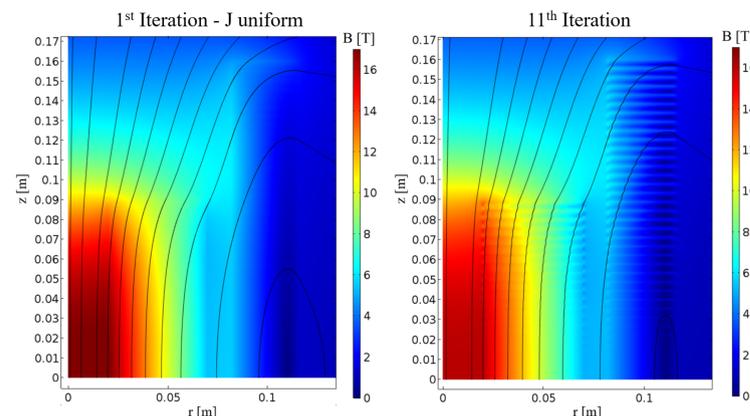




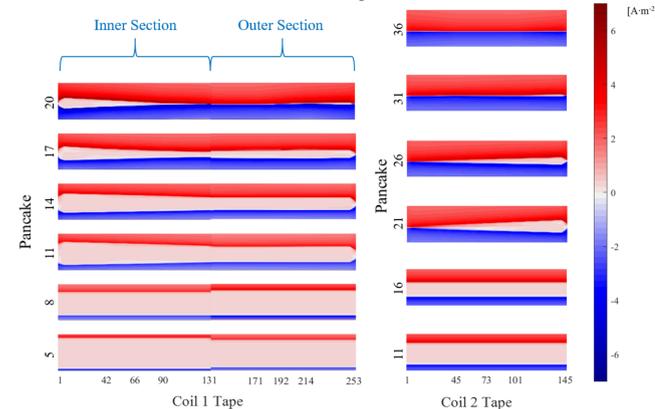
Abstract

The leading project in high magnetic field magnets is the 32 T DC all-superconducting magnet from the National High Magnetic Field Laboratory. This all-superconducting magnet, bath-cooled at 4.2 K, is comprised of a two-coil insert pancake-wound with (RE)BCO tapes supplied by SuperPower Inc. and a multi-coil LTS outsert. To ensure the reliable operation of such a complex magnet, it is important to estimate the hysteresis losses which arise in the insert during ramping operations. The insert coils are assembled from tens of pancakes and thus have thousands of turns, with notable variations in the critical current throughout the pancakes. Therefore, estimating the losses in such a large and complex superconducting magnet presents a significant challenge that requires an efficient strategy without compromising the accuracy of calculations. We propose here a new approach relying on a multi-scale scheme to achieve a high computational efficiency. This new method is flexible enough to simulate different sections of the entire insert with the right level of detail while providing a larger computational speed than other approaches. Estimates of the hysteresis losses in the 17 T insert for a ramping operation sequence are presented.

Background Magnetic Field



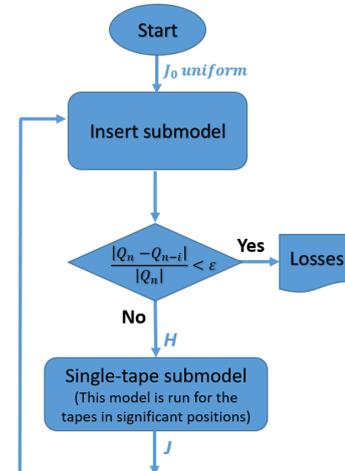
Current Density Distribution



Acknowledgments

This work was supported in part by the Programa de Maestría y Doctorado en Ingeniería of the Universidad Nacional Autónoma de México and the Consejo Nacional de Ciencia y Tecnología (CONACYT) under CVU: 490544.

