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A complete, coupled model for Electro-Magnetic, Electro-Thermal and Mechanical analysis for axi-symmetric coils using variational principles

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High-field REBCO magnets contain several pancake coils with many turns, which are vulnerable to high stress and strain due to the large background magnetic fields. In addition, screening currents substantially increase the stress. Electro-thermal quench is another issue which is required to be taken into account while designing a high field magnet. Thus, there is a need for fast and accurate software to numerically model the overall performance of full-scale magnets. High temperature superconducting coils can be modeled using different Finite Element Method (FEM) techniques for the electro-magnetic (such as H-formulation or A-V formulation), thermal, and mechanical analysis. However, it takes a lot of time to model the electro-magnetic, electro-thermal, and mechanical behavior of superconductors simultaneously in a commercial software. We have developed a novel and fast model programmed in C++, which performs coupled electro-magnetic, electro-thermal, and mechanical analysis, using variational methods based on Minimum Entropy Production [Minimum Electro-Magnetic Entropy Production (MEMEP), Minimum Electro-Thermal Entropy Production (METEP), and Minimum Mechanical Entropy Production (MMEP), respectively]. The models are applied to the case of an axi-symmetric coil for transient design (thermal quench reliability and mechanical strength), taking screening currents into account. The electro-magnetic formulation has been benchmarked with H-Formulation in our previous works. The electro-thermal model in our software, using METEP, is benchmarked with a Finite-Difference method. The mechanical model assumes the material as isotropic for initial simplicity, with the ability to extend the scope to consider the orthotropic nature of superconductors. The model developed can be used for a quick and complete electro-magnetic, electro-thermal, and mechanical analysis of practical superconducting applications such as coils for high field magnets or fault current limiters.

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