Investigation of Influence of Stabilizer Thickness on Stability of NI REBCO Pancake Coil by Numerical Simulation

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1. Introduction

This paper reports a bypass current behavior on the cross section of a No-Insulation (NI) REBCO pancake coil. The NI winding technique enhances the thermal stability and current density of the NI REBCO coil, as compared with a conventional turn-to-turn insulated coil, because the operating current can flow into adjacent turns when a local normal-state spot appears in the NI REBCO coil. The high stability of the NI REBCO coil is confirmed by experiment and simulation. However, others have targeted the performance evaluation of the whole NI REBCO coil. To realize the effective use of NI winding technique, it is desired to elucidate the turn-to-turn bypass current behavior from a local view of NI REBCO coil, e.g. the turn-to-turn contact resistance and the copper stabilizer thickness. To investigate such behaviors, the bypass current behavior on the cross section of NI REBCO coil is simulated using 2-D FEM. Then, various contact resistivity values and stabilizer thicknesses are employed to the simulation model to investigate the influence of the copper stabilizer thickness on the current behavior. From the simulation results, the current behavior in different contact resistivity values is shown. In addition, from these results, the influence of the copper stabilizer thickness on Joule heating generation is also presented.

2. Simulation Model

Fig. 1(a) shows the schematic drawing of an NI REBCO pancake coil. This coil is wound with a REBCO tape (SuperPower 2G HTS tape [1]) using the NI technique.

Fig. 1(b) shows the schematic view of cross section of an NI REBCO coil. That is simulation model.

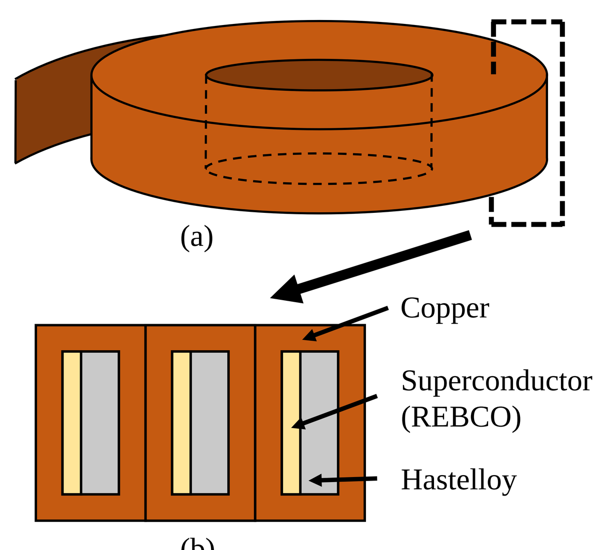

Fig. 1. (a) The schematic drawing of an NI REBCO pancake coil. (b) The schematic view of cross section of NI REBCO coil.

TABLE I
PARAMETER OF THE SIMULATION MODELS

Parameters	Values
Tape width [mm]	4.0
Copper stabilizer thickness [μm]	10.0, 20.0, 40.0
Superconductor thickness [μm]	1.0
Superconductor width [μm]	0.1
Hastelloy thickness [μm]	50.0
Copper resistivity @ 77K [μΩ·cm]	0.2
Hastelloy resistivity [μΩ·cm]	125.0

The simulation model is the three cross sections of REBCO tape aligning side by side with voluntary contact resistivity. Three kinds of copper stabilizer thickness are used for simulation models. These are 10, 20, and 40 μm thickness, respectively. Using these simulation models, detailed behavior of turn-to-turn current and thermal stability in the various copper stabilizer thickness are investigated.

