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Research paper

Modelization of the thermal coupling between the ITER TF coil conductor and the structure cooling circuit

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ABSTRACT

The ITER Toroidal Field (TF) coils are required not to quench during the most demanding event: a plasma disruption followed by a fast discharge of the Central Solenoid (CS), the Poloidal Field (PF) coils and the Correction Coils (CC). This event creates large heat deposition in the ITER magnet stainless steel structures in addition to the conductor AC losses. In order to prevent quench occurring in the TF conductor, cooling channels, implemented in the TF coil structure (TFCS), have to remove a large fraction of the heat deposited. The first integrated TF and structure mock-up has been manufactured and then tested in the HELIOS cryogenic test facility (CEA Grenoble) to determine the thermal coupling between the TFCS and the TF conductor, both actively cooled by supercritical helium at 4.4 K and 5 bar. It consists in a stainless steel casing, a cooling pipe glued with resin in the casing groove, winding pack (WP) ground insulation, a radial plate and a copper dummy cable-in-conduit-conductor (CICC). Steady state as well as transient thermal characterizations have been completed in May 2015. Simulation results by thermal hydraulic codes (VENECIA/SuperMagnet) and some of the experimental data are presented and discussed. The thermal coupling between the helium in the cooling tube and the TF coil structure is then modelled as an equivalent heat transfer coefficient in order to simplify the thermal hydraulic (TH) models. Comparison between simplified coupling and detailed coupling is presented.

1. Introduction

The ITER magnet system is composed of four different types of superconducting magnets: the Central Solenoid (CS), the Poloidal Field (PF) coils, the Correction Coils (CC) and the Toroidal Field Coils (TFC) (Fig. 1). These magnets are cooled by supercritical helium (SHe) in four independent loops (Fig. 2): the CS cooling loop, the PF coils and CC cooled in parallel in a second loop, the TFC in the third loop and the structure (STR) loop as the fourth cooling loop. The STR loop cools various stainless steel structures such as the TFC case, the PF supports, the CC supports or the CS structures. The TFC and the STR cooling loops are independent from the hydraulic point of view but since the TFC and its mechanical structure (case) are in contact, they are thermally coupled through different material layers such as gap filler (11 mm), WP ground insulation (6 mm), and radial plate.

One of the technical requirements of the ITER Project Requirements (PR) document [1] specifies that after a plasma disruption, the fast discharge of the PF coils, the CS and CC shall not trigger the fast discharge of the TFC. The TFC discharge is triggered if a conductor quench is detected. To avoid initiating a quench on the TFC conductor, the heat to the TFC cable has to be limited. Plasma wall cooling designed for cool down and to control the heat exchange from the case to the winding pack (WP) by limiting the case temperature at the interface. A set of 74 cooling pipes (40 in the inboard leg, 34 in the outboard leg), implemented at the inner surface of each TFC structure (Fig. 3) limits the heat transfer from the TFC casing to the TFC conductor. The density of pipe is higher at the plasma facing wall to better protect the TF conductor at high field.

In the present design, the cooling pipe is glued by a high thermal conductivity resin (0.15 W/(m K) at 4 K) into rectangular groove machined in the TF case [2] (see Fig. 4).

The cooling efficiency of the retained design has to match with the thermal requirements during operation, i.e. after coil manufacturing, assembly, cool down and electromagnetic loads. The thermal performance of the investigated solution should be maintained under mechanical loads. Mechanical study of this design is not part of this paper.

