Contact Resistance Dependent Transient Loss of REBCO No-insulation Magnet using T-A formula during Ramping Process

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Abstract

For commercial large-scale magnet systems, the transient loss during the ramping process is an important evaluation metrics for refrigeration requirements, and it is greatly influenced by contact resistance. Due to the intrinsic bypass current of no-insulation pancake, two components of transient loss were considered: turn-to-turn loss generated by radial direction current, and magnetization loss produced by azimuthal direction current. In this study, the turn-distributed model was used to calculate the non-uniform current distribution, where the pancake coil is radially subdivided by each turn. The radial current was employed to calculate the turn-to-turn loss. The turn azimuthal currents were applied to the boundary condition of the *T-A* formula to calculate magnetization loss in the cylindrical coordinate system. In the simulation, the superconductor index value model was used, in which the critical current density is conductor engineering current density estimated by a neural network fitting model. The contact resistance dependent turn-to-turn loss and magnetization loss were concluded in this study. This approach is expected to be used in the magnet-level systems.

Introduction

- No-insulation (NI) winding method for second-generation high temperature superconductor (2G-HTS) coils and its variants.
  - NI technology shows excellent thermal stability and higher current density than traditional insulated counterpart.
  - Some variants occurs to reduce intrinsic delay during charging process, while keep thermal stability and further improve mechanical integrity.
  - Once the magnet has completed its steady-state design, the contact resistance R_{ct} is further to determined to reduce transient losses.
- Non-Uniform ramping loss
  - The equivalent circuit of each turn partial element, each turn or the whole pancake could be modeled by an inductor and a parallel contact resistance during the charging process, which is called partial element equivalent circuit model (PEECC), turn-distributed model [1], and lumped circuit model, separately. Then, the entire magnet can be represented by series connection of the parts.
  - Leakage loss was mainly manifested as Joule heating between turns along the radial direction.
  - Magnetization loss was mainly generated from flux creep and flux jump in the 2G HTS interior by azimuthal current.
- *'Magnet-level'* HTS systems electromagnetic simulation
  - 2G HTS REBCO is tape structure with large aspect ratio and highly nonlinear property.
  - ***T-A*** formula was used to solve *Maxwell's* formulas, where 1° order of ***T*** and 2° of ***A*** elements were employed [2].
- Field-angle critical current estimation
  - A neural network fitting method was employed to fit all of experiment data at magnet operating temperature.
  - Then, the prediction value was substituted into index model to represent conductivity of the superconductor.

Magnet parameters

TABLE Ⅰ
KEY PARAMETERS OF REBCO MAGNET

Tape Parameters		
Conductor		Super Power SCS 4050
Tape width	[mm]	4.0
Tape thickness	[mm]	0.1
HTS layer thickness	[μm]	1
Self field I_c at 77 K	[A]	152
n value		25
Magnet Configurations		
Inner/outer diameter	[mm]	100/118.4
Overall height	[mm]	35.8
Number of DP		4
DP spacer	[mm]	1.0
SP spacer	[mm]	0.2
Operation		
Operating temperature	[K]	20
Operating current at 3 T	[A]	372
Charging speed	[A/s]	1
Inductance	[mH]	66.7

Tape critical current model

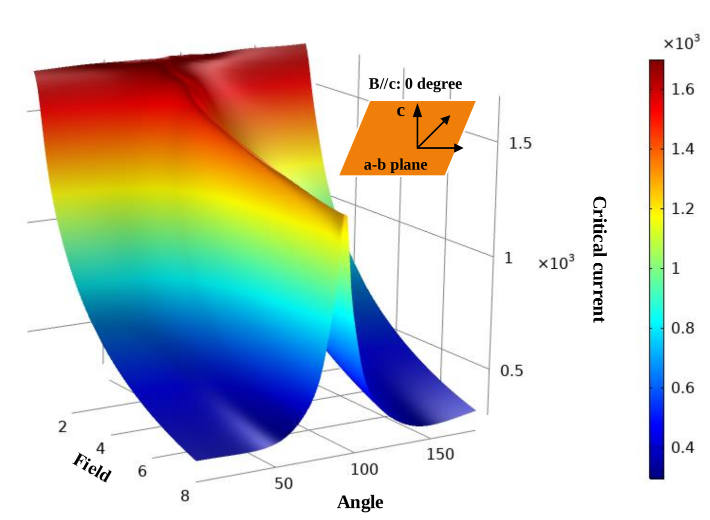

Fig. 1. Tape critical current under different field and angle at 20K by neural network fitting

