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

E⌽ Bosque

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Introduction: Field homogeneity is required for nuclear magnetic resonance (NMR), and the next generation of high field magnet designs are wound with high temperature superconductors (HTS). Modeling the proposed magnet system makes it possible to address key design parameters.

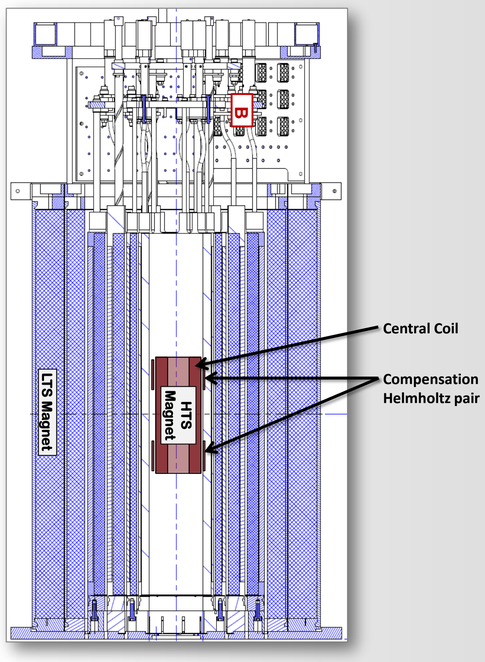

Figure 1. Schematic of HTS NMR magnet system

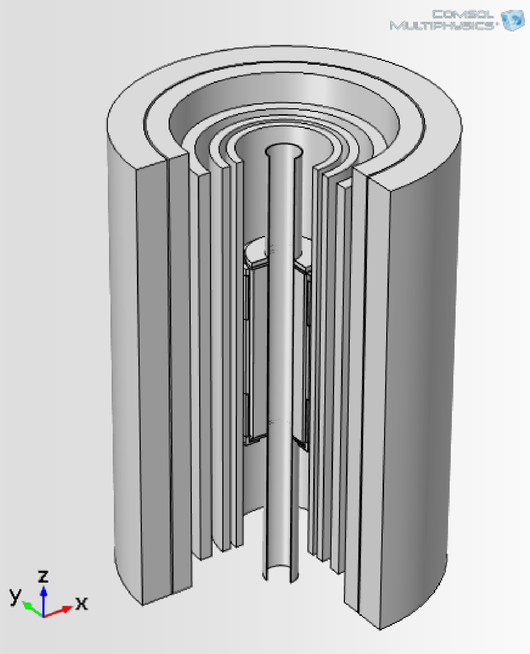

Figure 2. Geometry of models

Computational Methods: Three physics modules are used for these studies. Magnetic fields (*mf*) are computed with the geometry shown in Fig 2. Thermal stress (*ts*) is applied to the HTS system, as highlighted in Fig 5, with a moving mesh (*ale*) to follow all geometric deformations. The general PDEs solved for are shown below:

Magnetic Fields (*mf*)	Thermal Stress (*ts*)
$\nabla\times\mathbf{H} = \mathbf{J}_e$	$-\nabla\cdot\sigma = \mathbf{F}_V$
$\mathbf{B} = \nabla\times\mathbf{A}$	$\rho C_p\mathbf{u}\cdot\nabla T = \nabla\cdot(k\nabla T) + Q$

Results: As illustrated in Fig 3, the homogeneity of the ideal field is very good (calculated < 0.4 ppm).

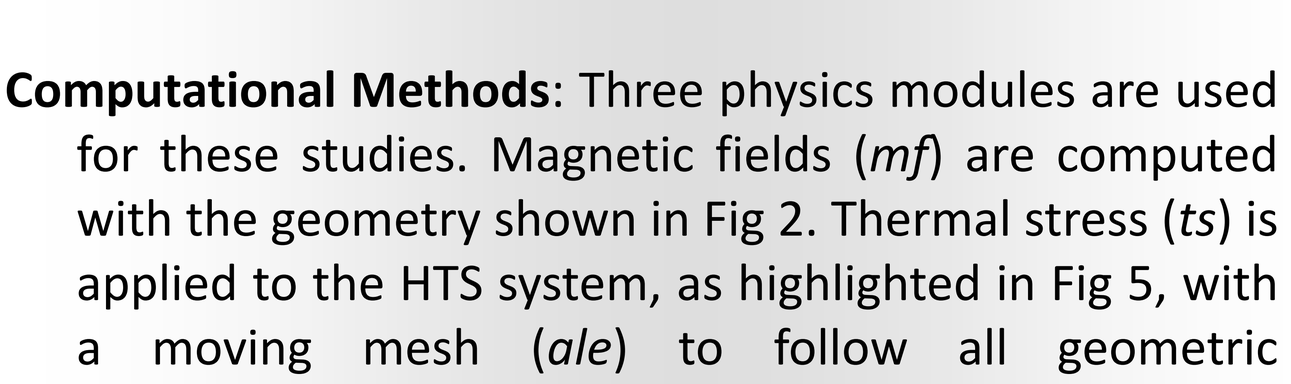

Figure 3. Magnetic analysis of the LTS, HTS, and total field generation

References:

1. M. Dalban-Canassy, et al. A study of the local variation of the critical current in Ag-alloy clad, round wire Bi2Sr2CaCu2O8+x multi-layer solenoids, *Superconductor Science and Technology*, 25, 11 (2012).
2. U.P. Trociewitz, et al. 35.4 T field generated using a layer-wound superconducting coil made of (RE)Ba2Cu3O7−x (RE = rare earth) coated conductor, *Appl. Phys. Lett.*, 99, 20 (2011).

Results (continued): Approximating a real coil begins with study of mandrel magnetization.

