Thermohydraulic Analyses on CEA Concept of TF and CS Coils for EU-DEMO

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In the framework of the European fusion program for energy, EUROfusion funds the studies for the future fusion power demonstrator reactor DEMO. CEA is involved in the conceptual design of the superconducting conductors for the Toroidal Field (TF) and Central Solenoid (CS) magnets. The CEA design proposal corresponds to Wind and React Nb3Sn pancake-wound coils using Cable-In-Conduit Conductors (CICCs) cooled at about 4.5 K by forced flow of supercritical helium.

Objectives

- Thermal-hydraulic analyses performed on TF and CS conductors.
- Two TF conductor designs have been analyzed, with nominal current of 111 kA and 88 kA respectively in normal (burn) and off-normal (quench) conditions.
  - Burn simulations: aim at assessing the temperature margin (ΔTma) - Focused on the central and lateral pancakes with a head load corresponding to neutron heating.
  - Quench studies consider a quench initiated either on the innermost turn or at the middle of hydraulic length with the aim to assess the hot spot temperature (maximal jacket temperature).
- CS WP Results on
  - Magnetic field distribution along 88 and 111 kA CW median conductors.
  - Thermal-hydraulic: 1D THEA model
  - Magnetic field maps: TRAPS code
  - Thermal-hydraulic: 1D THEA model

Background

- The conductor is made out of 659 strands CSJA6 strands and 596 pure Cu strands, of 0.83 mm diameter.
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Toroidal Field Conductor (TF)

- ΔTma – sensitivity to AC losses
- ΔTma vs. sensitivity to dwell duration
- ΔTma along CS1 median conductor

Central Solenoid Conductor (CS)

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Conclusions

CEA proposed conceptual designs for EU-DEMO TF and CS conductors, based on Nb3Sn strands and inspired from ITER magnets. thermo-hydraulic analyses focused on normal (burn) and off-normal (quench) scenarios for TF conductor, and on normal scenario for CS conductor. Two TF conductor designs (111 kA and 88 kA) were studied, focusing on ΔTma and Tdwell criteria assessment in burn and quench scenarios respectively. The hot spot criterion was satisfied for all cases except when it was initiated at middle of conductor, and when the quench detection was simulated with the aim to reduce the voltage threshold from 0.5 V to 0.35 V. For the CS conductor, analyses focused on the ΔTma sensitivity to AC losses and to dwell duration, showing the dominant impact of coupling losses and the relevance of the 10 minutes proposal for dwell duration.

Thermal-hydraulic: 1D THEA model
Thermal model: 2D Cast3M
Magnetic field maps: TRAPS code

TF Quench scenarios

(Heat spot Temperature criterion: Tmax jacket < 150 K)

The current decay during the fast safety discharge (FSD) took into account the discharge resistance heating.

Main TF quench results

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<tr>
<th>TF &amp; CS Burn scenario</th>
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<tr>
<td>ΔTma criterion (Tc(Tc-Tpu)) &gt; 1.5 K</td>
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<tr>
<td>Ref. scenario 88 kA – casing cooling channels (CICCs) influence. ΔTma at critical location (x=32 m from helium inlet) for CW median and lateral pancakes.</td>
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<th>TF Results</th>
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<td>For CW median pancake, CICCs allow to increase the ΔTma by 0.18 K (88 kA) and 0.20 K (111 kA).</td>
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