Changing Delay of R_{ct} = 20 $\mu\Omega\cdot cm^2$

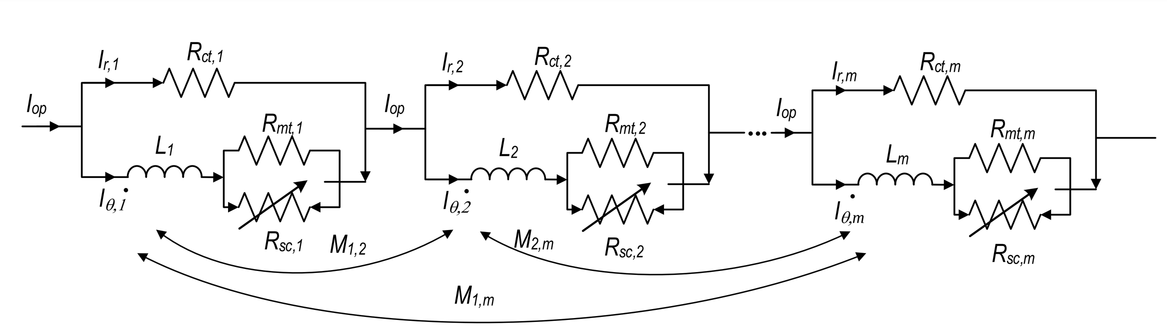

Fig. 2. Equivalent simulation model of the NI REBCO turn-distributed model

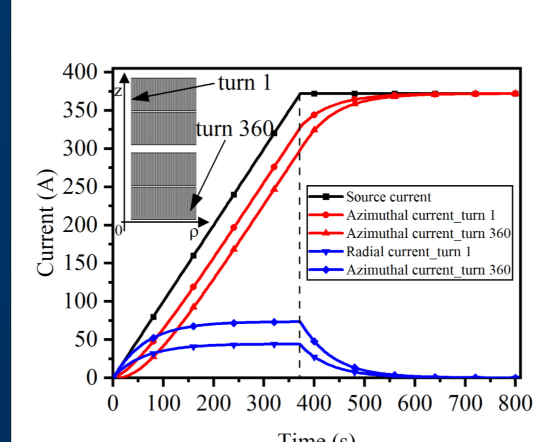

Fig. 3. Calculated result of charging delay between turns and source current

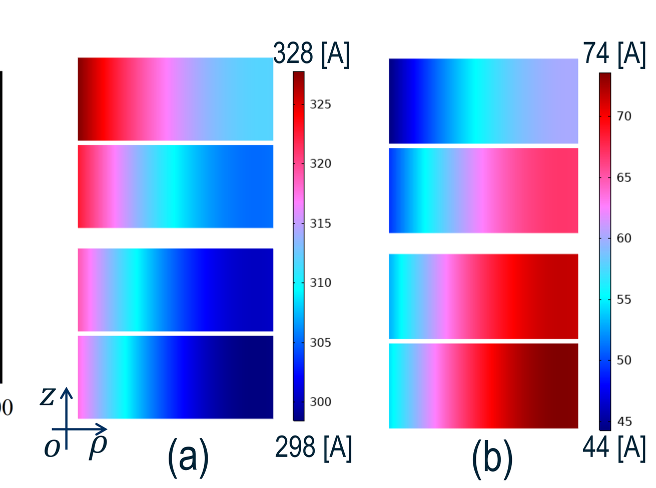

Fig. 4. Non-uniform current distribution of each turn at 372s. (a) azimuthal current; (b) radial current.

Magnetization results of R_{ct} = 20 $\mu\Omega\cdot cm^2$

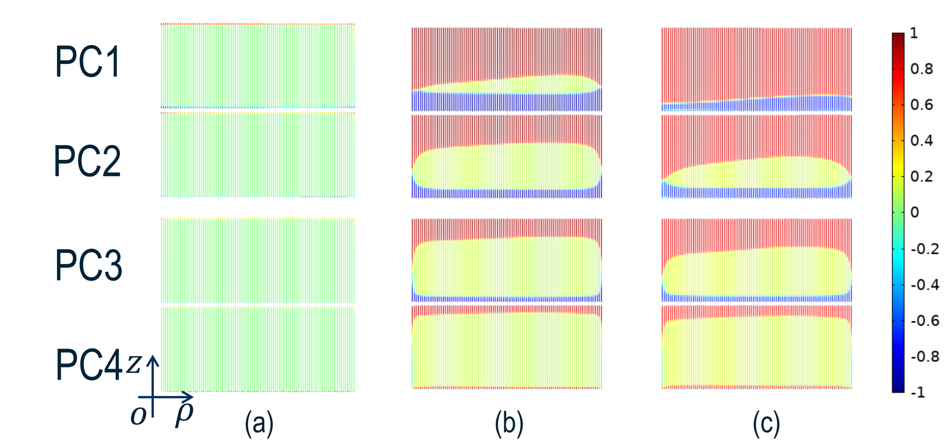

Fig. 5. Normalized current density J/J_c. (a) t = 45 s; (b) t = 372 s; (c) t = 800 s

