Closed-loop ReBCO Coil Under Varying Magentic Field:

A Study of its Current Distribution and Dynamic Losses

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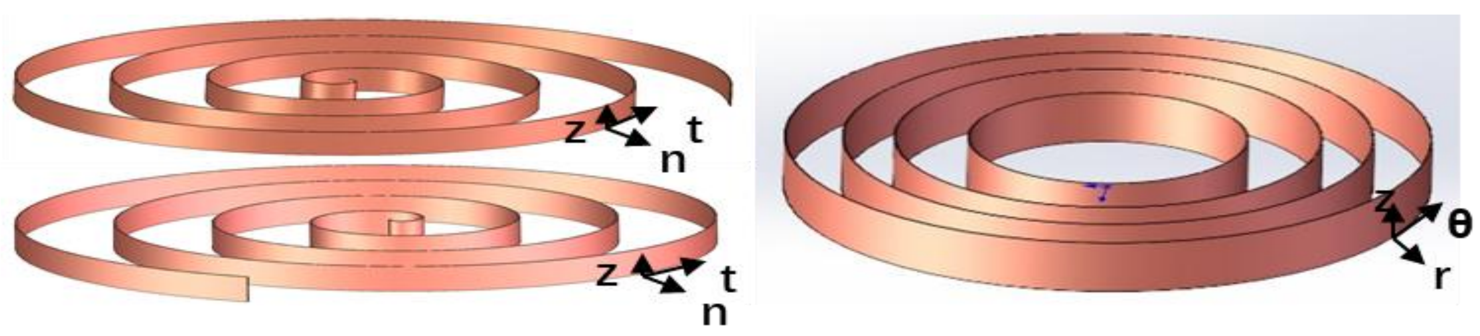
Abstract

In this work, a 2D axisymmetric model was established based on the H-formulation.By coupling electromagnetic and thermal modules, the variation in dynamic losses of the NI closed-loop HTS coil was analyzed when an induced current was generated under a parallel time-varying external magnetic field. The accuracy of the simulation calculations was verified by measuring the coil's temperature rise. Furthermore, the research was extended to the combined structure of insulated (INS) and non-insulated (NI) HTS coils: for this combined structure, the current density distribution and dynamic loss variation of the coil were analyzed, and the dynamic loss characteristics of the coil under complex electromagnetic fields were discussed in detail. This study provides a theoretical basis and technical reference for optimizing the design of HTS coils and reducing their dynamic losses.

Modelling method

Modeling of non-insulated coils:



$$g=\begin{pmatrix}\cos\alpha & -\sin\alpha\\ \sin\alpha & \cos\alpha\end{pmatrix}\ \text{(anticlockwise)}$$

$$g=\begin{pmatrix}\cos\alpha & \sin\alpha\\ \sin\alpha & -\cos\alpha\end{pmatrix}\ \text{(clockwise)}$$

$$\begin{pmatrix}n\\ t\end{pmatrix}=g\cdot\begin{pmatrix}r\\ \varphi\end{pmatrix}$$

$$J_r=-\frac{\partial H_\varphi}{\partial z}\qquad E_r=\rho_{rr}J_r+\rho_{r\varphi}J_\varphi\qquad \mu\frac{\partial H_r}{\partial t}+\left(-\frac{\partial E_\varphi}{\partial z}\right)=0$$

$$J_\varphi=\frac{\partial H_r}{\partial z}-\frac{\partial H_z}{\partial r}\ \Rightarrow\ E_\varphi=\rho_{\varphi r}J_r+\rho_{\varphi\varphi}J_\varphi\ \Rightarrow\ \mu\frac{\partial H_\varphi}{\partial t}+\left(\frac{\partial E_r}{\partial z}-\frac{\partial E_z}{\partial r}\right)=0$$

$$J_z=\frac{1}{r}\frac{\partial(rH_\varphi)}{\partial r}\qquad E_z=\rho_z J_z\qquad \mu\frac{\partial H_z}{\partial t}+\left(\frac{1}{r}\frac{\partial(rE_\varphi)}{\partial r}\right)=0$$

