NCSX Coil Topology Studies – Modular Coils

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NCSX Modular Coil Studies

- Modular coil optimization - COILOPT
- VMEC reconstruction and NESCOIL analysis
- Engineering design issues

COILOPT Model for a Modular Coil

- Coils are represented as filament model in real space

$$x = R\cos(\phi), \quad y = R\sin(\phi), \quad z = Z$$

- Coils are typically constrained to a winding surface

$$R = \Sigma\, R_{mn} \cos(m\theta + nN\phi)$$
$$Z = \Sigma\, Z_{mn} \sin(m\theta + nN\phi)$$

- Toroidal variation given by Fourier series in θ

$$\phi = \Sigma\, a_k \cos(k\theta) + b_k \sin(k\theta)$$

- COILOPT independent variables are the parameters a_k, b_k, R_{mn}, Z_{mn}

Method of Optimization

- COILOPT uses a Levenberg-Marquardt method to solve the nonlinear least squares problem
- Objective function consists of magnetic field approximation at plasma edge, together with penalty functions (constraints)
- Targets include :
  RMS error in normal component of magnetic field, δB_{rms}
  Minimum plasma-coil distance, Δcp
  Minimum coil-coil separation, Δcc
  Coil length, Lc
  ϕ-variation of coils

COILOPT Strategy for c82a Modular Coil Optimization

Step 1:

- o Specify the number of modular coils per period (N_{mod} = 9)
- o Conformal winding surface (28 cm)
- o Variable currents in 4 VF coils (fixed position)
- o Start with small number of variable ϕ-coefficients ($N\phi$ = 5 – 9)
- o Include Δcc penalty

Step 2:

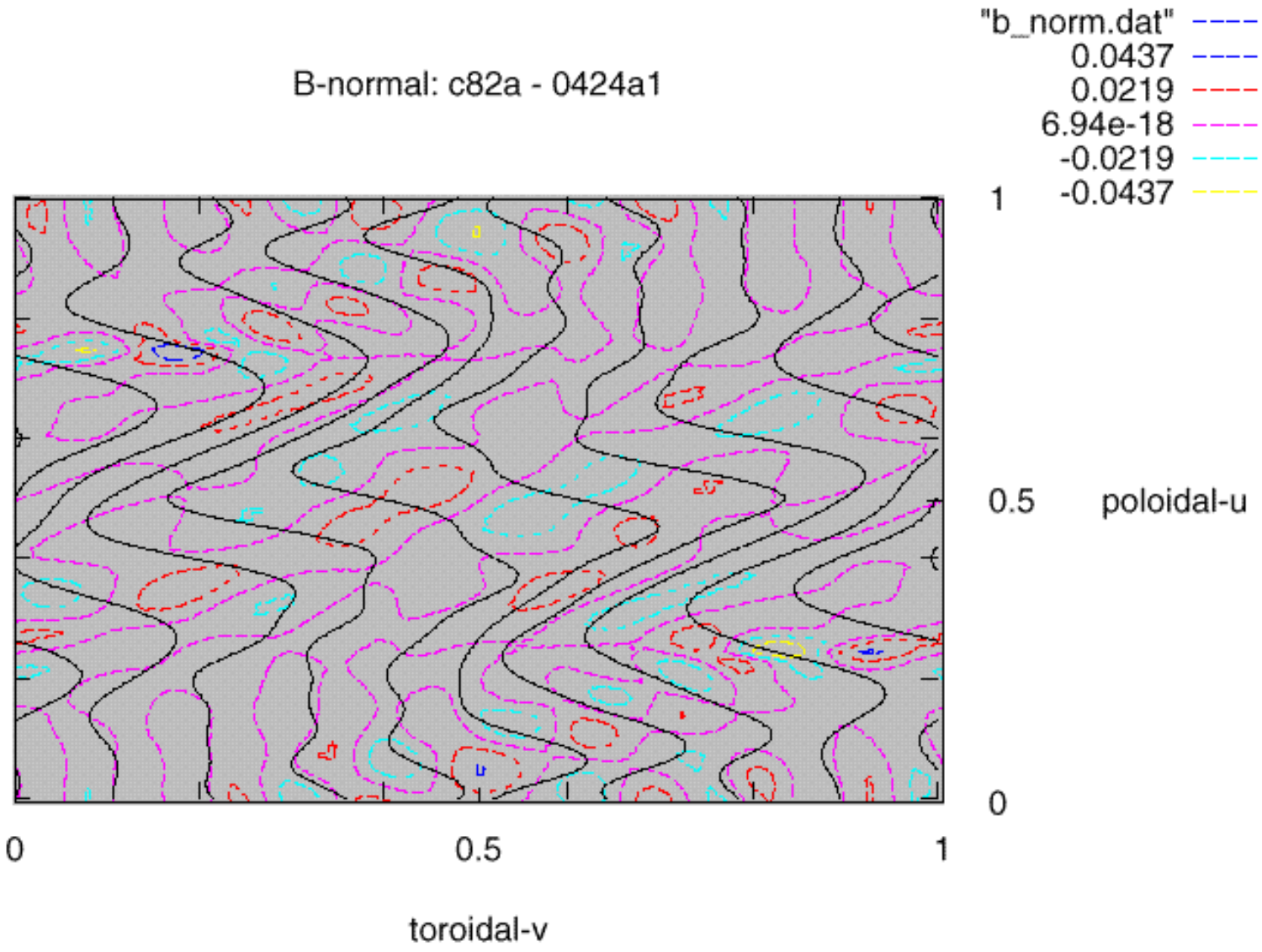
- o Fix number of variable ϕ-coefficients ($N\phi$ = 9)
- o Vary winding surface coefficients (R_{mn}, Z_{mn})
- o Include both Δcc and Δcp penalties