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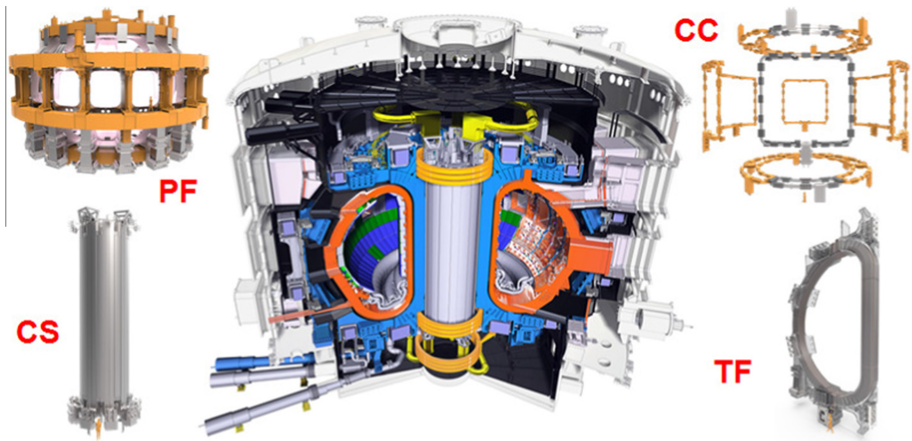

Fig. 1. ITER magnets.

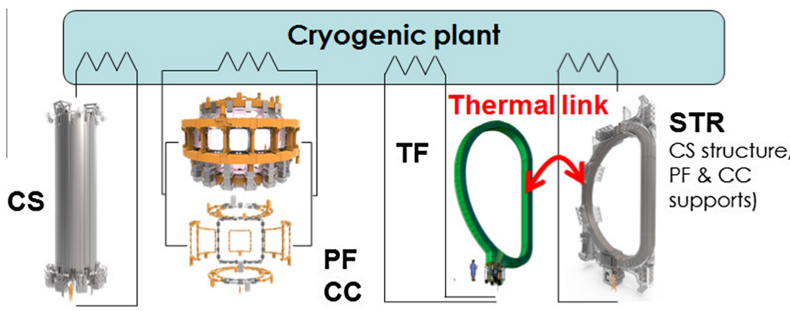

Fig. 2. Magnet cooling loops.

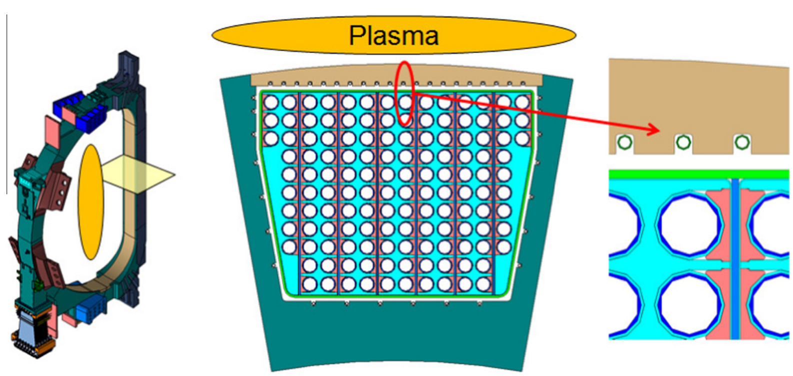

Fig. 3. Thermal coupling between TFC case and TFC CICC.

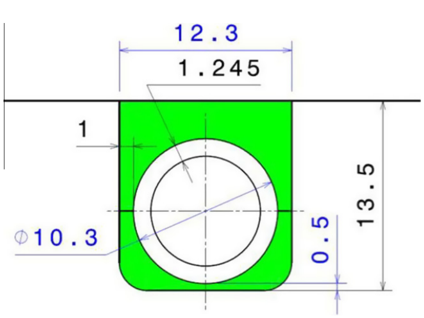

Fig. 4. Investigated cooling pipe design.

The thermal coupling issue between the two cryogenic loops, i.e. TFC WP and STR, was first addressed with the TFMC test experiment [3]. The experimental results (discharge of the TFMC) were best fitted using a degraded thermal conductivity (fiber glass thermal conductivity divided by 6).

Previous TH analyses [4] have been carried out with complex model (VENECIA [5]) in which details of the cooling pipe design are not included. The thermal coupling between the helium channel and the TFC structure case is modelled by an equivalent heat transfer coefficient (heq).

As the thermal coupling between the STR cooling circuit and the TFC has some impact on the TFC conductor temperature, the validation of the global model is based on a two steps process: