Design Studies of 16 T Nb_3Sn dipole at Fermilab*

U.S. MAGNET DEVELOPMENT PROGRAM

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Introduction

Fermilab in collaboration with other members of the US-MDP is developing a 15 T Nb_3Sn dipole demonstrator based on a 4-layer graded cos-theta coil with a 60 mm aperture and a ~600 mm diameter cold iron yoke. In parallel, magnet design studies are being conducted to explore the limits of the Nb_3Sn accelerator magnet technology while pushing the nominal bore field to 16 T. The first results of these studies, including a possible stress management technique are discussed and compared with the baseline (BL) design parameters.

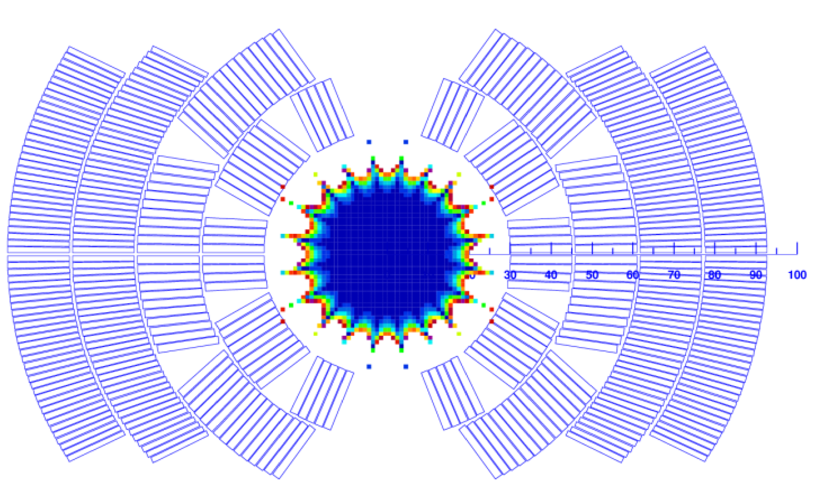
Magnetic Analysis

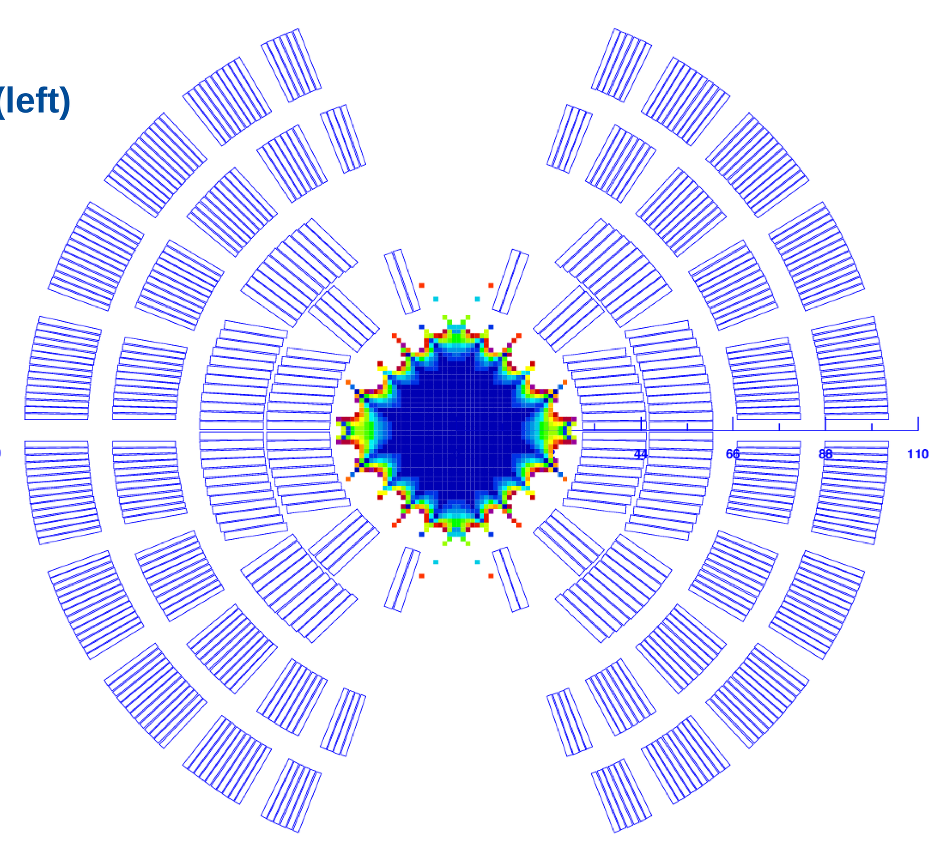
The BL design analysis has shown that achieving higher fields above 15 T is limited by unloading and separation of the inner layer pole turns under the Lorentz forces. The increase the coil preload, however, is not possible as the stress in the coil midplane approaches 180 MPa, which is close to the limit for the brittle Nb_3Sn conductor.

