Numerical investigation of thermoelastic coupling behaviors of stacks of high temperature superconductor during a quench

Yujin Tong[1,2], Mingzhi Guan[1,2], Wei Wu[2], Xingzhe Wang[1]

[1] Key Laboratory of Mechanics on Disaster and Environment in Western China, College of Civil Engineering and Mechanics, Key Laboratory of Special Function Materials and Structure Design of Ministry of Education, Lanzhou University, Lanzhou, China

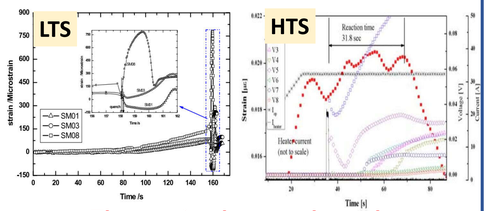
[2] Institute of Modern Physics of Chinese Academy of Science, Lanzhou, China

TUE-PO1-708-06

tongyj@impcas.ac.cn

Introduction

- High temperature superconducting (HTS) materials have been **widely utilized** for fabricating coils and cables applied in high field magnets, rotating machines and fault current limiter etc.
- **Quench detection** is one of the **challengeable problems** for the operation of HTS devices especially for insulted coils and magnets.
- It was found that the **strain/strain-rate** would occur abrupt changes for the quenched HTS tapes and LTS magnets, which can be used to **detect a normal zone**.
- In this work, the thermoelastic coupling behaviors of HTS stacks are numerically investigated and the **internal relations mechanism** between quench and mechanical response are analyzed.



The strain change abruptly during a quench

Model theory

Thermal model

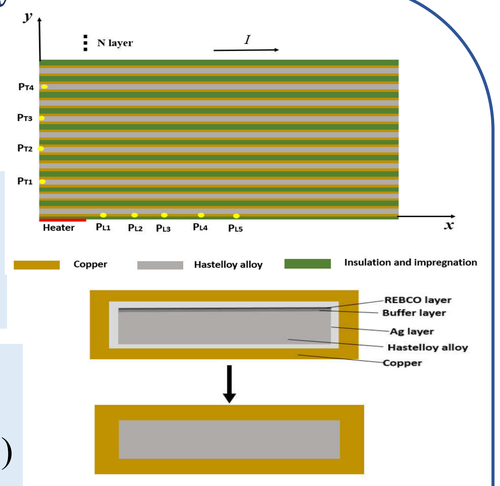
$$\rho c(T)\frac{\partial T}{\partial t} = -\nabla\cdot\mathbf{q} + Q_I + Q_J \qquad Q_J = \frac{1}{\sigma_m}\left(\frac{I_m}{S_{Cu}}\right)^2$$
$$\mathbf{q} = -\mathbf{K}(T,B)\nabla T$$

Current shearing model

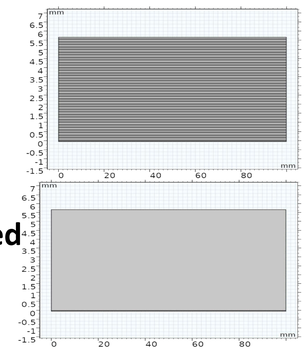
$$I_m = \begin{cases} 0 & (T < T_{cs}) \\ I - I_c(T) & (T_{cs} \le T \le T_c) \\ I & (T > T_c) \end{cases} \qquad I_c = I_{c0}\left(\frac{T_c - T}{T_c - T_0}\right)^n$$

Mechanical model

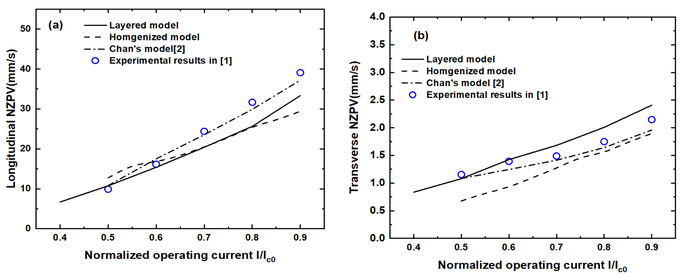
$$\rho\frac{\partial^2 u_i}{\partial t^2} = \sigma_{ij,j} + f_i \qquad \varepsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i})$$
$$\varepsilon_{ij} = S_{ijkl}\sigma_{ij} + \varepsilon_{ij}^{th} = S_{ijkl}\sigma_{ij} + \alpha_{ij}(T - T_r)$$