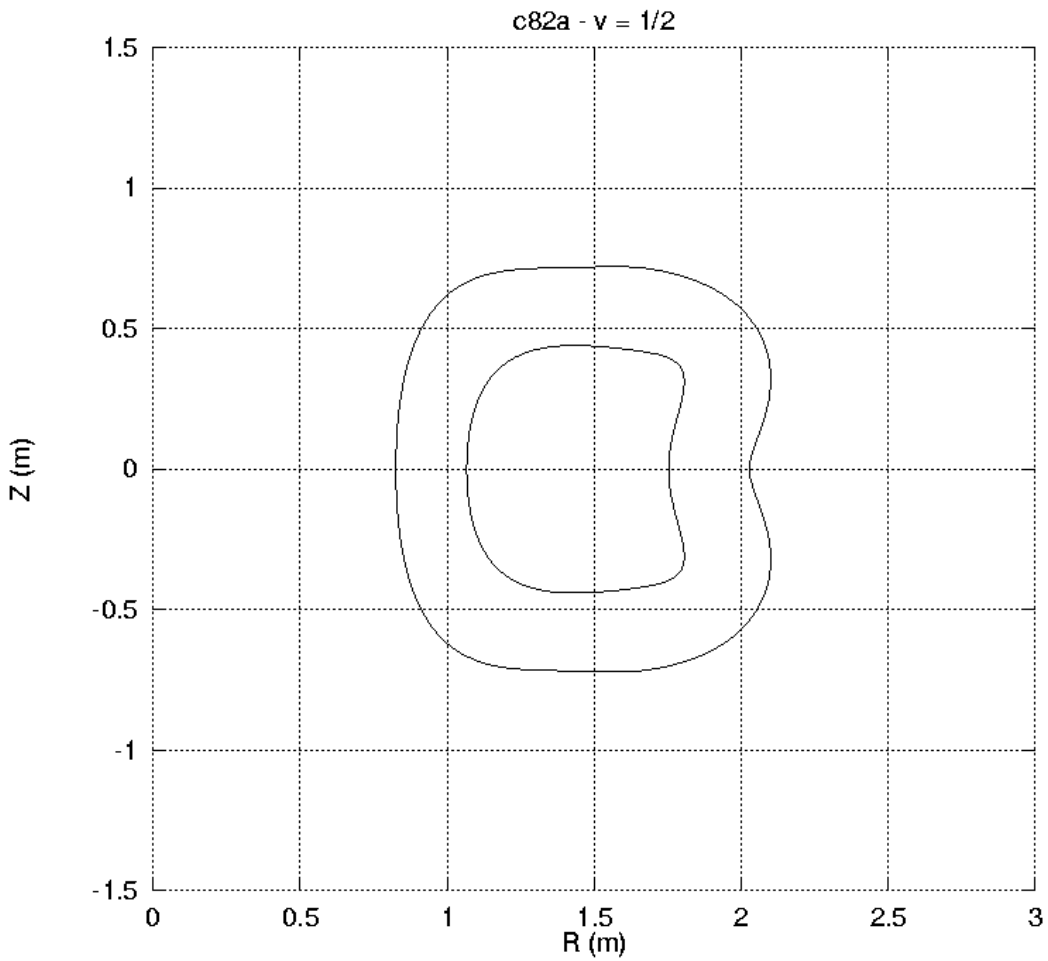
Step 3: For "optimized" winding surface, examine the effect of further increase in $N\phi$, varying penalty weights, etc.

