# Use of FEM in the Design of an HTS Insert Coil for a High Field NMR Magnet

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## Abstract

High temperature superconductors (HTS) have opened the potential to drive larger current densities through coil wound electromagnets, which in turn produce higher magnetic fields. At the Applied Superconductivity Center within the National High Magnetic Field Laboratory in Tallahassee, Florida, work is ongoing to produce a high field HTS magnet insert with an aim of ~1 part per million (ppm) field homogeneity in a 10 mm diameter spherical volume (DSV) for application in nuclear magnetic resonance (NMR). The HTS NMR system is inserted into the bore of an existing high field magnet to augment and achieve an NMR quality field homogeneity in the 10 mm DSV. A compensating Helmholtz coil pair is placed around a central solenoid to flatten the magnetic field profile.

COMSOL Multiphysics® software was used to model the existing magnet, the designed HTS NMR magnet insert, and the combined system. As the compensation coils sit within the bore of the existing magnet, their placement relative to the HTS central coil is of critical importance. Moreover, the location of the entire HTS system with respect to the center of field of the existing magnet is also paramount. Hence, simulations of the thermal stresses and deformations were performed to account for the thermal contraction and location shifts of the designed inserts. Ultimately, a multiphysics model was simulated with the Moving Mesh, Thermal Stress, and Magnetic Field interfaces to develop a virtual field map of the thermally strained insert design. This virtual field map was then used to redesign the HTS insert to more appropriately account for these effects and achieve the desired NMR-quality field homogeneity. Also, a material selection process included studies of form magnetization curves and their effect on field homogeneity. A partial 3D model is included (Figure 1), wherein the magnetized coil form is highlighted in blue.

2D axisymmetric models were utilized to validate methods against analytic solutions and to better understand the appropriate and necessary boundary conditions. Ultimately, 3D models were developed to fully take into account the asymmetries in magnetized coil form, terminal posts, and other geometries. A sample graph of the axial field profile is included (Figure 2), wherein the thermal contraction (from 293 K to 4.2 K) is shown to adversely affect what was otherwise a successfully flattened field profile at room temperature centered around z=0.

This study exemplifies the versatility and robustness of COMSOL Multiphysics. It assisted our team in adequately designing the cutting edge HTS NMR insert.

# Figures used in the abstract

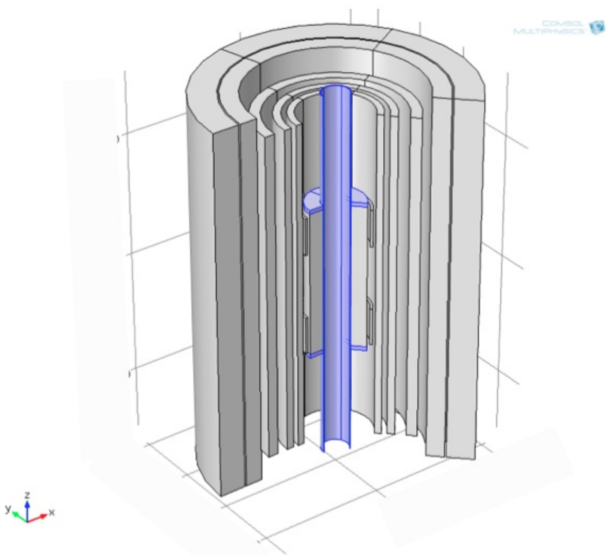

**Figure 1**: Rough Design of HTS Insert in the Existing Magnet.

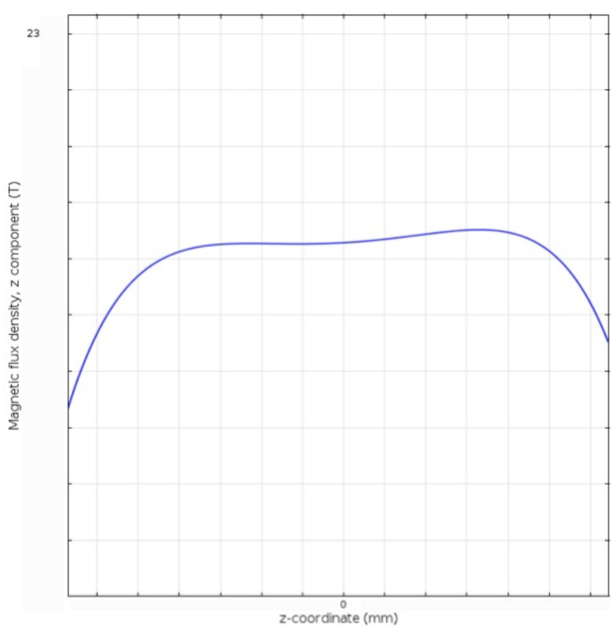


**Figure 2**: Axial Field Computation after Thermal Contraction.