



**HAL**  
open science

# Mechanical behavior of HTS coils in high field magnets based on the electromechanical coupling

Huadong Yong, Mengdie Niu, Jing Xia, Youhe Zhou

► **To cite this version:**

Huadong Yong, Mengdie Niu, Jing Xia, Youhe Zhou. Mechanical behavior of HTS coils in high field magnets based on the electromechanical coupling. 7th International Workshop on Numerical Modelling of High Temperature Superconductors (HTS 2020), Kévin Berger (Université de Lorraine - GREEN), Jun 2021, Nancy (Virtual), France. hal-03296064

**HAL Id: hal-03296064**

**<https://hal.science/hal-03296064v1>**

Submitted on 22 Jul 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Mechanical behavior of HTS coils in high field magnets based on the electromechanical coupling

Huadong Yong

Key Laboratory of Mechanics on Disaster and Key Laboratory of Mechanics on Disaster and Environment in Western China, Ministry of Education of China, Lanzhou University, Lanzhou, Gansu 730000, PR China  
yonghd@lzu.edu.cn

Youhe Zhou

Key Laboratory of Mechanics on Disaster and Environment in Western China, Ministry of Education of China, Lanzhou University, Lanzhou, Gansu 730000, PR China  
zhouyh@lzu.edu.cn

Mengdie Niu

Key Laboratory of Mechanics on Disaster and Environment in Western China, Ministry of Education of China, Lanzhou University, Lanzhou, Gansu 730000, PR China  
niumd18@lzu.edu.cn

Jing Xia

Institute of Applied Physics and Computational Mathematics, Beijing 100094, People's Republic of China  
power\_xj@163.com

**Abstract**—With the increase of both current-carrying capability and mechanical performance, 2G HTS tape is gradually becoming the dominant materials in the high field magnet. HTS coil co-wound by the REBCO coated conductor and insulated material is the insert coils, while the LTS coils usually provide a high background field. Both LTS coils and HTS coils together contribute to a high central magnetic field to meet the design requirements. However, due to the shielding current effect in coated conductor, the central field contributed by the HTS coils deviates from the design field. Moreover, HTS coils in normal operation would withstand the large electromagnetic force. Under the combined effect of electromagnetic force and thermal strain, the coated conductor may experience a large deformation. Investigations of the electro-mechanical characteristics in REBCO coated conductor is vital as the large strain in superconducting layer would cause the degradation of critical current. Thus, 2D electro-mechanical coupling numerical model is adopted, in which the  $I_c$  degradation caused by the strain is taken into account. The profiles of magnetic field and current density in HTS coils are presented for the cases with and without the electro-mechanical coupling effect. Then, the effect of shielding current on the distributions of magnetic field in HTS coils is discussed. The profiles of stress and strain of HTS coils in high field are calculated. The maximum stresses in the coil for different cases are also analyzed.

**Keywords**—HTS coil, electromechanical coupling, stress, strain

## I. INTRODUCTION

HTS tapes are promising for the applications of superconducting magnet. The HTS coil can be used as the insert coil in high field magnet [1]. The mechanical behavior is of significance in the design and operation of superconducting magnet. Firstly, the interaction of magnetic field and current can generate the Lorentz force. When the HTS coil is subjected to the high Lorentz force, the coil will experience the large mechanical deformation. With the increasing of applied field, the remarkable stress and strain can also affect the superconducting properties. It is well known that the critical current of HTS is strain sensitive [2-4]. Recently, the degradation of critical current has attracted many attentions. Then, the reduction of critical current may change the distribution of magnetic field and current density, which can lead to the variation of central field. During the simulation of the mechanical behavior of HTS coil, the strain sensitivity is usually neglected [5-7]. However, the degradation of critical

current will become more important for the magnet with higher field. Thus, it is vital to consider the electromechanical coupling during the design of superconducting magnet.