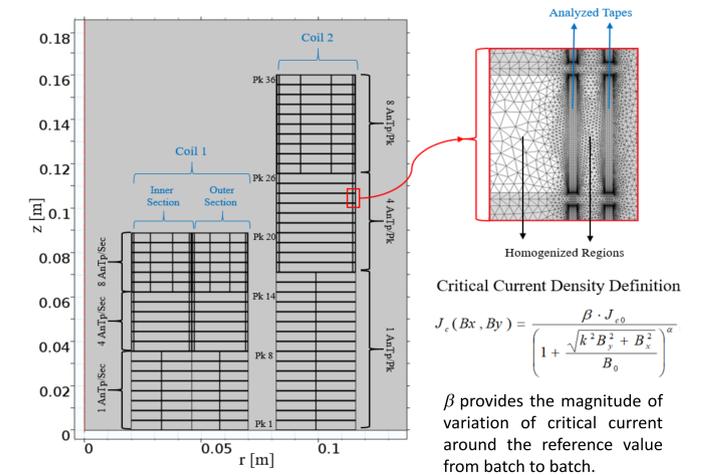
Iterative Multi-scale Method



- The main drawback of the multi-scale method is the difficulty to estimate the background magnetic field.
- A solution enabling us to overcome this limitation is the iterative multi-scale method.
- There are two submodels. The insert submodel (A-formulation), and the single-tape submodel (H-formulation).
- The magnetic field is exported to the single-tape submodel as a time-varying Dirichlet boundary condition.
- The current density distribution is interpolated with a new technique is based on the Inverse Cumulative Distribution Function (ICDF).

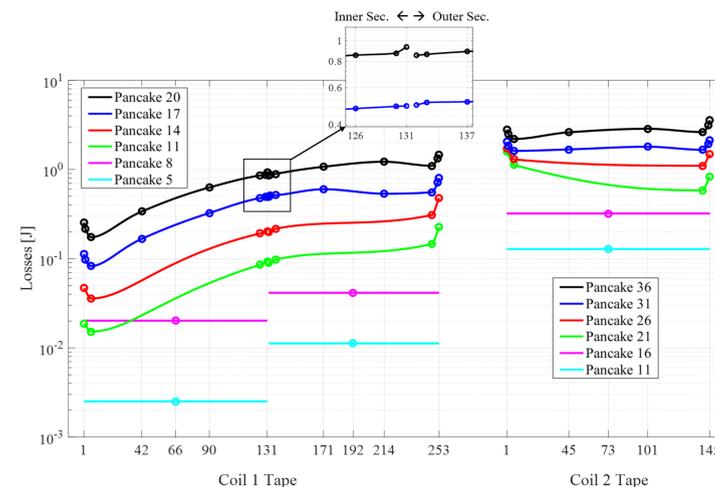
Method

Insert Magnet Description



Modeling

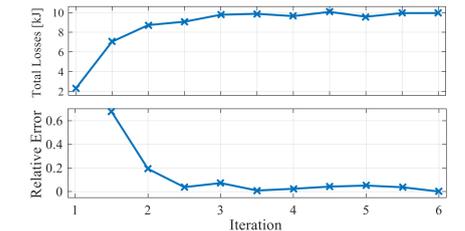
Local Losses in Selected Pancakes



Results - Losses

- The insert magnet is charged from 0 A to 175 A during 1 min and subsequently discharged at the same rate. Additionally 18 s are simulated to analyze the losses in the first instants of the relaxation process.
- The iterative multi-scale method has enough resolution to reproduce the losses variations due to variations in J_c .
- The total losses at 11th iteration are $Q_{11} = 9.946$ kJ, and the relative error at the same iteration equals $7 \cdot 10^{-4}$ that is lower than the criterion, $\epsilon = 1 \cdot 10^{-3}$.
- The losses in Coil 2 are 82 % of the total losses.
- The 8 pancakes with one analyzed tape in Coil 1 give 1.7 % of the losses in Coil 1, while 16 pancakes with one analyzed tape in Coil 2 are responsible for the 5.4 % of the losses in Coil 2.
- The upper half of Coil 2 adds up to 75 % of the total losses.

Total Losses and Error



- A desktop computer (6 cores, Intel (R) Xeon(R) ES-2630, 2.2 GHz, 64 GB RAM) was used to conduct the simulations.
- The time required to run the insert submodel is around 1.5 hour.
- Every single tape simulation requires an average of 8 min.
- Since we have 296 analyzed tapes in total, each iteration of the iterative multi-scale method takes about 42 hours.

Conclusions

- The single tape analyses can be parallelized. Thus the iterative multi-scale method can be performed in commercially available desktop computer that do not have the memory and computer power of a dedicated cluster supercomputer.
- The pancakes located at the upper region exhibit higher hysteresis losses. Thus, to select tapes with higher critical currents for the upper pancakes is a correct choice.
- The losses in Coil 2 are flatter than the losses in Coil 1, the losses in Coil 1 increase close to Coil 2, this behavior is caused by the increment in the angle of the background field along Coil 1.
- The homogenization method has been previously applied to analyze smaller prototype coils of the 32 T magnet insert. The iterative multi-scale method allows analyzing the entire 17 T insert.
- It is also proved that the iterative multi-scale method permits to do the analysis with any required accuracy increasing the number of analyzed tapes.
- The advantage of the iterative multi-scale method over the multi-scale method becomes clear when the total losses at the last iterations are compared with the total losses at the first iteration. The total losses at the last iteration are more than four times larger than those after the first iteration.