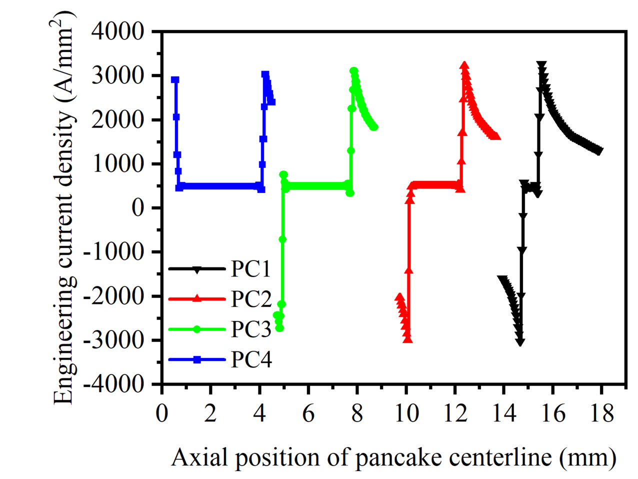

Fig. 6. Current density profiles along the axial direction at the pancake centerline (t = 372s).

Transient loss with different contact resistance

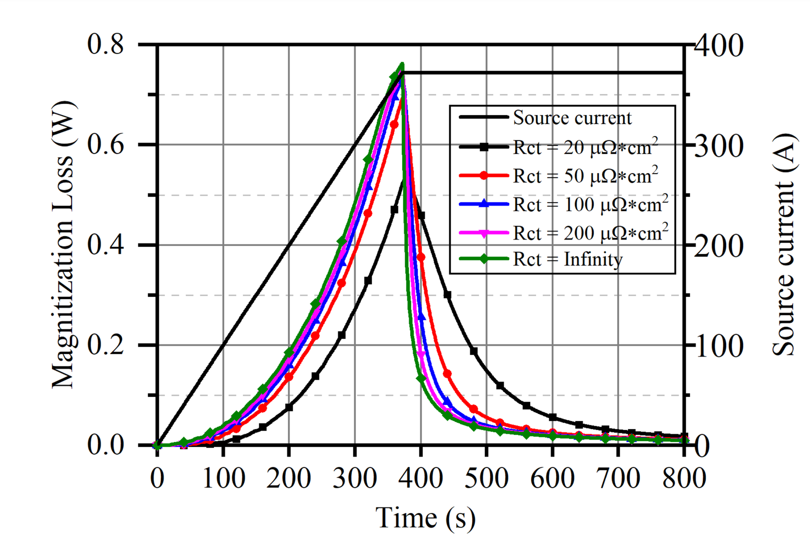

Fig. 7. Simulated results of magnetization loss along time by different contact resistivity. 'R_{ct} = infinity' represents the insulated case. (1) As the contact resistivity decrease, the magnetization speed decreases. (2) When the supply current changes to a constant value, the magnetizing power of the insulated coil starts to decrease, while the non-insulated coil will experience a delaying time before starting to decrease. As the contact resistivity decrease, the delaying time increase. (3) As the contact resistivity decrease, the maximum peak power point also decreases.

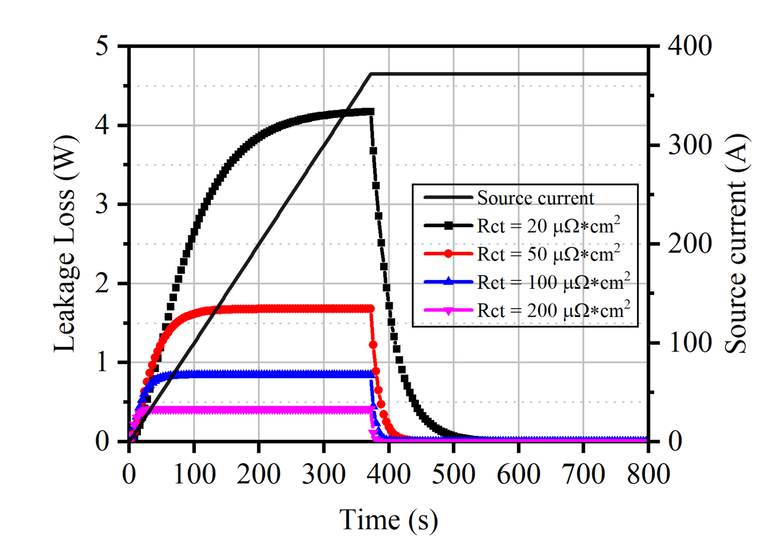

Fig. 8. Simulated results of Leakage loss along time by different contact resistivity. (1) As the contact resistivity decrease, the total leakage loss increase. The Insulated pancake represents no leakage loss. (2) When the supply current changes to a constant value, leakage power starts to decrease.

