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

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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 Ic 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 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 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 electromagnetic field is described in the following part. The Maxwell's equations are

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \tag{1}$$

$$\nabla \times \mathbf{H} = \mathbf{J} \tag{2}$$

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

$$\mathbf{f} = \mathbf{J} \times \mathbf{B} \tag{3}$$

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

$$\sigma_{ij,\ j} + f_i = 0 \tag{4}$$

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

$$J_c = J_c\left(\mathbf{B}, \boldsymbol{\varepsilon}\right) \tag{5}$$

The above equations can be solve numerically with Comsol Multiphysics software [9] based on the electromagnetic 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 Ic 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.

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