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Sat-Mo-Po.03-04: Electromagnetic and mechanical analyses of an explorative HTS-based central solenoid for the DTT Tokamak

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This work investigates the potential advantages of using a High-Temperature Superconducting (HTS) Central Solenoid (CS) in the Divertor Tokamak Test (DTT), an Italian nuclear fusion project based in Frascati, Italy, aiming to complete its engineering design phase by 2025 and construction by 2031. To sustain sufficiently long plasma discharges, the project requires a high-performing CS capable of partially balancing resistive and inductive losses through the poloidal magnetic flux it induces. The objective of this study is to quantify the improvements in induced poloidal magnetic flux achievable with a ReBCO VIPER-like HTS-CS, instead of the Low-Temperature Superconducting (LTS) configuration currently proposed.

The analysis evaluates the electromagnetic and mechanical performances of a conceptual HTS-based CS. The design optimizes the cable layout and turn distribution to ensure manageable conductor currents while avoiding excessive mechanical and thermal loads. Electromagnetic simulations, based on two-dimensional axisymmetric static plasma equilibrium models, are developed achieving a gain in terms of poloidal magnetic flux, enabling longer plasma discharges.

The mechanical behaviour of the CS is assessed through a preliminary equivalent elastic model derived by homogenizing detailed conductor components, including copper/ReBCO sections, cooling channels, stainless steel jackets, and insulation. A subsequent mechanical analysis of the equivalent CS stack identifies the most stressed module under Lorentz forces and precompression, allowing an accurate evaluation of displacements and stresses by incorporating orthotropic insulation properties and contact interfaces. These results confirm compliance with ITER mechanical standards and validate the structural reliability of the HTS-CS under operational conditions.

Thermal performance of the conductors is optimized by refining the copper cross-section of the ReBCO VIPER-like conductors through a power balance model, which accounts for Joule heating and thermal dissipation. Hotspot temperature simulations for quench prediction, considering the thermal and electrical properties of the materials, demonstrate rapid stabilization and efficient heat dissipation, ensuring the system's safety and reliability during transient events.

This integrated analysis suggests that HTS technology could offer advantages in terms of electromechanical performances and thermal stability, highlighting the potential of HTS-based configurations for high-field tokamak applications, and potentially contributing to the development of more efficient and resilient fusion devices.

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