Multi-scale Approach to the Thermal--hydraulic Modelling of the ITER Superconducting Magnets

Roberto Zanino, Senior Member, IEEE, and Laura Savoldi Richard

Abstract - Superconducting (SC) magnets for ITER require the forced flow of supercritical He at ~ 4.5 K and ~ 0.5 MPa giving thermal-hydraulics (TH) a key role in the multi-physics arena of SC magnets. Here we introduce a multi-scale approach to the problems of ITER magnets TH modelling taking, into account that the TH relevant space scales range from the 10-100 of magnet size/Cable-In-Conduit Conductor (CICC) length, down to the 10^{-2} m of the transverse size of a CICC, while the relevant TH time scales also cover several orders of magnitude. On the "macro-scale", the entire system (winding + structures + cryogenic circuit) is considered; this requires the treat "meso-scale", where single CICC are treated, weakly thermally coupled inside a winding as needed. The constitutive relations needed by the 1D meso-scale models, i.e., friction factors and heat transfer coefficients, may in turn be derived analyzing a limited portion of the CICC on the "micro-scale", with detailed 2D-3D Computational thermal-Fluid-Dynamics (CtFD) models. At each scale, different issues related to code development, benchmarking/validation and application considered in the paper. The choice of developing a code in-house is compared to the commercial codes and/or freeware. The reciprocal benefits obtained from these codes' magnet R&D program (which led, e.g., to the realization and test of Model and Insert coils, as well as many short samples), vice versa, are discussed. Several examples of the multi-scale approach to the TH modelling of superconducting (SC) magnets will be presented in the paper, based on the experience developed during the last 15 years within our group, in collaboration with laboratories in the EU, Japan, Russia, South Korea, and the US, It is argued that the intrinsic modularity of the multiapproach leads to significant benefits. It is also argued that the effort towards verification & validation of the existing TH models of the ITER SC magnets has been rather limited so far, sometimes notwithstanding the existence of a significant experimental database; therefore, it is recommended to launch a systematic initiative in that direction in the next future with particular attention to the assessment of the of the *predictive* capabilities of the existing TH codes. These capabilities are going to be more and more relevant for the ITER nuclear device, for operation and safety studies in particular, but at this time there is hardly any evidence on these capabilities in the published literature.

Keywords - ITER, superconducting magnets, thermalhydraulics, computational modeling.

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