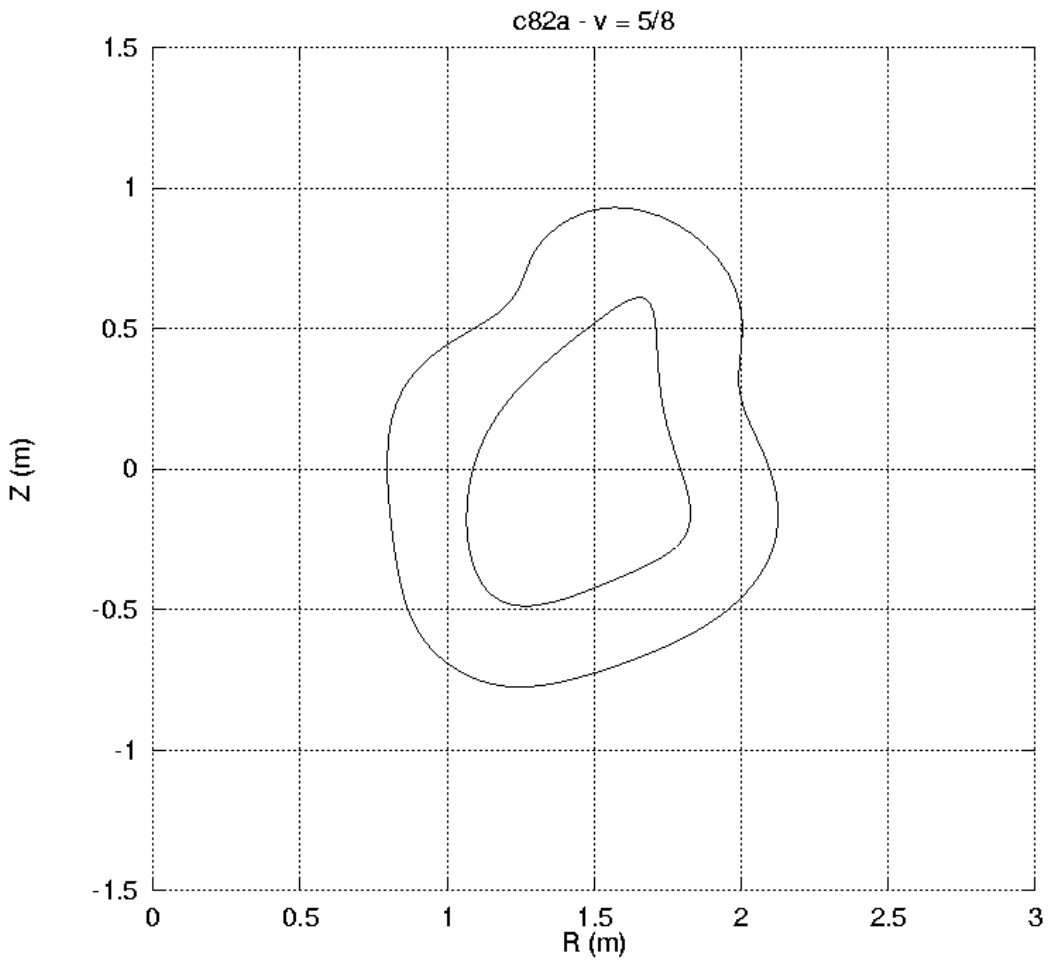
Representative COILOPT Results for c82a

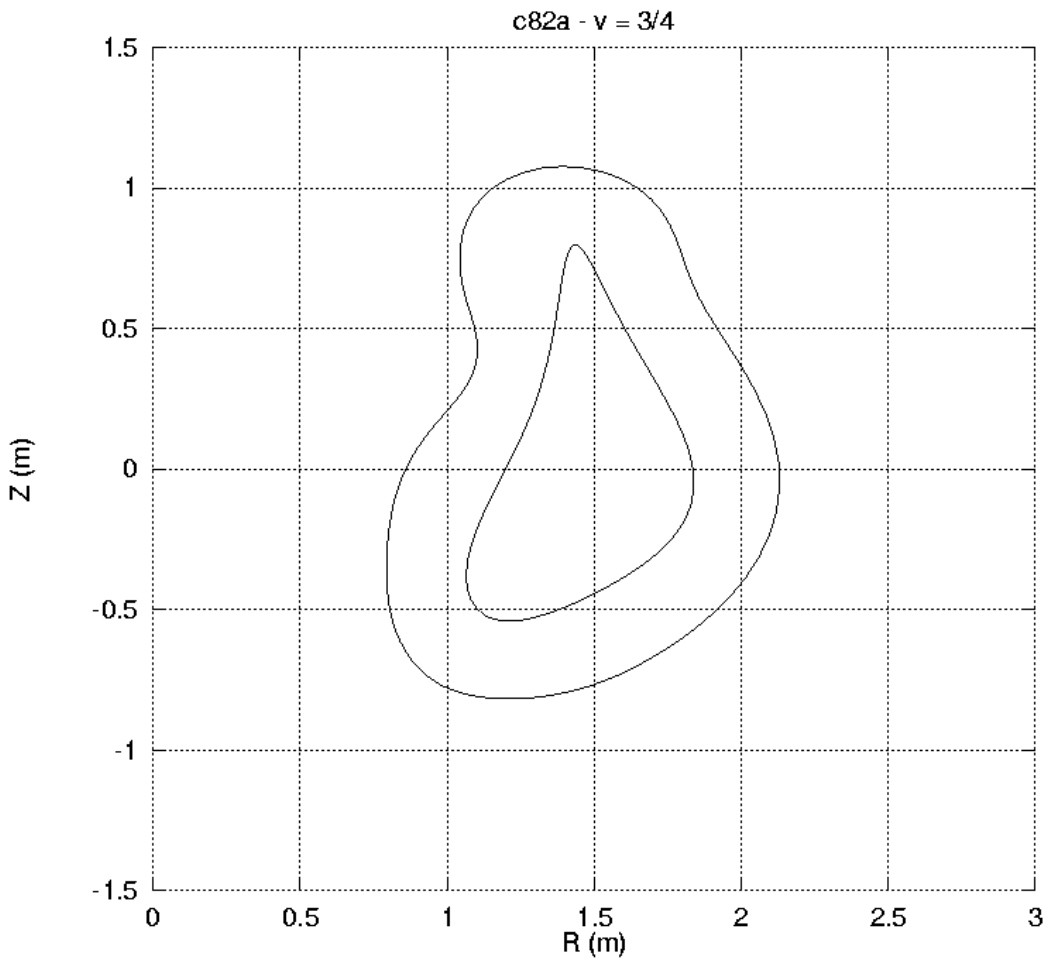
Run#	N_{mod}	N_{vf}	$N\phi$	δB_{rms}(%)	δB_{avg}(%)	δB_{max}(%)	Δcc(cm)	Δcp(cm)
0424a1	9	4	13	1.47	1.14	6.55	9.91	21.7
0411a4	9	4	11	0.87	0.67	4.85	8.77	18.5
0501a4	8	4	11	1.29	0.98	6.33	9.50	19.8