[1] http://www.superpower-inc.com/content/2g-hts-wire

3. Simulation Method

To simulate the current flow between two or three adjacent turns, the 2-D FEM is used. The governing equation in the simulation is as follows:

$$\nabla \cdot \sigma \nabla \varphi = 0 \qquad (1)$$

where σ and φ are the electrical conductivity and the scalar potential, respectively. On the contact surface of the NI REBCO tapes, the double-nodes method [] is used. The electrical contact condition is given by

$$\varphi_l - \varphi_r = \rho_{\mathrm{ct}} J_{\mathrm{ct}} \qquad (2)$$

where φ_l, φ_r, ρ_{ct}, and J_{ct} are the scalar potential on the left turns l and right turns r on the contact surface, the turn-to-turn contact surface resistivity, and the current density from the turn l to r, respectively. In the simulation, the current per unit length from the left to the right turn in the REBCO coil is set to 1.0 A/cm. In the Fig. 1 (b), superconducting layer has a normal state condition. Current flow from the left turn to the right turn through the center turn in the Fig. 1 (b). In the simulation, using various contact resistivity, current flow and joule heat are calculated

4. Simulation Results

Current Density Distribution

The simulation is carried out on various contact surface resistivities, $\rho_{ct} = 10^{-4}$ to 10^4 μΩ·cm² and three kinds of copper stabilizer thickness, 10, 20, and 40 μm, respectively.

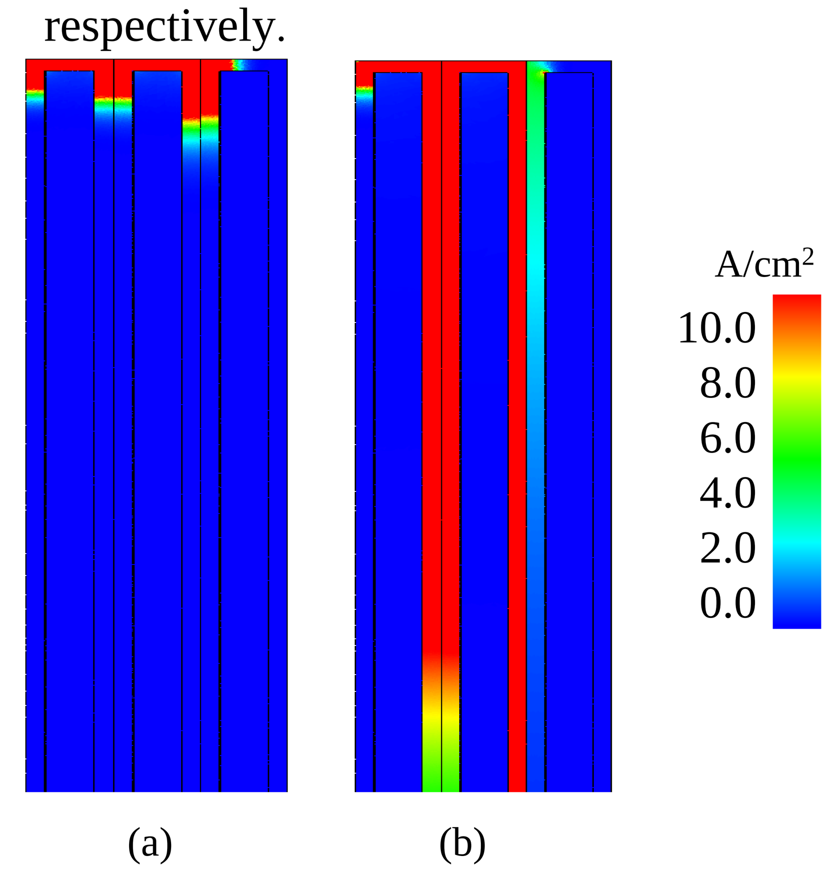

Fig. 2 Current density distribution at ρ_{ct} = (a) 10^{-4} and (b) 10^4 mW·cm² in a copper stabilizer thickness of 20 mm. Only the one-quarter top of the cross section is visualized.