To overcome these limitations, the following strategy was used:

- use coil with the floating wedges for the inner coil
- unload the inner coil by moving turns to the outer coil
- introduce the azimuthal and radial SM in the outer coil

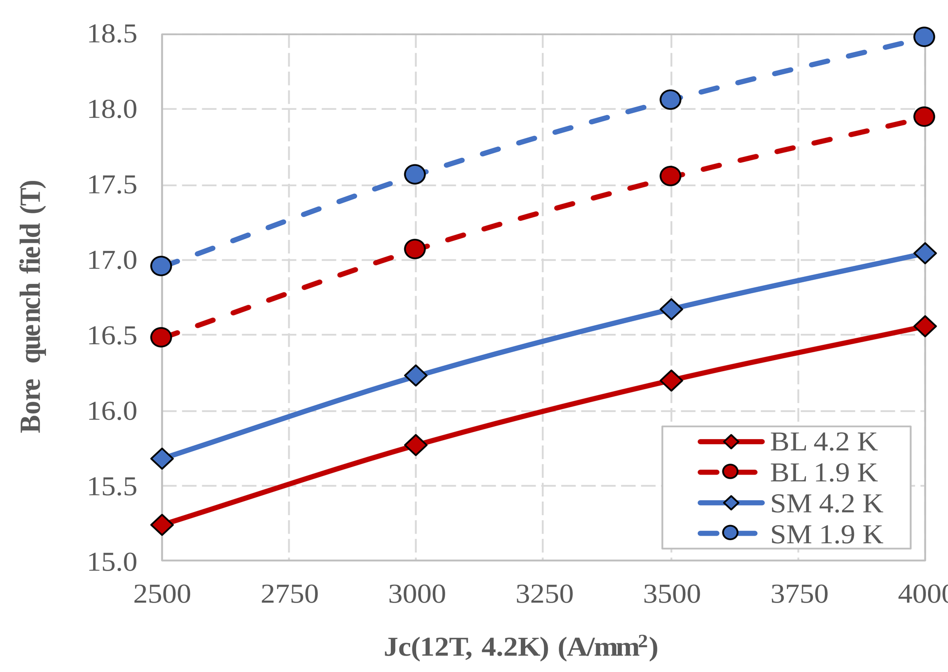
Cross-sections of the baseline (BL) coil design (left) and the stress-management design (SM) (right)





Cable parameters

Parameter	Inner Coil	Outer Coil
Number of strands	28	40
Mid-thickness, mm	1.870	1.319
Width, mm	15.10	
Keystone angle, deg.	0.805	
Cu/nonCu ratio	1.13	
J_c(15T, 4.2K), A/mm^2	1500	



Bore quench field vs. critical current density

Magnet parameters at SSL and 4.2 K

Parameter	BL IC	BL OC	SM IC	SM OC
Bore field, T	15.61		16.07	
Peak field, T	16.25		16.44	
Current, A	11.34		10.80	
Inductance, mH/m	25.61		35.42	
Stored energy, MJ/m	1.65		2.06	
F_x, MN/m/quadrant	5.8	1.6	4.8	4.7
F_y, MN/m/quadrant	-1.2	-3.3	-0.5	-3.6
Number of turns	44	65	38	102