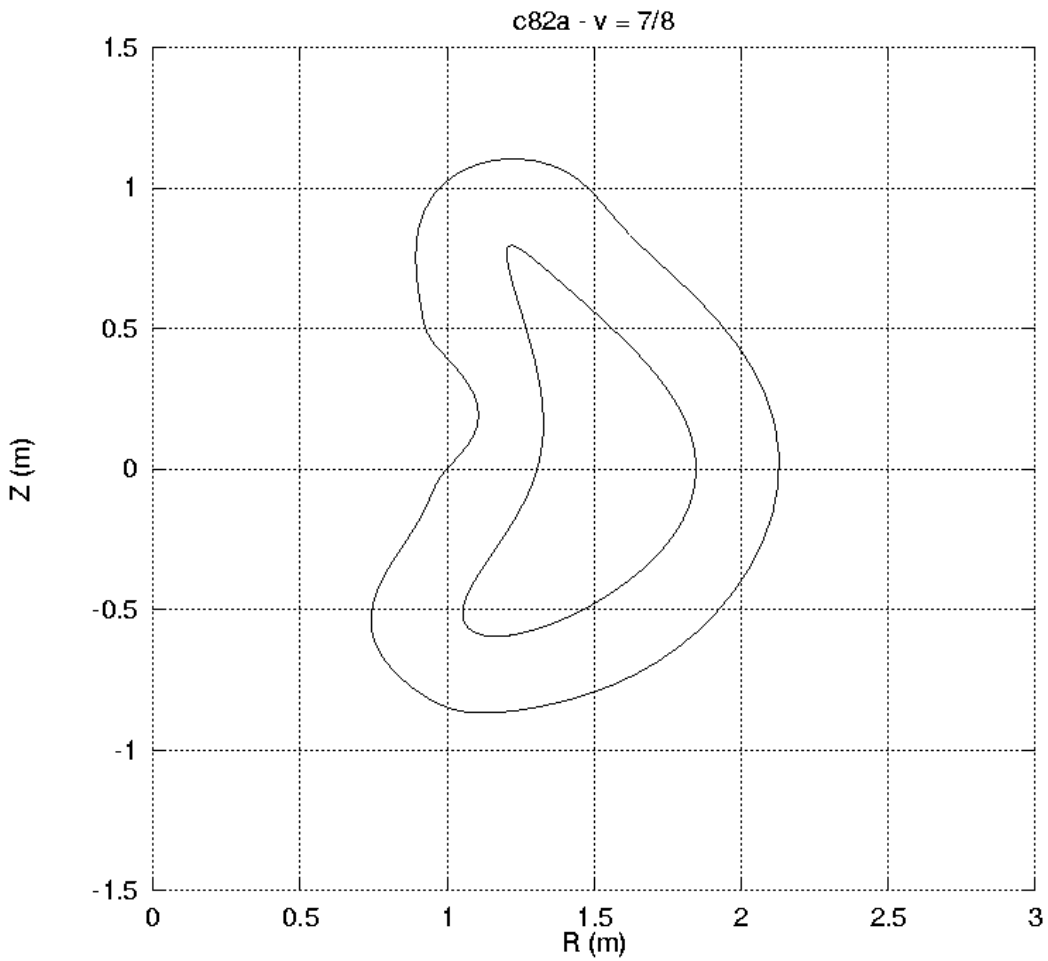
- 0411a4 reconstructs reference equilibrium with ~1 cm axis shift
- 0424a1 reconstructs reference equilibrium with ~2 cm axis shift
- Four filament (per coil) model based on 0424a1 resulted in δB_{rms} = 1.46%