resistivity: $\rho_{sc}=\frac{E_c}{J_c(B,T)}\left|\frac{J}{J_c(B,T)}\right|^{(n-1)}$

dynamic loss: $Q=Q_n+Q_t$

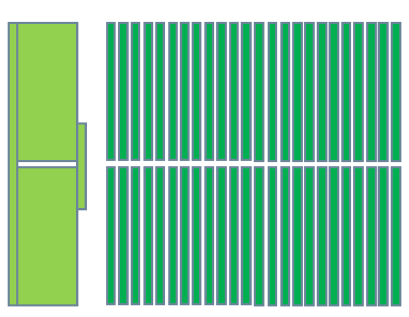
coupling loss: $Q_n=\iiint \rho_n J_n^2\,dv$ hysteresis loss: $Q_t=\iiint \rho_t J_t^2\,dv$

Parameters of HTS coils

Parameters	Value(100mm)	Value(1m)
HTS tape's width(mm)	4	5
HTS tape's thickness(mm)	0.1	0.1
HTS coil's radius(mm)	50	500
I_{c0}@77K(A)	200	200
n	20	20
μ_0(H/m)	$4\pi*10^{-7}$	$4\pi*10^{-7}$
α_0	1.5181	1.5181
β	2.3251	2.3251
Inter-turn resistivity($\Omega\cdot m^2$)	10^{-11}	-

Model of HTS coils

rotating coil:
- Non-insulation
- Simplified modeling

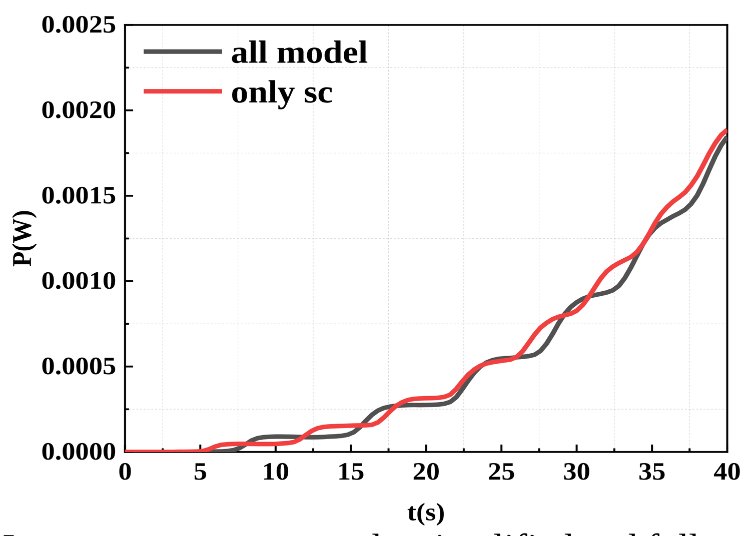


Background coil:
- Insulation
- Independent modeling

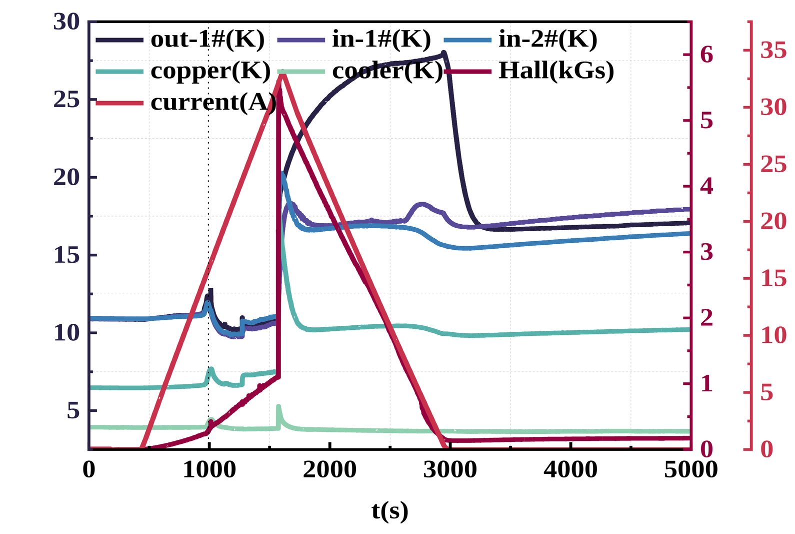
Dynamic loss of 100mm coils

Numerical model:

