Contribution ID: **12** Type: **not specified**

Modelling the thermo-hydraulic response of ITER TF coils under representative fast-discharge scenarios in the Magnet Cold Test Facility

The 18 Nb_3Sn toroidal field (TF) coils of ITER, based on cable-in-conduit conductors (CICC) cooled by forced-flow supercritical helium, provide a peak field of 11.8 T at the plasma and store about 41 GJ of magnetic energy, making controlled fast discharge a key aspect of the magnet protection strategy (Ref [1]). To support commissioning and ensure reliable integration into the machine, selected TF coils and PF1 will undergo full-scale cold tests in the ITER Magnet Cold Test Facility (MCTF), where the main objectives are to validate electrical, thermal and mechanical performance of the coils –together with their protection and insulation systems - under operational vacuum and cryogenic conditions, at currents up to the nominal 68 kA for TF coil (Ref [2]). In this context, numerical modelling is essential to complement the diagnostics and support the definition of robust and efficient test procedures. Previous analyses have addressed fast discharge and quench behaviour of ITER TF coils at system (Ref [3]) and conductor level (Ref [4]) during plasma operation. However, published studies specific to the MCTF configuration remain scarce, despite their relevance for anticipating key transients and guiding test campaigns.

This work presents a set of electro-thermo-hydraulic analyses performed with the CryoSoft suite code (Ref [5], Ref [6]) on a detailed model of the ITER TF coil in the MCTF configuration. Two fast-discharge scenarios are discussed: (i) 34 kA with a 60 s decay, a time-constant-relevant case selected to limit the inter-terminals voltages (200 V); and (ii) 68 kA with a 5 s decay, the nominal-current discharge, that is identified as the ITER voltage-relevant scenario (4.1 kV) and generates significant eddy-current losses in the TF radial plates (~32 MJ) and case (~40 MJ). For both cases, the analysis resolves the coupled thermo-hydraulic behaviour of TF winding pack and TF case, including the forced-flow cooling of the CICC, the TF case-cooling loop and their mutual heat transfer. This integrated approach provides the transient temperature distribution in the pancakes, together with the evolution of helium pressure, mass-flow rate and energy deposition in the conductor and TF casing, allowing the identification of phases where thermal margins are reduced and providing temperature, pressure and voltage signatures for comparison with facility measurements. Altogether, these insights consolidate the physical picture of fast-discharge transients in the MCTF configuration, providing a robust basis for the preparation and interpretation of the test facility tests.

Ref [1] Neil Mitchell et al 2021 Supercond. Sci. Technol. 34 103001
Ref [2] Barabaschi et al., Fusion Engineering and Design 215 (2025) 114990
Ref [3] Fink et al., Fusion Engineering and Design, 75–79 (2005) 135-138
Ref [4] L. Bottura, Journal of Computational Physics, 125 (1), 26–41, 1996
Ref [5] L. Bottura et al., Cryogenics, 40 (8–10), 617–626 (2000)
Ref [6] https://htess.com/cryosoft/

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