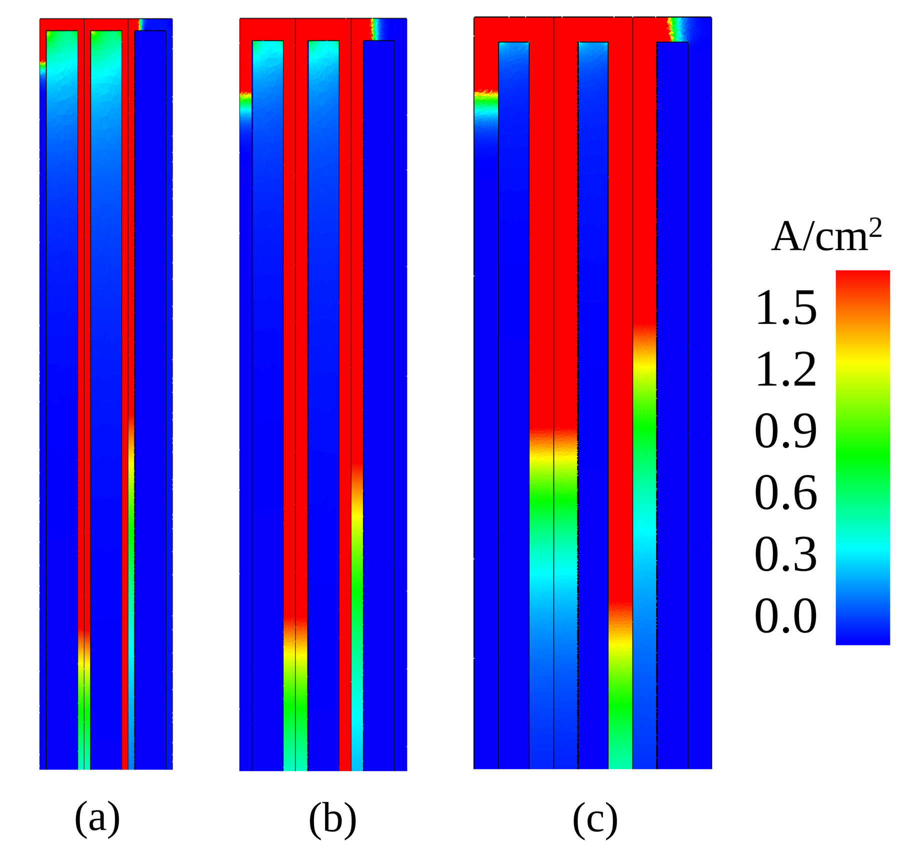

Fig. 3. The current distributions with a copper stabilizer thickness of 10, 20, and 40 mm, with $\rho_{ct} = 10^{-2}$.

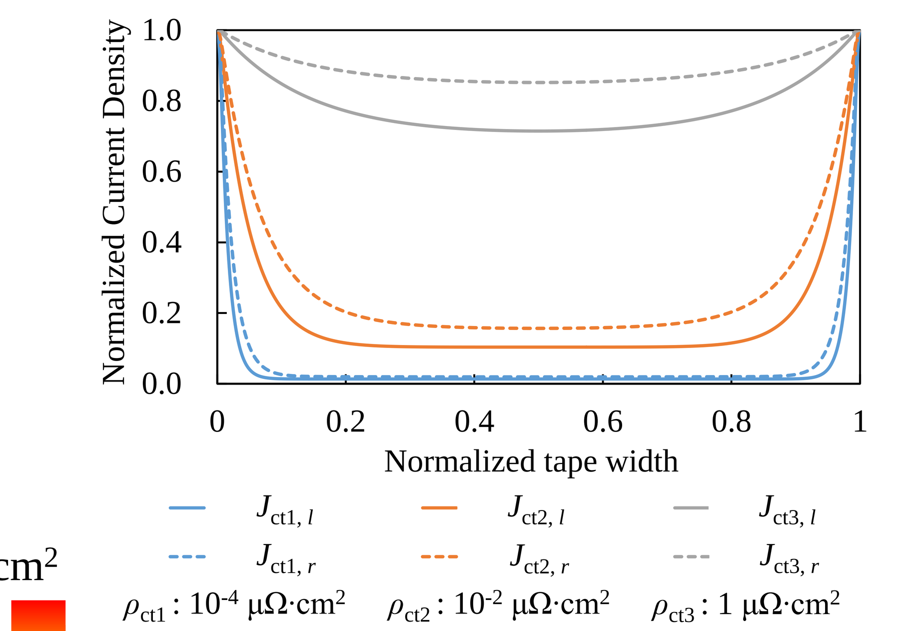

Fig. 4. The normalized current density on the turn-to-turn the contact surface in 20 μm copper stabilizer thickness.