- Only consider the superconducting layer



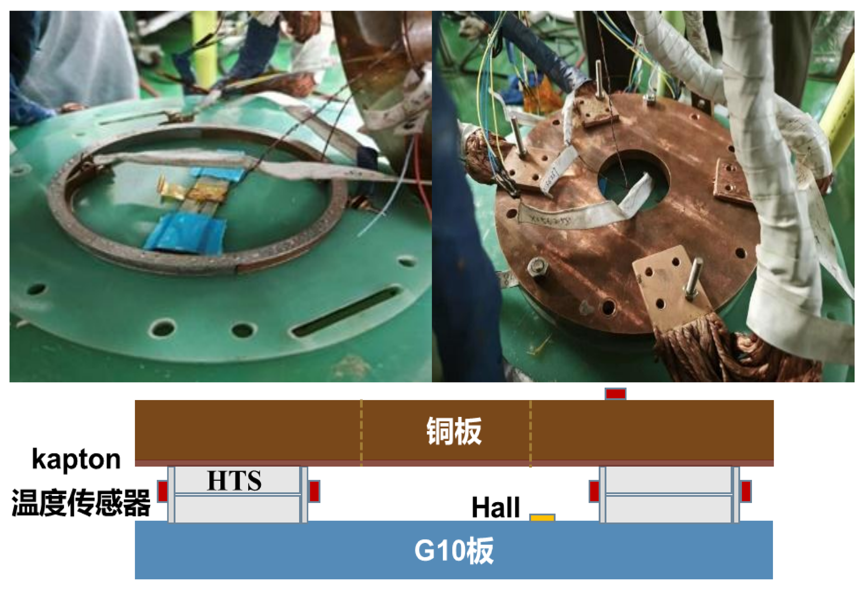
Instantaneous power under simplified and full models



Temperature and shielding magnetic field changes

Experiment:

- Thermal method



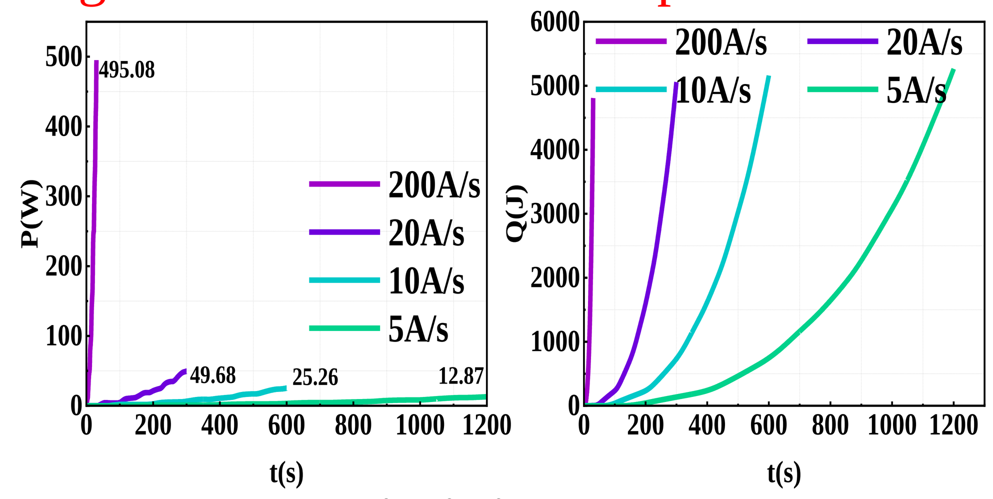
Dynamic loss experiment of rotating coil excitation