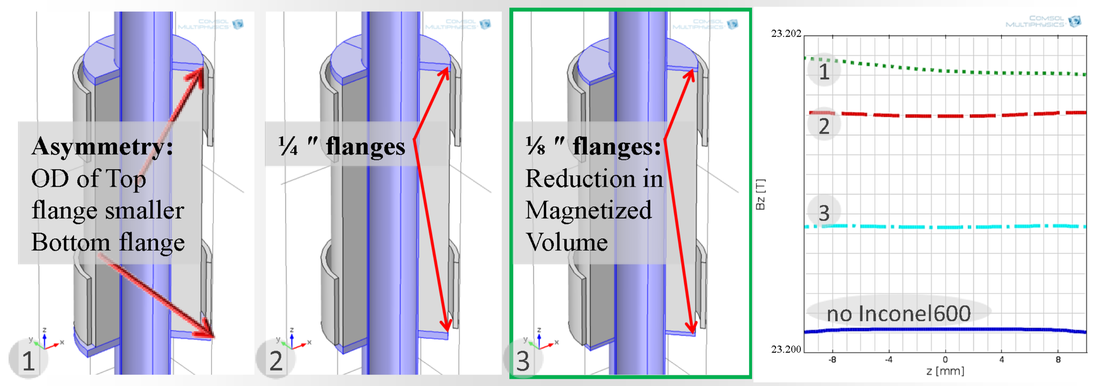

Figure 4. Mandrel magnetization effect on field homogeneity

Thermal stress is then applied to the HTS Insert to study its effect on the field homogeneity.

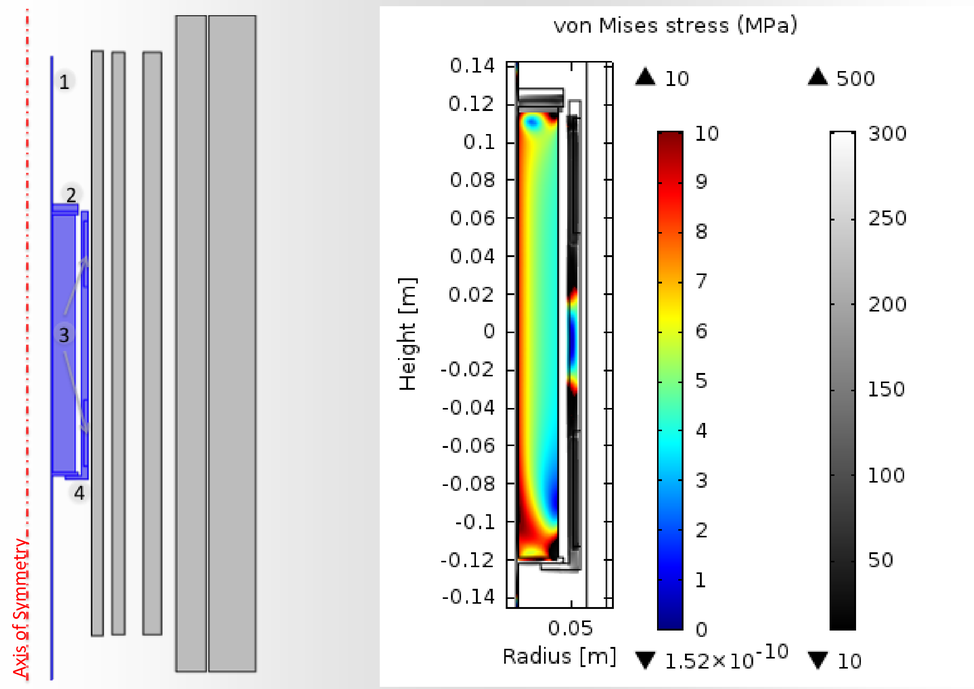

Figure 5. Materials for thermal stress (ts):
1) Inconel 600; 2) Alumina; 3) Stycast 1266; 4) G-10
Plot of von Mises stresses with geometric deformation

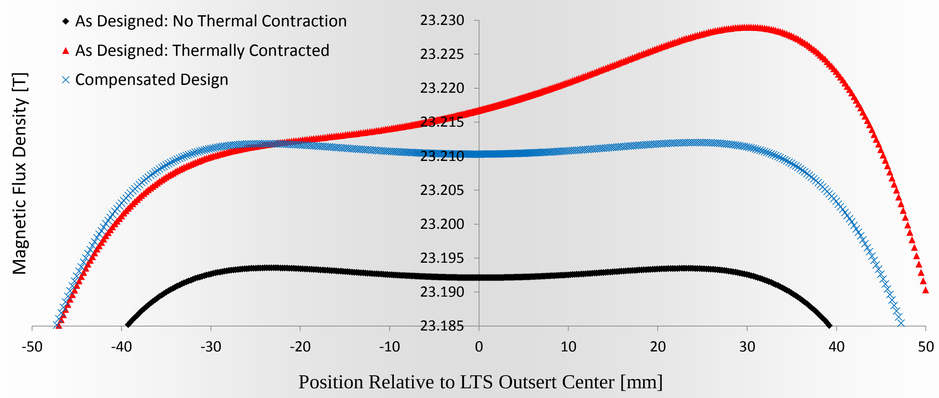

Figure 6. Effect of thermal contraction on the generated field

Conclusions: Magnetic field analysis shows that the compensated design will approach NMR-quality homogeneity. Magnetization of the mandrel does effect the generated field homogeneity. As the operating temperature of this magnet system is 4.2 K, modeling the thermal stress quantifies the contraction of the HTS Insert as well as the adverse effect on the homogeneity. These effects can be incorporated into a modified design before building the coil.