Modelling Superconductor AC Losses In The STEP TF Magnet During Plasma Initiation.

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Abstract

The AC losses that superconducting magnet systems experience during transient events are an important design consideration in fusion reactors. We present results on the approach for calculating AC losses in the high temperature superconducting (HTS) toroidal field (TF) magnets of the Spherical Tokamak for Energy Production (STEP) tokamak.

We focus on the transient electromagnetic response of the centre (TF) column to the charging and discharging of the central solenoid (CS) and poloidal field (PF) magnets during a plasma initiation scenario. The AC losses in the TF column vary both in space and time. This is a consequence of the magnetic field from the CS and PF, which also varies in space (due to coil geometry) and time (due to ramping).

To accurately capture this 3D effect, a quasi-2.5D method is employed. This greatly simplifies modelling, as well as being computationally advantageous. This approach is valid if the coupling losses are negligible, which is shown by using an analytical approach. The quasi-2.5D method works by modelling superconductivity in representative 2D slices at discrete heights of the TF column. The background field of the CS and PF magnets is modelled separately in axisymmetry and projected onto the TF column slices using extrusion operators in COMSOL. Current is imposed on the current carrying turns of the TF coil using a novel method, employing an H-H_0-Φ formulation. This solves a common issue with H-Φ formulations, where current is cumbersome to impose on many separate current-carrying regions. The formulation was implemented in COMSOL using the Magnetic Field Formulation (mfh) and Magnetic Fields, No Currents (mfnc) interfaces, and coupled using custom equations.
The total AC losses are finally determined by weighting the losses per slice according to the spatial distribution of the slices. Using this approach allowed estimating the full spatial- and time-dependent losses in the TF centre column.

This study shows that although the modelling of superconductors and losses in these systems can be computationally challenging, creative approaches can be found to tackle these problems. Being able to implement custom formulations and having the freedom to adapt the dimensionality of systems is essential in allowing such approaches.

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Reference

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Figures used in the abstract