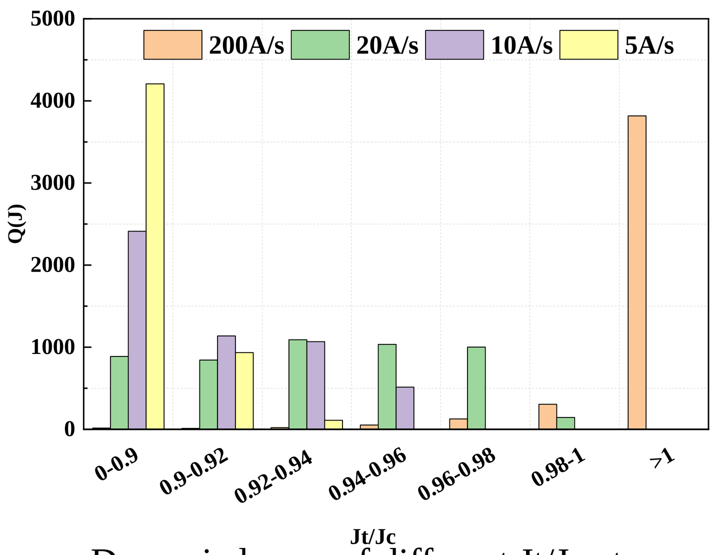
- ➢ The calculation error of the simplified model is less than 5%
- ➢ Rotating coils will generate dynamic losses under changing external fields
- ➢ Dynamic loss causes the coil temperature to rise

Dynamic loss of 1m coils

Excitation rate:

➢ The greater the excitation rate, the greater the instantaneous power

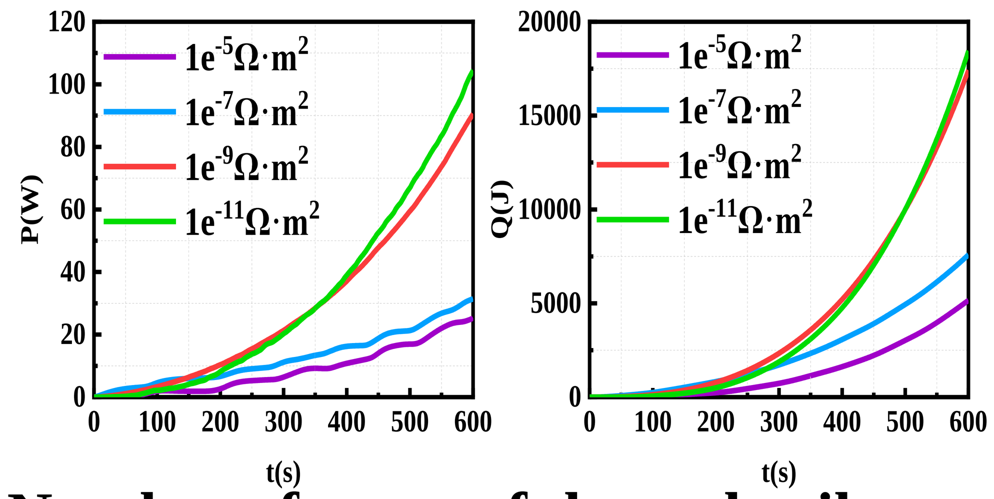


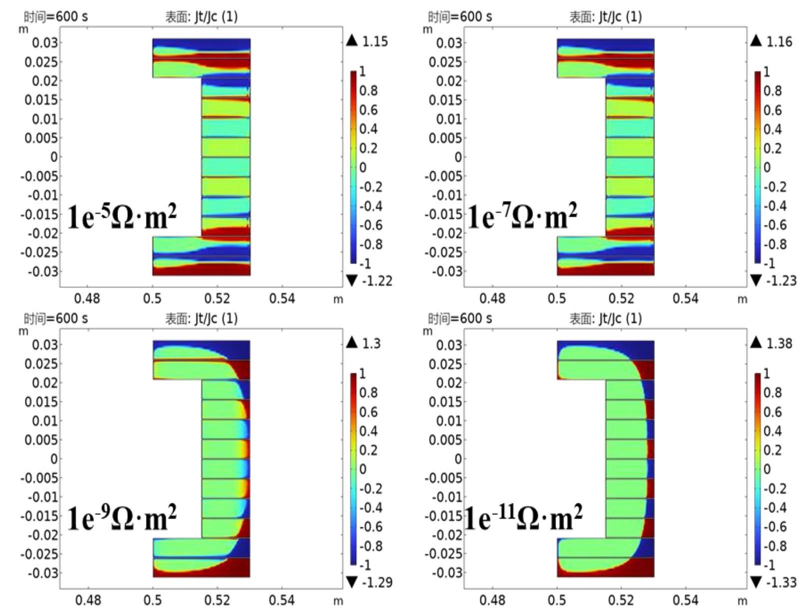


Dynamic losses of different Jt/Jc at different excitation rates

Inter-turn resistivity:

➢ The smaller the inter-turn resistivity, the greater the dynamic loss

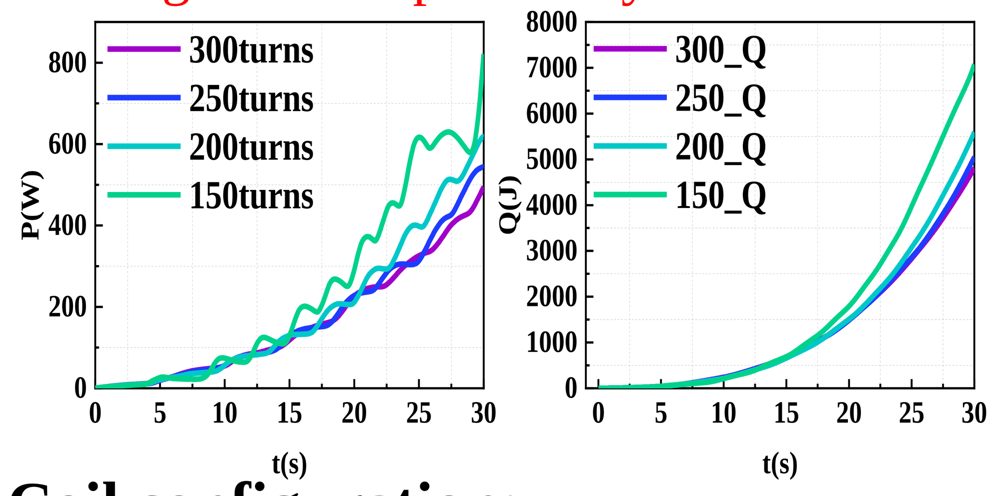


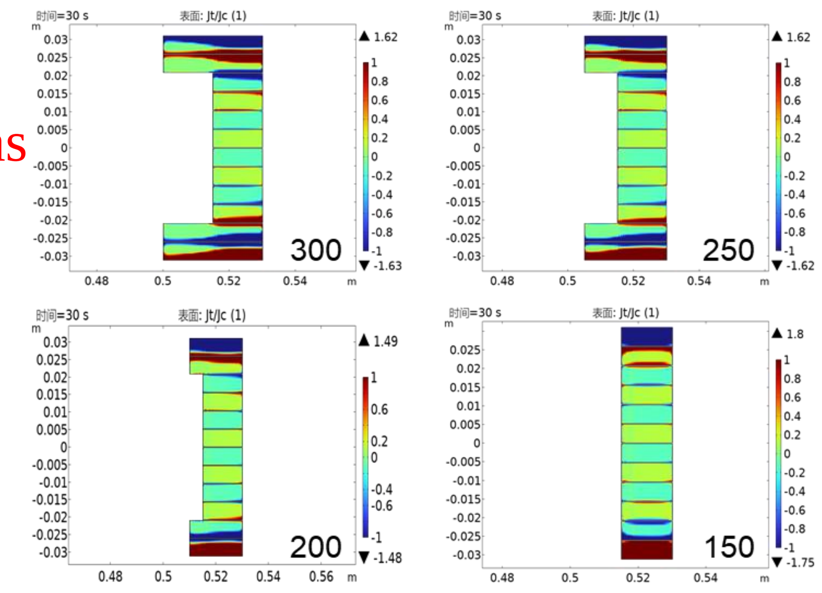


The distribution of Jt/Jc under different Rc0

Number of turns of the end coil:

➢ The number of turns in the end coil has the greatest impact on dynamic loss

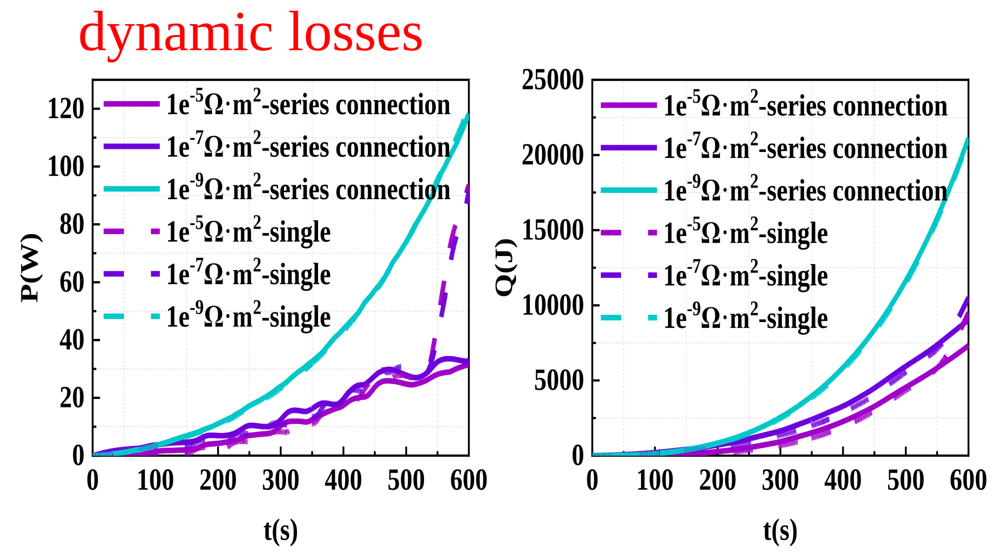




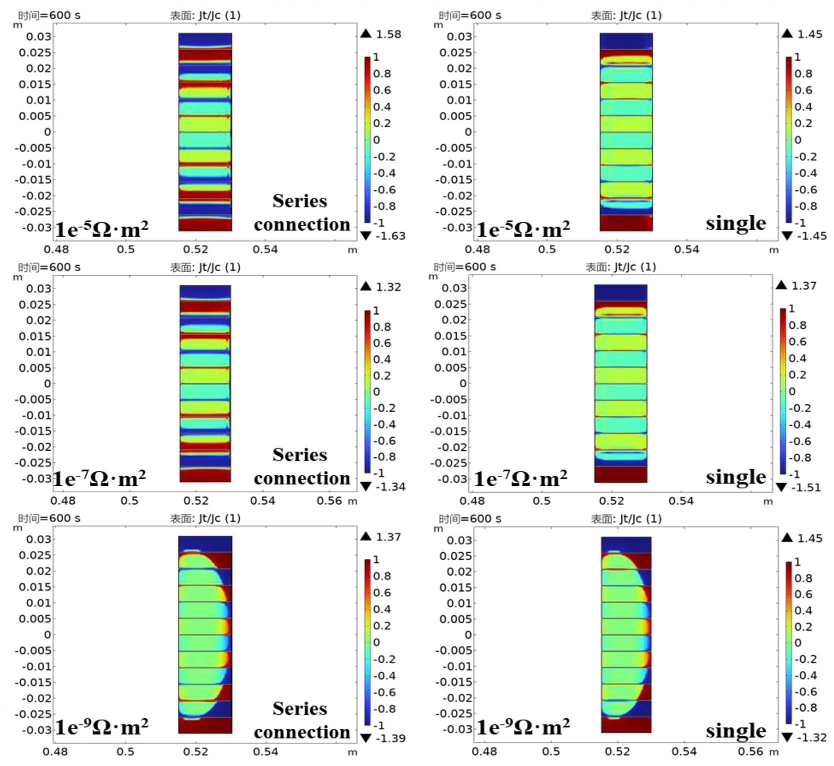
The distribution of Jt/Jc under different turns

Coil configuration:

➢ Series connection of coils can reduce dynamic losses



Instantaneous power and dynamic losses



The distribution of Jt/Jc under different connection methods