Contribution ID: **354** Type: **Poster**

Wed-Af-Po.11-08: Calculating the expected critical current for 3D coils of arbitrary shape made with VIPER-like HTS cable

Wednesday 2 July 2025 14:30 (2 hours)

Superconducting coils utilizing VIPER-like HTS cable for tokamaks and stellarators are being designed, built, and tested. In order to assess a coil's ability to operate at the desired current, and/or to evaluate possible degradation of a coil's performance due to manufacturing processes, it is necessary to calculate the expected critical current, Ic, of the coil. This is actually a difficult task, since the Ic of HTS tape varies non-linearly with B-field magnitude, B-field angle to the tape plane, and temperature. VIPER-like cables consist of stacks of HTS tape, and even though the cross-sectional area of a stack is typically only a few mm^2, the near-field generated by the current in the stack is high enough to drastically reduce the Ic of the tapes within the stack. Therefore an accurate calculation of the expected Ic at any location along the coil requires modeling each stack of HTS tape as a dense array of current filaments, and the geometry of these filaments must reflect the geometry of the tape stacks, which wind helically around the cable axis with a twist pitch of order 100-200 mm. At high currents the far-field generated by the non-local parts of a coil can also reduce Ic at the location of interest, and therefore must also be modeled as a set of current filaments, which can be of lower spatial resolution, but which must reflect the geometry of the full coil. For irregular coil shapes, this entails using specialized 3D coordinate systems, such as Frenet-Serret or related frames of reference.

A code to calculate the expected Ic for arbitrarily shaped 3D coils using VIPER-like HTS cable has been developed at MIT PSFC. The code is specifically for coils operating in steady-state (such as for optimized stellarators). The basic physics assumption is that at any location along the coil, the E-field is uniform across the cable cross-section and equal to 1 μV/cm (10^{-4} V/m), which is the definition for HTS being at critical current. The code reads in a .csv file containing the xyz-coordinates of the cable centerline, and generates a dense array of current filaments representing the HTS tape stacks at the desired location of interest along the coil, and a low-resolution array of filaments representing the balance of the coil. The filaments reflect the actual geometry of the coil, and include the twisting geometry of the HTS tape stack in VIPER-like cables. The code iterates the current in each of the many current filaments at the location of interest, until each filament is at its Ic, which depends on the B-field magnitude at each filament, and the B-field angle to each filament. Due to the non-linearity of the problem, the calculation must be iterative, since changing the filament currents changes |B| and its angle, which changes the Ic of each filament, and so on. In addition to requiring the coil geometry as input, the code also requires the HTS tape characterization, Ic(B, angle, T) where T is the operating temperature of the coil.

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Session Classification: Wed-Af-Po.11 - Modelling of Fusion Conductors and Coils I