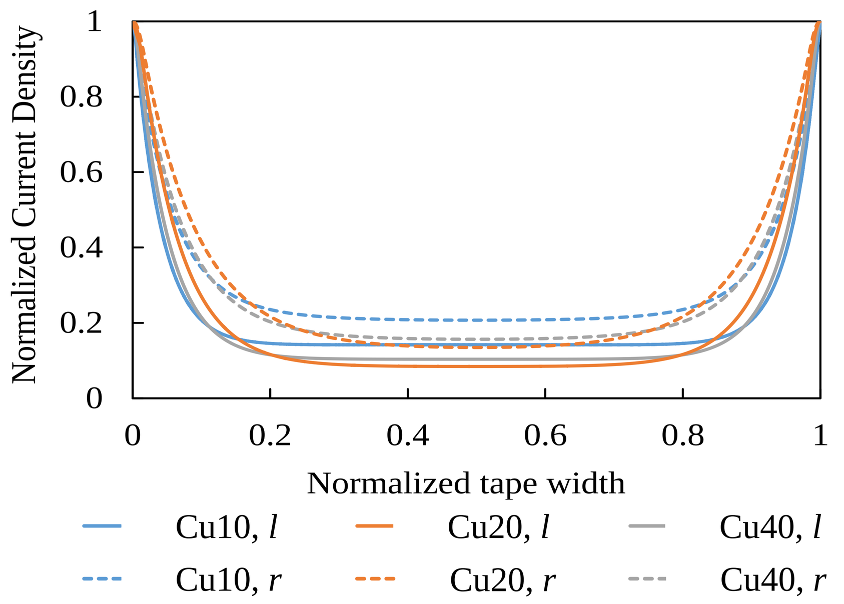

Fig. 5. The normalized current density on the turn-to-turn the contact surface with copper stabilizer thicknesses of 10, 20, 40 mm, with $r_{ct} = 10^{-2}$ mW·cm².

Coil-Radial Contact Resistivity

The coil-radial contact resistivity ρ_r is obtained as follows:

$$Q_{\mathrm{all}} / V = I \qquad (3)$$

$$V \times w / I \times 1/2 = \rho_{\mathrm{r}} \qquad (4)$$

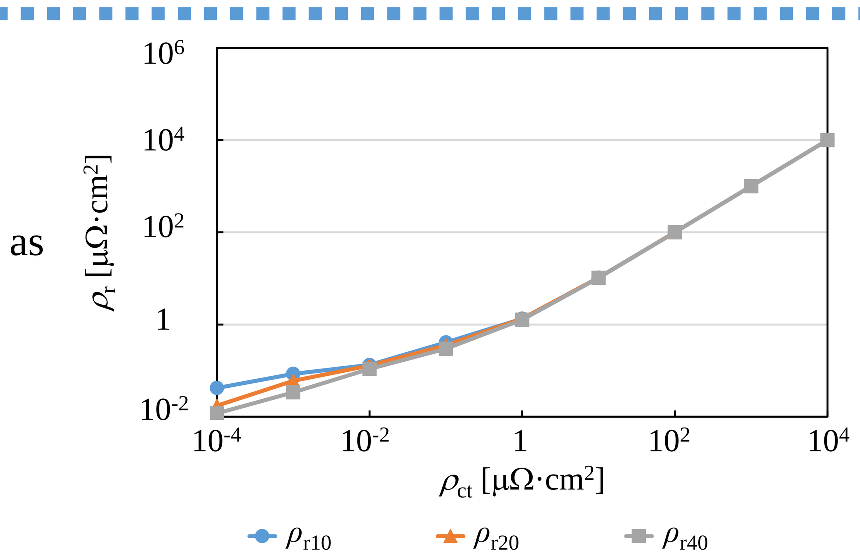

Fig. 6. The contact resistivity ρ_{ct} versus the coil-radial contact resistivity ρ_r with different copper stabilizer thicknesses.