Layered model ⇑ FEM ⇓ Homogenized model



NZPV (simulations vs experiments)

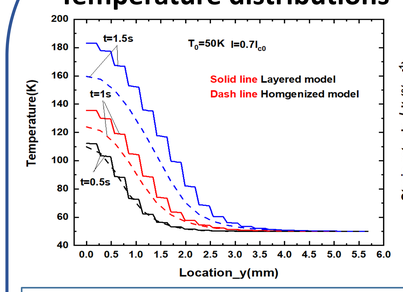


✓ **The present quench model is validated**

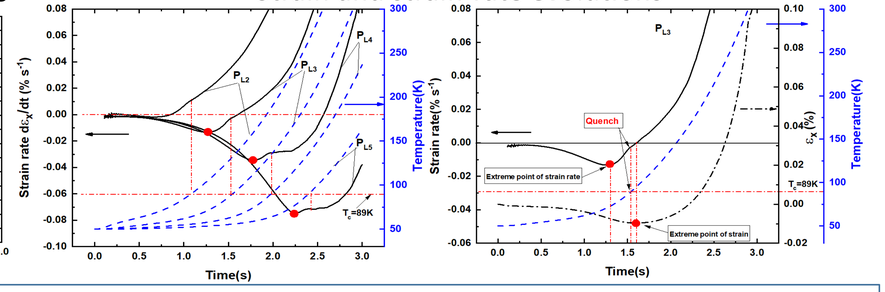
Results and discussion

➢ Thermoelastic behaviors during a quench

Temperature distributions



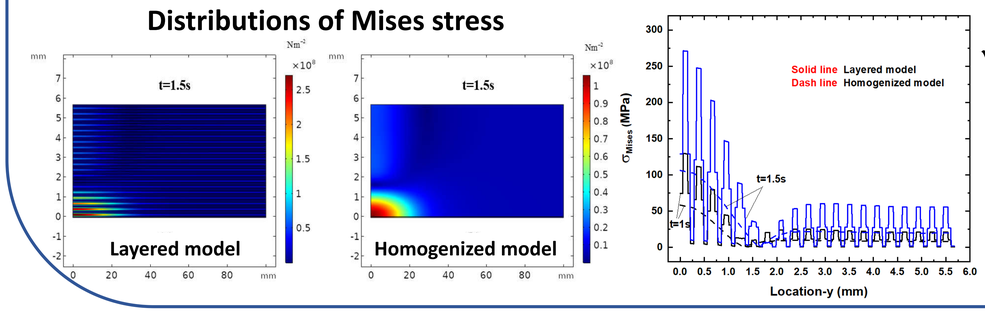
Strain and strain-rate evolutions



- ✓ Turn-to-turn **temperature jumps** are observed in simulations of the **layered model**.
- ✓ The strain and strain rate curves occur **decrease behaviors** with the normal zone propagating.
- ✓ At a location far away the heater (e.g. P_{L3}) , extreme points of strain-rate **appear earlier** than the critical temperature is reached, which might be a more **effective criterion** for quench detection.

➢ Analyses of the stress during a quench

Distributions of Mises stress



- ✓ **Discontinuous distributions** of stress are predicated by a layered model, compared to the homogenized one.

Conclusion

- A thermoelastic coupling **quench model** is developed to analyze the quench behaviors as well as the mechanical responses for HTS stacks during quench propagating process.
- Before a normal zone arrives, the strain and **strain-rate** occur obvious changes with **extreme points**, which could be used to detect a quench earlier for HTS insulated coil.
- The **layered model** can describe more details of the transient response of the stacks during a quench, like **discontinuous distributions** of temperature and stress etc.

References

[1] H. Song, K. Gagnon and J. Schwartz. Superconductor Science and Technology. 2010, 23(6):65021.
[2] W. K. Chan and J. Schwartz. IEEE Transactions on Applied Superconductivity. 2012, 22(5):4706010.
[3] X. Wang, M. Guan and L. Ma. Superconductor Science and Technology. 2012, 25(9):095009
[4] M. Guan, X. Wang, Y.-H. Zhou, et al.. IEEE Transactions on Applied Superconductivity. 2014, 24(3): 4700804.
[5] Y. G. Park, H. C. Jo, J. Lee, et al.. IEEE Transactions on Applied Superconductivity. 2016, 26(3): 4602104.

This work is supported by key project of NSFC (*No. 11932008*) and open project of Key Laboratory of MOE (*No.lzujbky-2021-kb06*)