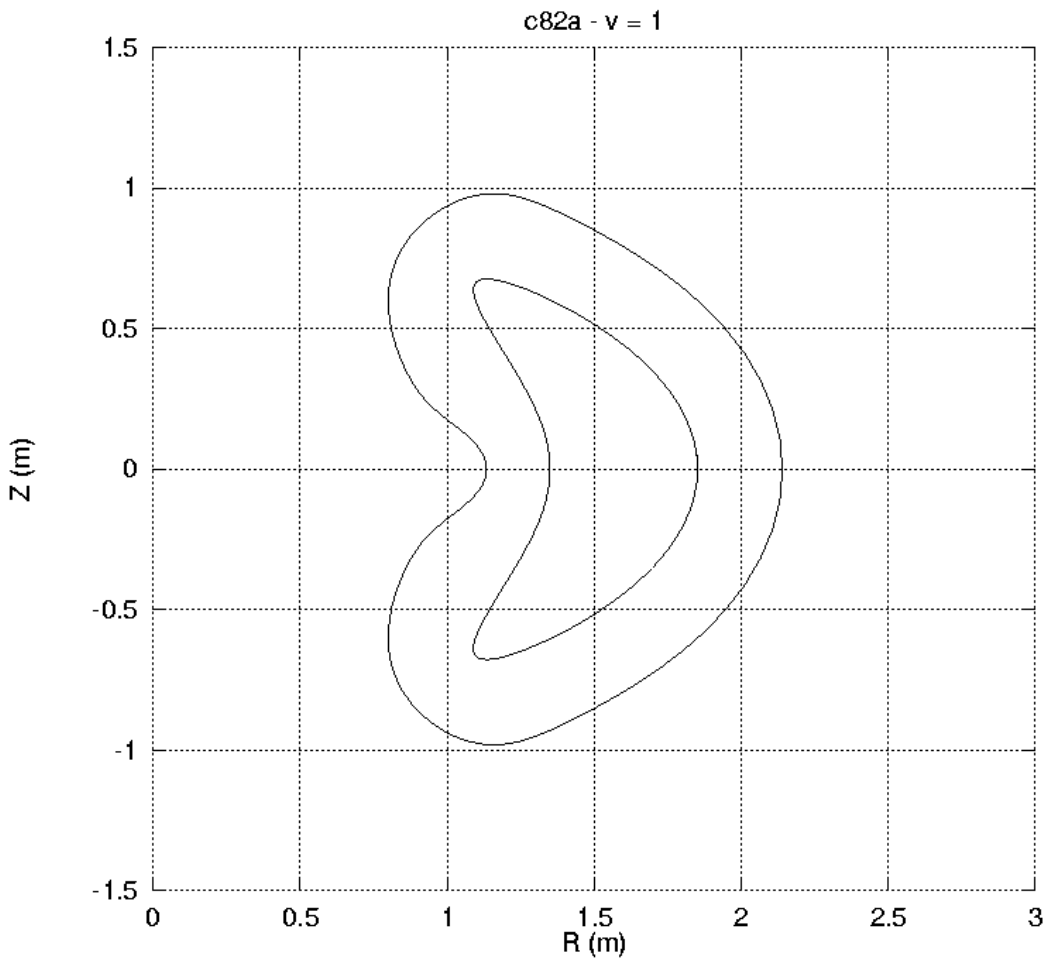

B-normal: c82a - 0424a1
"b_norm.dat"
0.0437
0.0219
6.94e-18
-0.0219
-0.0437
1
0.5
0
poloidal-u
0
0.5
1
toroidal-v


c82a - v = 1/2
1.5
1
0.5
0
-0.5
-1
-1.5
Z (m)
0
0.5
1
1.5
2
2.5
3
R (m)


c82a - v = 5/8
1.5
1
0.5
0
-0.5
-1
-1.5
Z (m)
0
0.5
1
1.5
2
2.5
3
R (m)