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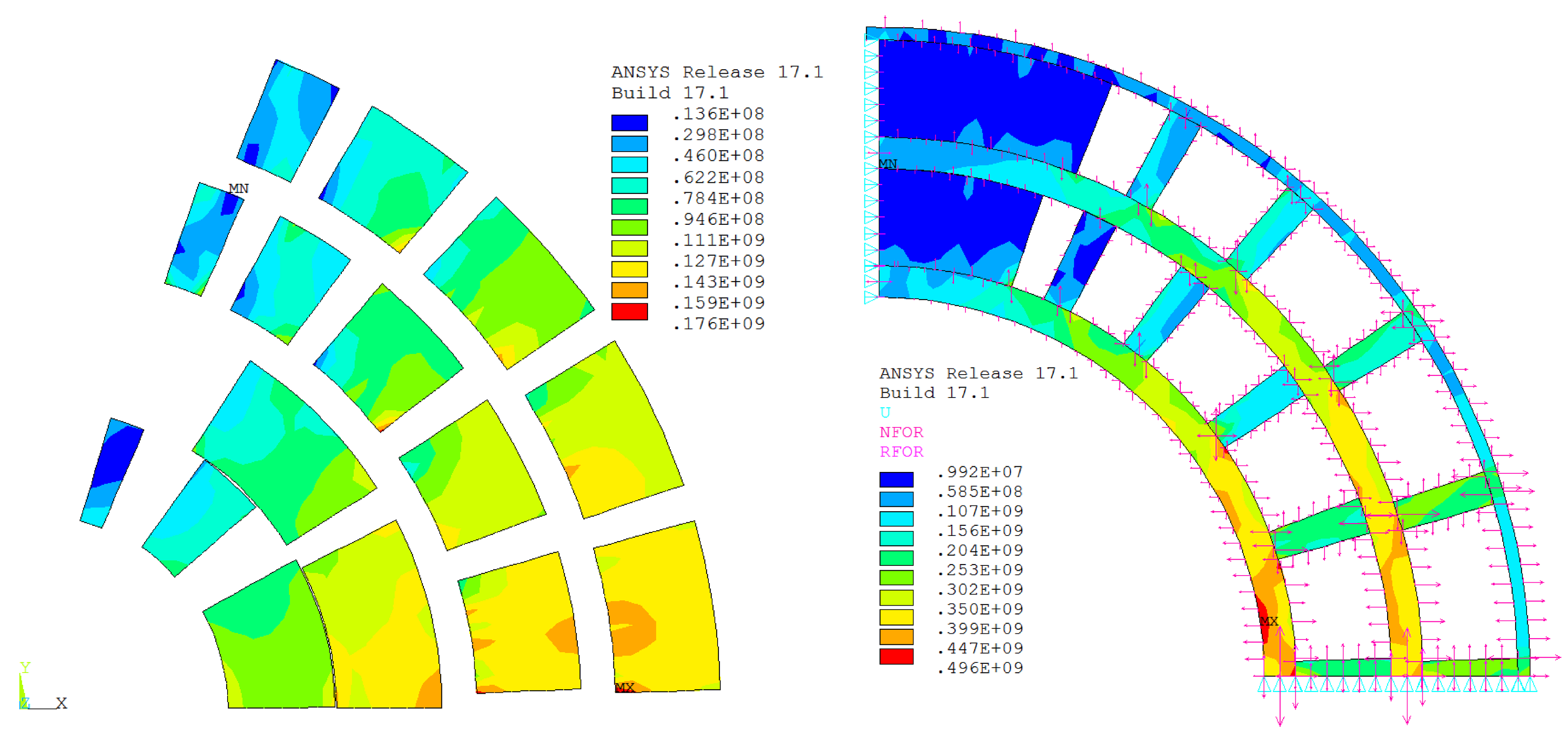
Structural Analysis