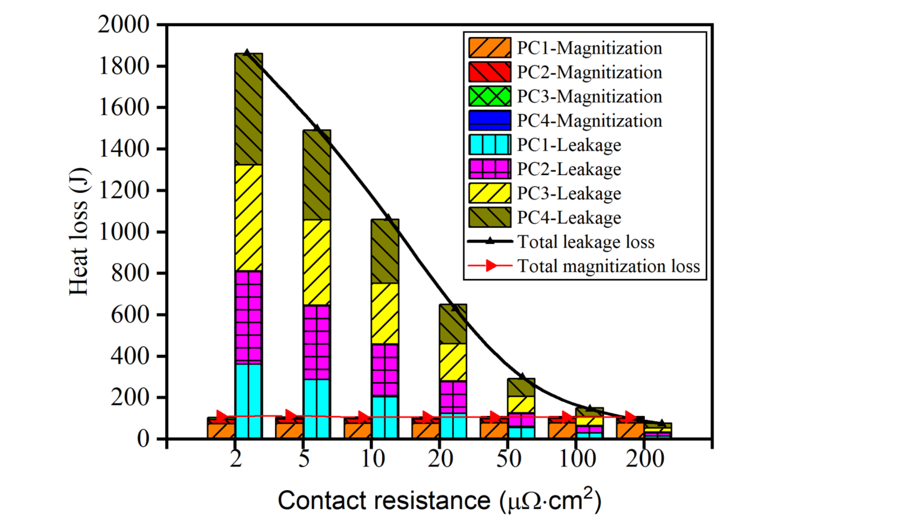

Fig. 9. Simulated results of heat loss on each pancake and total magnet using different contact resistance. (1) As for total magnetization loss, different contact resistance keep the total loss constant. (2) For total leakage loss, it will decrease with increasing contact resistance. (3) For magnetization loss, the upper pancake generates more heat loss than the other pancakes. The middle pancake of the whole magnet is the least. (4) For leakage loss, the upper pancake produce the least heat while the middle pancake of the magnet generate the most heat.

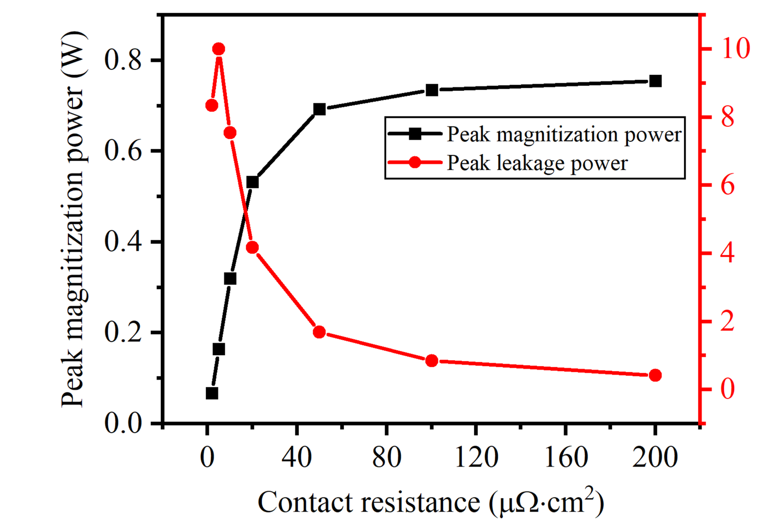

Fig. 10. Simulated results of peak power with different contact resistance. (1) The peak magnetization power increases with increasing contact resistance. Higher contact resistance represents shorter charging time. (2) The peak leakage power increases to a certain value and then decrease as the contact resistance increases. The peak power reaches the maximum when R_{ct} = 5 $m\Omega\cdot cm^2$ in this simulation.

Conclusion

- A non-uniform transient loss simulation model was developed during ramping process by combination the *T-A* method and turn-distributed equivalent circuit model.
- The total magnetization loss and leakage loss was studied, which shows that (a) the total loss decreases with increasing contact resistance; (b) the proportion of magnetization loss in total loss gradually increase as contact resistance increase;
- Combing with thermal stability analyses, the contact resistance would be further studied in the later work.

Reference

[1] W. D. Markiewicz, J. J. Jaroszynski, D. V. Abraimov, R. E. Joyner, and A. Khan, "Quench analysis of pancake wound REBCO coils with low resistance between turns," *Supercon. Sci. Technol.*, vol. 29, no. 2, Dec. 2015, Art. no. 025001.

[2] F. Liang et al., "A finite element model for simulating second generation high temperature superconducting coils/stacks with large number of turns," *Journal of Applied Physics*, vol. 122, no. 4, Jul. 2017, Art. no. 043903.

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