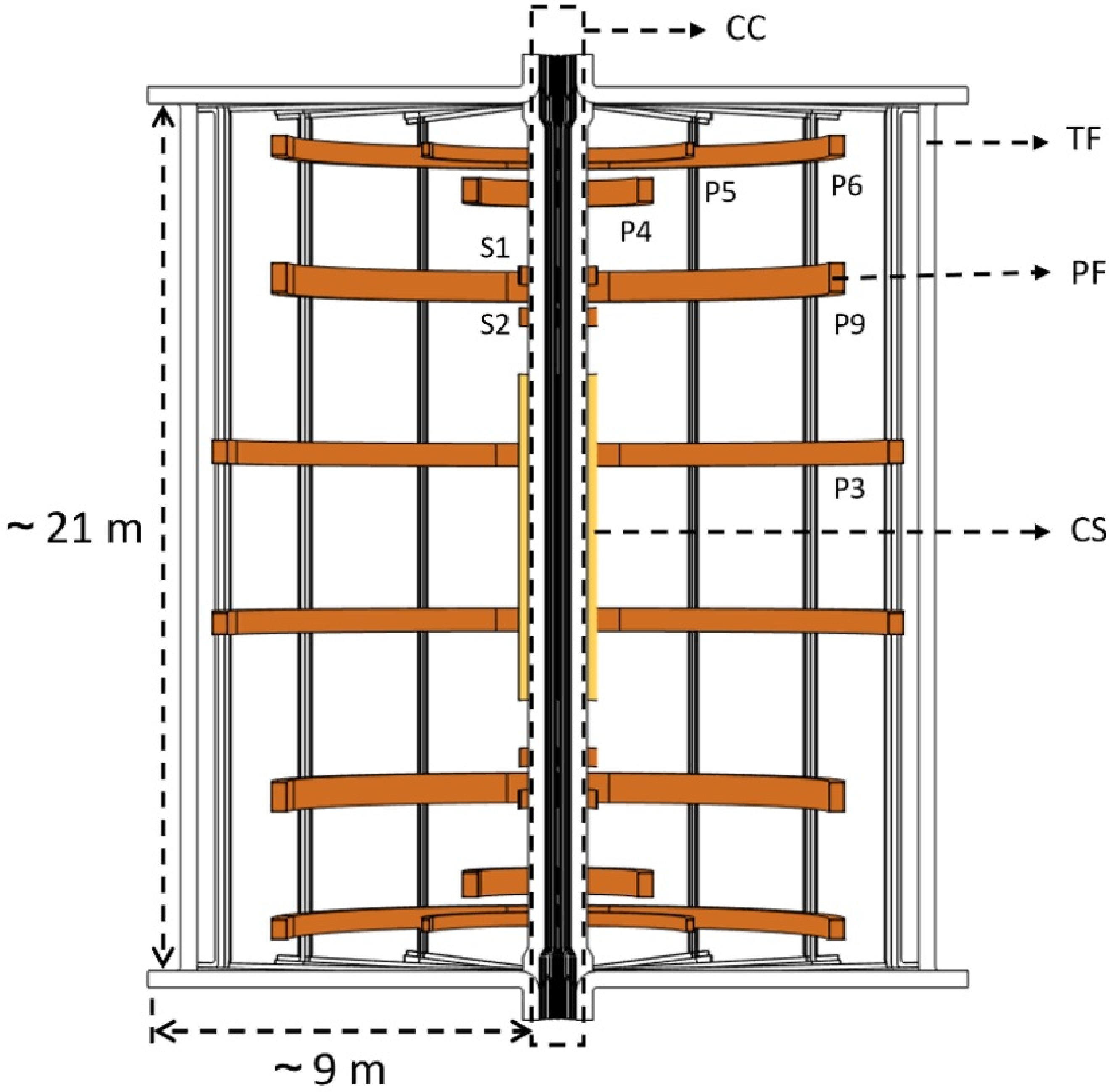

Figure 1 : Cutaway schematic diagram of the STEP magnets: TF toroidal field coils (×16), PF poloidal field coils (labelled S1 through P9), and CS central solenoid. The centre column is labelled CC.

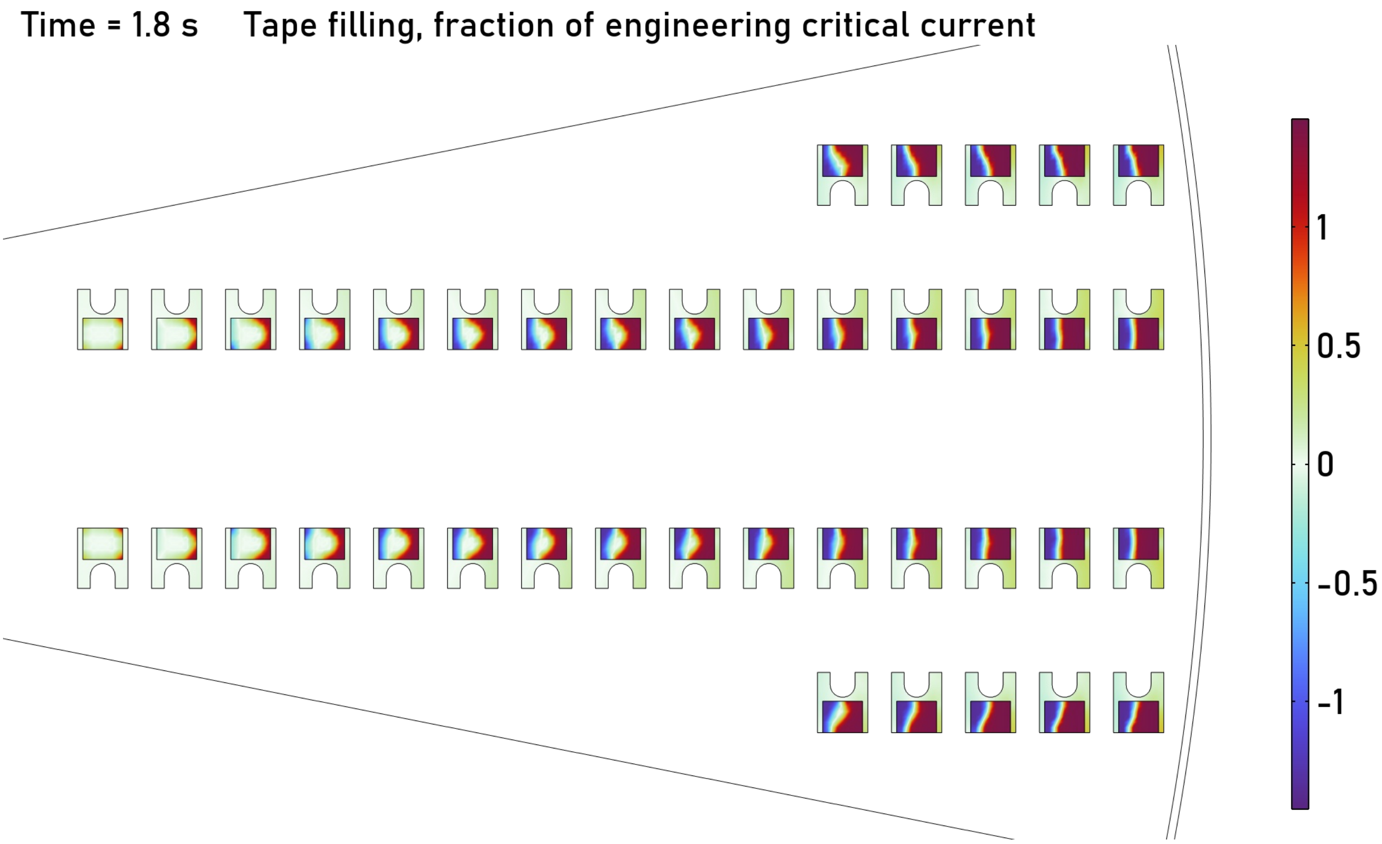

Figure 2 : Tape filling of a 2D slice of the TF centre column near the end of the CS, after 1.8s of current ramping at a temperature of 40K. The current perpendicular to the plane is plotted, normalized to the local engineering critical current.

