Dynamic Evolution of Multi-Physics-Dependent Non-Uniform Inter-Turn Contact Resistivity in No-Insulation REBCO Magnets: Modeling and Experimental Validation

Magnetic confinement fusion has led to the remarkable development of high temperature superconducting magnet technology. No-insulation REBCO magnets have important application prospects in the field of high-field magnets due to their high critical current density and excellent electromagnetic properties. However, the influence of multi-physics field-dependent inter-turn contact resistivity (such as stress and temperature) on magnet performance has not been sufficiently studied. It leads to substantial deviations in traditional analytical models during practical applications. This study focuses on the no-insulation REBCO superconducting magnet, systematically investigating the dynamic evolution laws of non-uniform inter-turn contact resistivity under multi-physics field coupling (electromagnetic, thermal, mechanical), and elucidating its impact mechanisms on magnet performance. A modified model for non-uniform inter-turn contact resistivity considering multi-physics field dependence based on the weak form of the T-A formula is proposed. This model can simulate the radial shunt characteristics and the dynamic non-uniform inter-turn contact resistance of no-insulation coils during magnetic flux changes and its impact on the magnetic field, thermal properties, and mechanical behavior. The model was verified in the experiment of 32.4T REBCO high field magnet for the first time and revealed the relationship and influence of multiple physical field parameters (electromagnetic force and temperature rise) and the inter-turn contact resistance. The model simulates the no-insulation REBCO magnet during the discharge process, where the coil turns separate, resulting in a large inter-turn contact resistance and a short time constant, similar to experimental measurement results. The model has important application value in the analysis of electromagnetic characteristics, thermal stability, and quench propagation of no-insulation REBCO magnets.