## II. BASIC EQUATIONS

Consider a superconducting magnet, which is composed of HTS coil and LTS coil. The HTS coil co-wound by the REBCO coated conductor is the insert coil. The external current is applied in LTS coil to provide the high background field. In order to consider the mechanical behavior in the HTS coil, it is necessary to obtain the magnetic field and current density distribution firstly. The procedure for evaluating the electromagnetic field is described in the following part. The Maxwell's equations are

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad (1)$$

$$\nabla \times \mathbf{H} = \mathbf{J} \quad (2)$$

The Maxwell's equations are solved with the T-A formulation [8]. The magnetic field and current can generate the Lorentz force  $\mathbf{f}$

$$\mathbf{f} = \mathbf{J} \times \mathbf{B} \quad (3)$$

With the Lorentz force, the mechanical equilibrium equation can be given by

$$\sigma_{ij,j} + f_i = 0 \quad (4)$$

During the simulation, the electromechanical coupling is considered. The critical current density is dependent on the magnetic field. However, the stress or strain can lead to the degradation of critical current. Here, the critical current density is given by

$$J_c = J_c(\mathbf{B}, \boldsymbol{\varepsilon}) \quad (5)$$

The above equations can be solved numerically with Comsol Multiphysics software [9] based on the electromechanical coupling effect.

### III. DISCUSSION AND CONCLUSIONS

In this section, several influencing factors including winding tension, the overband and turn-to-turn friction are investigated on the stress and strain state of HTS coils under normal operating conditions. Meanwhile, the effect of those factors on the current carrying capability of local REBCO coated conductor is analyzed. According to the numerical simulation, the  $I_c$  decline induced by local large strain directly affects the distributions of magnetic field and current density in magnets. We also conclude that the stress-strain state analysis of HTS coils is indeed necessary for the correction of deviations in electromagnetic field calculation of magnets. Besides, the overband made of stainless steel strip is found to have a significant impact on suppressing the peak hoop tensile stress in superconducting layers.

#### ACKNOWLEDGMENT

The authors acknowledge the support from the National Natural Science Foundation of China (Grant Nos. 11872195, 11472120, and 11802036).

#### REFERENCES

- [1] H. W. Weijers et al, "Progress in the development and construction of a 32-T superconducting magnet," *IEEE Trans. Appl. Supercond.* vol. 26, 4300807, 2016
- [2] D. C. van der Laan and J. W. Ekin, "Large intrinsic effect of axial strain on the critical current of high-temperature superconductors for electric power applications," *Appl. Phys. Lett.* vol. 90, 052506, 2007
- [3] H-S. Shin and Z. Bautista, "Establishing a test procedure for evaluating the electromechanical properties of practical REBCO coated conductor tapes by the uniaxial tension test at 77K," *Supercond. Sci. Technol.* vol. 32, 064004, 2019.
- [4] K. Osamura, S. Machiya, and D. P. Hampshire, "Mechanism for the uniaxial strain dependence of the critical current in practical REBCO tapes," *Supercond. Sci. Technol.* vol. 29, 065019, 2016
- [5] J. Xia, H. Bai, H. D. Yong, H. W. Weijers, T. A. Painter, and M. D. Bird, "Stress and strain analysis of a REBCO high field coil based on the distribution of shielding current," *Supercond. Sci. Technol.* vol. 32, 095005, 2019
- [6] D. Liu, W. Zhang, H. Yong, and Y. Zhou, "Thermal stability and mechanical behavior in no-insulation high-temperature superconducting pancake coils," *Supercond. Sci. Technol.* vol. 31, 085010, 2018
- [7] Y. Li et al, "Magnetization and screening current in an 800 MHz (18.8 T) REBCO nuclear magnetic resonance insert magnet: experimental results and numerical analysis," *Supercond. Sci. Technol.* vol. 32, 105007, 2019
- [8] H. Zhang, M. Zhang, and W. Yuan, "An efficient 3D finite element method model based on the T-A formulation for superconducting coated conductors," *Supercond. Sci. Technol.* vol. 30, 024005, 2017
- [9] <https://cn.comsol.com/>