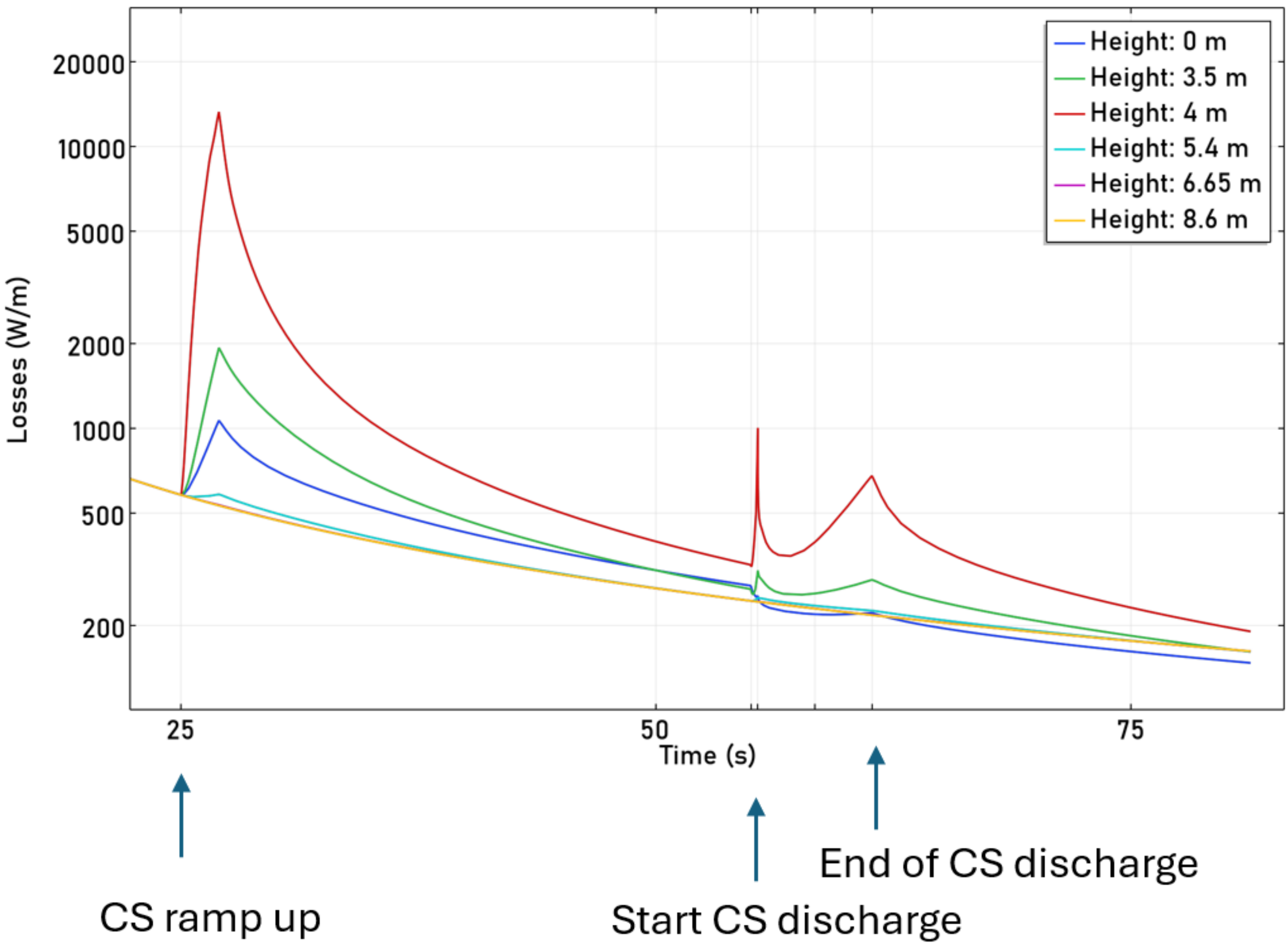

Figure 3 : Total AC losses in separate slices during CS ramp up and discharge in the TF centre column, at several heights of interest.