Joule Heat Loss

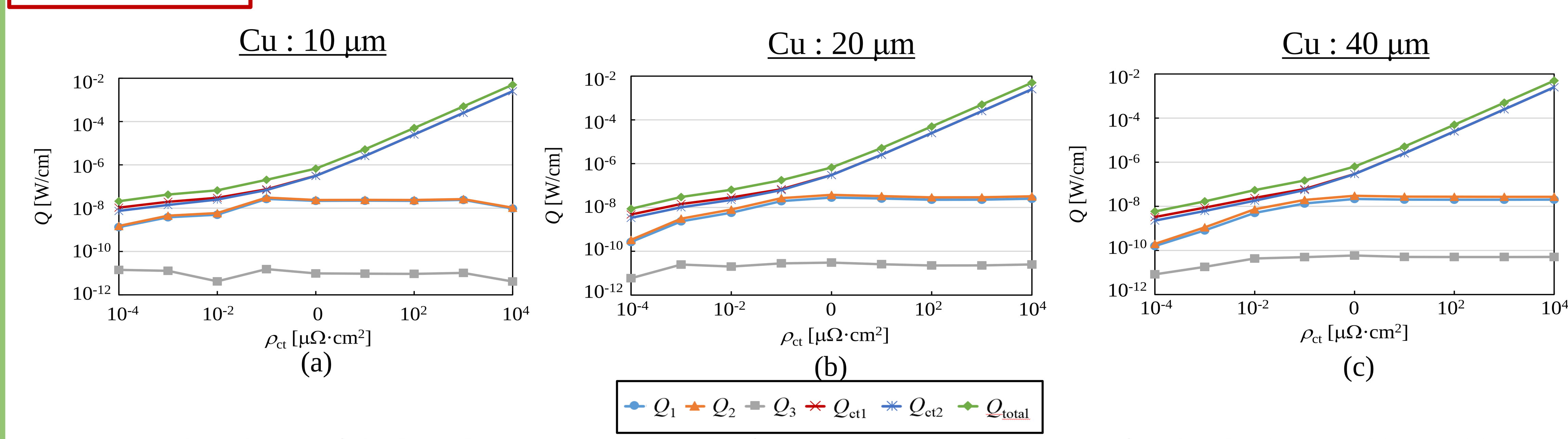

Fig. 7. The relation of the heat density per unit length of every turn and the contact surface by the (a) 10-, (b) 20-, (c) 40-μm copper stabilizer thickness, respectively.

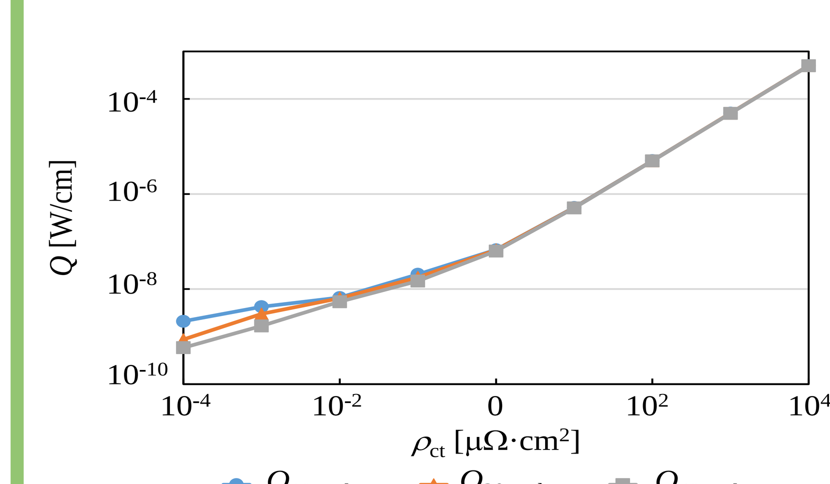

Fig. 8. The comparison of total heat density in the three kinds of copper stabilizer thickness.

It is possible to enhance the current density of the NI REBCO coil regardless of the copper stabilizer thickness from a viewpoint of bypassing current behavior in cross-section simulation.

However, since the copper stabilizer thickness affects circumferential heat diffusion, it is necessary to decide the copper stabilizer thickness considering the thermal condition.

