaluation of AC Loss and Stability of JT-60SA Poloidal Field Coil

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i) Introduction

The magnet system of the JT-60 Super Advanced (JT-60SA) tokamak consists of 18 toroidal field (TF) coils, 4 stacks in the central solenoid (CS) and 6 plasma equilibrium field (EF) coils. These coils generate a field to confine charged particles, drive the plasma current inductively, and shape the plasma with a plasma current of up to 5.5 MA for 100 s flat top. The CS consists of a stack of four electrically independent modules to allow control of the plasma shape. Octa (8) or quad (4) pancakes are used in the winding in order to reduce the number of joints using maximum manufacturing conductor length (less than 600 m). Coolant outlets and pancake-to-pancake joints are located at the outer diameter, and superconducting bus bar connections run vertically in the gap between the CS and the TF coils. The CS joints are located at the coil outer diameter and are embedded within the winding pack. Between pancakes, the conductors are connected by a butt-type joint where a sintered joint is made between the two conductor ends. The butt joint for the CS is a compact joint, but it has a limited stability because of poor helium cooling. When a time-varying magnetic field is applied to the joints, AC losses occur, and temperature at the joint rises due to the AC losses. The loss is the main origin of instability in the joint, and hence, to protect this coil system from quench, it is necessary to investigate the operational limit of the butt joint of the CS for scatter of joint resistance, magnitude of magnetic field and cooling condition (temperature and mass flow rate) versus a time-varying magnetic field.

In this study, based on the former experimental results of the butt joint, we calculated the AC losses and temperature rises of the butt joint of the CS by using FEM. The FEM simulation software is COMSOL Multiphysics®.

ii) Analytical results and disccusion

The simplified model of the butt joint for the temperature rise is shown in Fig. 1. From this figure, the analytical model consists of the multiplicative model, the copper sheet and the copper sleeve. The strands area is defined as the multiplicative model of copper, bronze and Nb_3Sn. The thermal conductivity of the multiplicative model has anisotropy. In the multiplicative model, the thermal conductivity of the Z direction is calculated by the component ratio of the conductor, while, that of the X (Y) direction is estimated by Wiedemann-Franz laws.

Fig. 2 shows the maximum temperature of the butt joint by changing the joint resistance (ΔB = 0.96 T and the mass flow = 6.0 g/s). As shown in the figure, when the joint resistance increases, the Joule losses rise and the maximum temperature of the butt joint increases. The Joule losses in the butt joint is dominant in the losses. However, at 5 nΩ (the nominal value of the joint resistance), the maximum temperature (12.4 K) at the plasma disruption becomes less than the current sharing temperature (T_{CS} = 13.5 K).

iii) Conclusion

Based on the AC losses and the Joule losses of the butt joint, the temperature rise of the butt joint for JT-60SA are analyzed by changing certain operating conditions. The results of the work[1] are as follows:

(1) When the joint resistance increases, the AC losses decrease, but the maximum temperature of the butt joint rises because of the Joule losses. The Joule losses in the butt joint is dominant in the losses of the butt joint. But if the joint resistance is <5 nΩ, the maximum temperature (12.4 K) at the plasma disruption becomes less than T_{CS}.
(2) The butt joint of the CS in the JT-60SA has an enough temperature margin for operational condition.

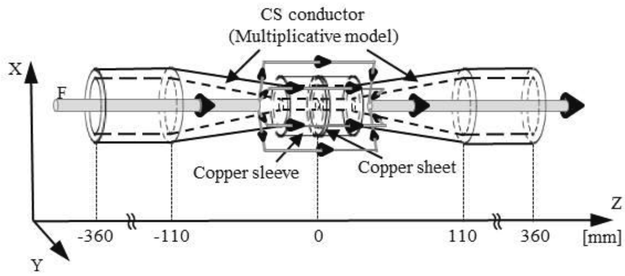

Fig. 1. Simplified model of the butt joint for temperature rise.

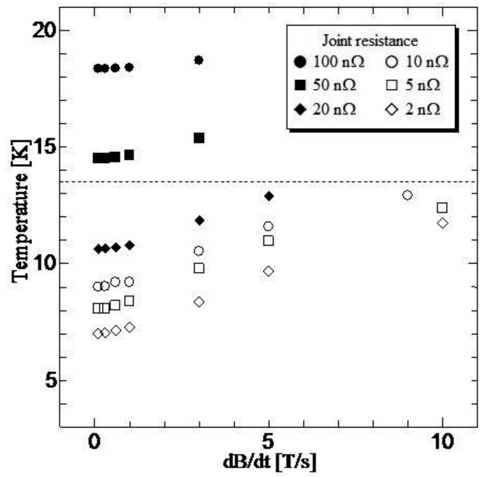

Fig. 2. Maximum temperature by changing joint resistance (ΔB = 0.96 T and mass flow = 6.0 g/s).

1) Nakamura, K. et al. : IEEE Trans. Appl. Supercond. Vol. 26 (2016).