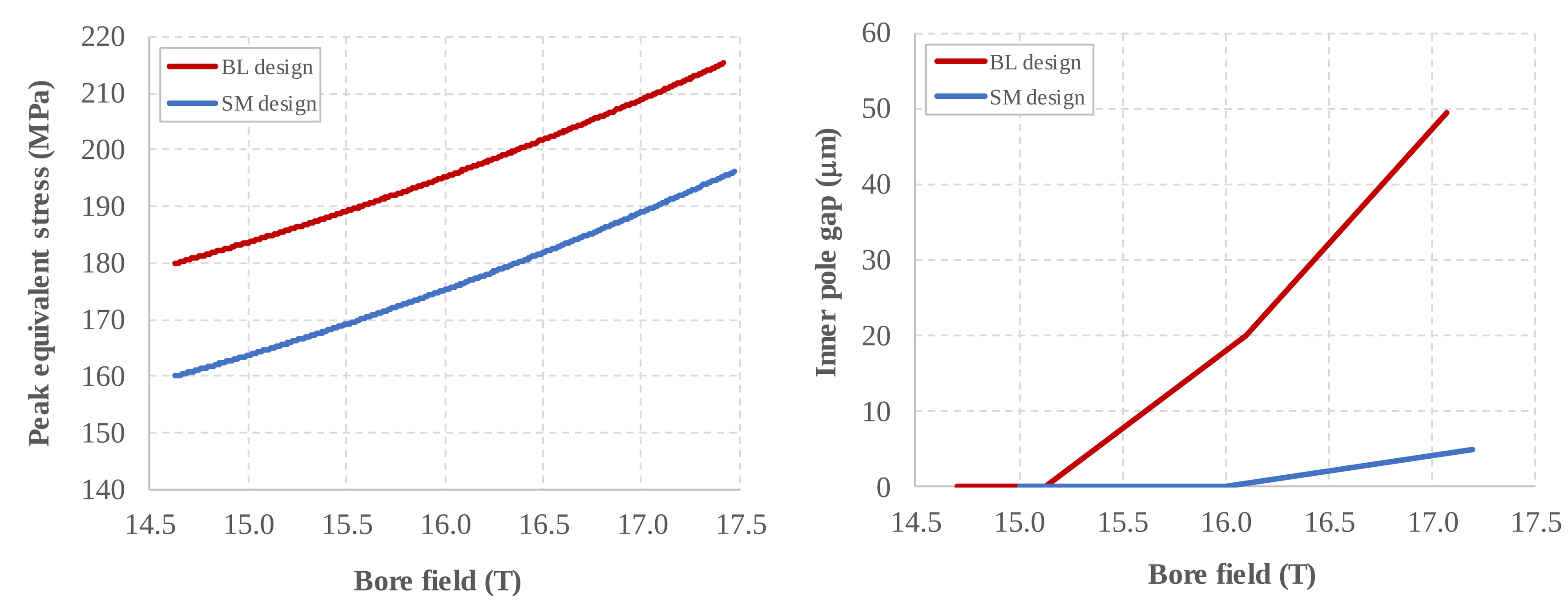
A structural analysis was performed with ANSYS code to evaluate displacements and stresses in both designs using a special parametric model.

The pole turn in the SM design remains in contact with the pole block at the fields up to 16 T whereas in the BL design, the pole turn separates from the pole block at the fields above 15 T and the gap reaches ~20 μm at 16 T.

For the outer SM coil, the peak equivalent stress is under 180 MPa at 16 T, located in the mid-plane block of the outer layer.



Equivalent stresses in the coil (left) and the support structure of the outer layers (right) at 16 T



Peak stress (left) and the gap between the inner pole turn and the spacer (right) vs. bore field

Conclusion

A stress management technique has been proposed together with the turn re-distribution between the inner and outer coils to increase the level of magnetic field.

It was found that the stresses in the inner and outer coils are below 150 MPa and 180 MPa respectively, and that the inner pole turn stays in contact with the pole spacer at up to 16 T bore field. Given the 10% margin at 1.9 K, it can be considered as the nominal operating field for this design.

The studies and optimization of this design concept will continue.