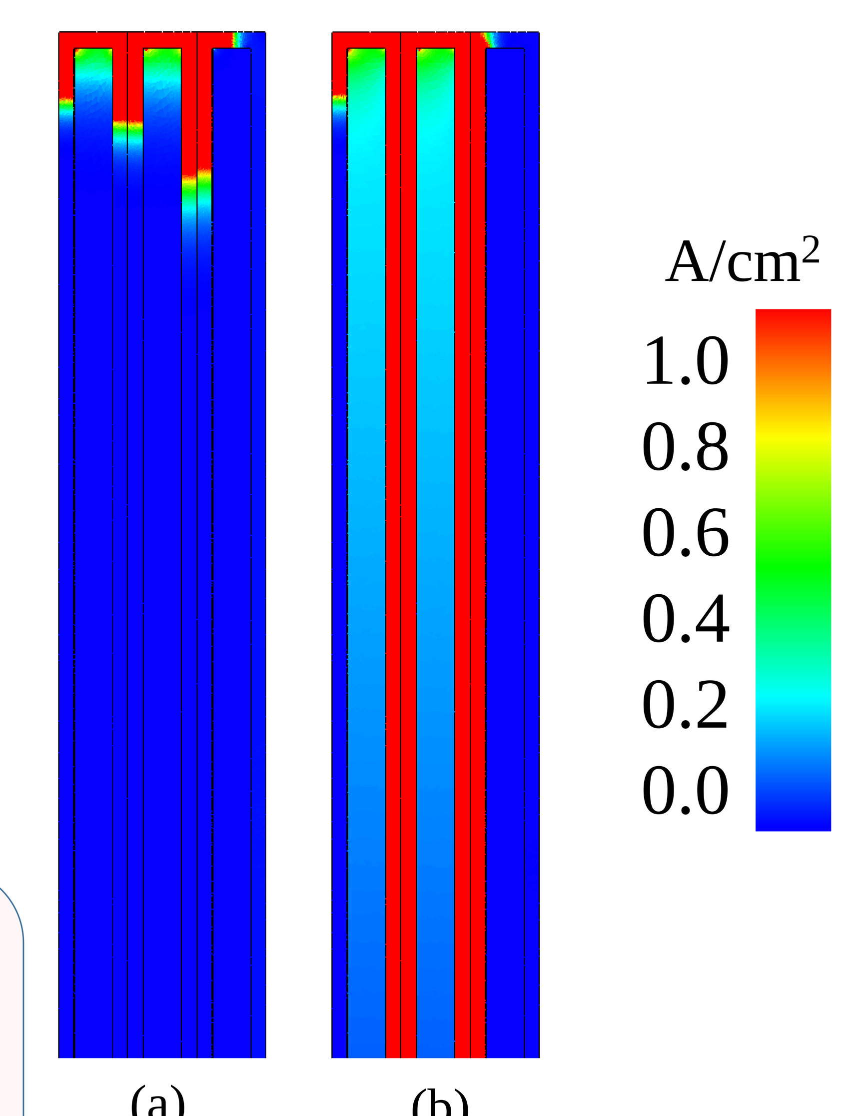

Fig. 9. The current density distribution of the Hastelloy substrate in the 20 μm copper stabilizer thickness when ρ_{ct} are (a) 10^{-4} and (b) 10^2 μΩ·cm²

5. Conclusion

The NI winding technique for REBCO pancake coil is expected for enhancing the thermal stability and the current density in terms of applying to NMR, MRI, and accelerator applications. Therefore, it is necessary to investigate the cross-sectional structure of the REBCO tape feasible for the NI winding technique. In this paper, we showed the bypass current behavior and the joule heat loss through the simulation. When contact resistivity is enough large, coil-radial contact resistivity is dominated by contact resistivity. In addition, in each copper stabilizer thickness, influence them on joule heat is so small. It is possible that copper stabilizer thickness can be attenuated and current density of NI REBCO coil can increase. However, since the copper stabilizer thickness has a function that it resorb and radiate the heat, it is necessary to consider the balance of its thickness and function.

In the future study, we simulate heat conduction in each copper stabilizer thickness to investigate the influence its thickness on resorbing and radiating the heat.