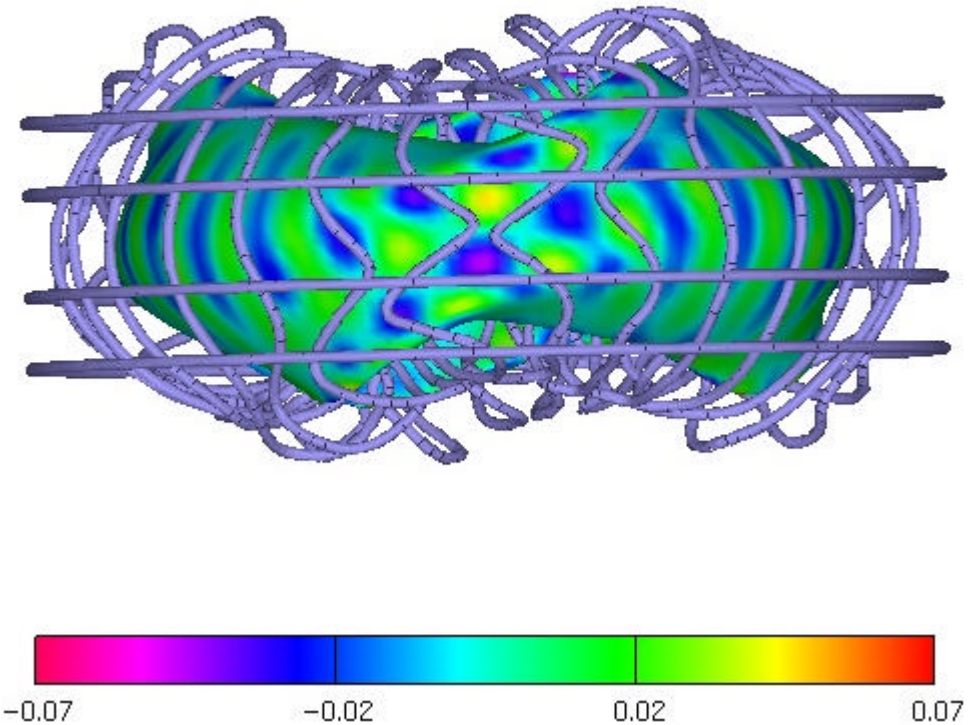

c82a - v = 3/4
1.5
1
0.5
0
-0.5
-1
-1.5
Z (m)
0
0.5
1
1.5
2
2.5
3
R (m)


c82a - v = 7/8
1.5
1
0.5
0
-0.5
-1
-1.5
Z (m)
0
0.5
1
1.5
2
2.5
3
R (m)


c82a - v = 1
1.5
1
0.5
0
-0.5
-1
-1.5
Z (m)
0
0.5
1
1.5
2
2.5
3
R (m)

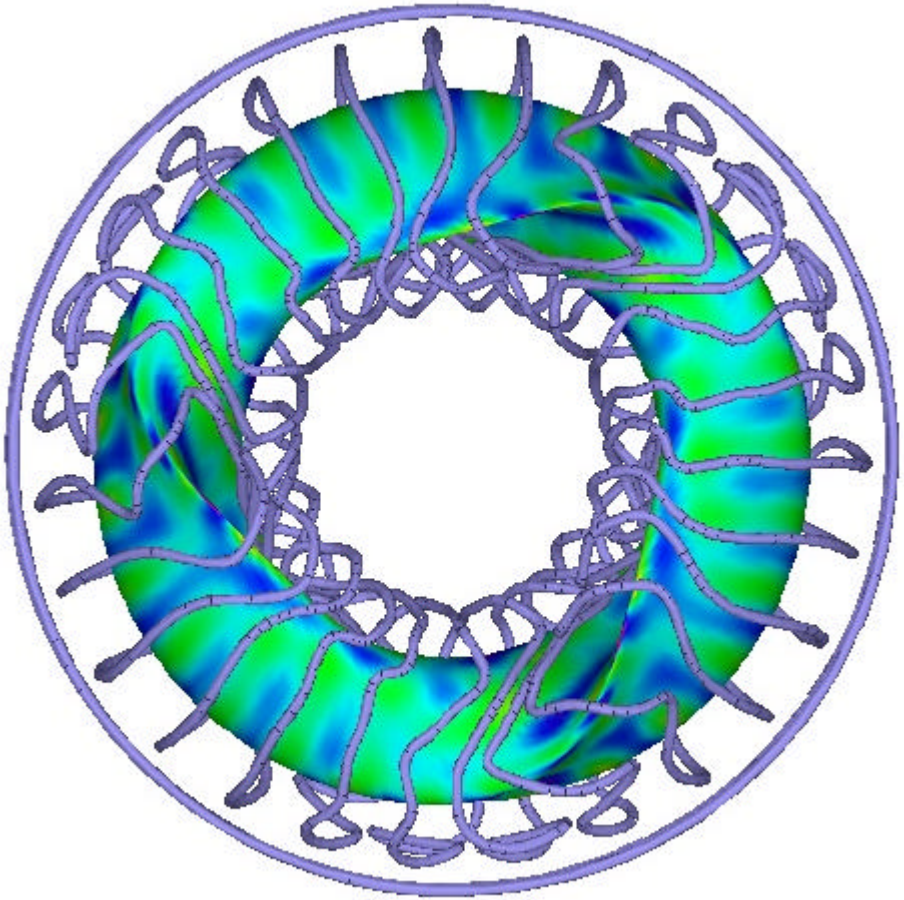
Modular Coils for NCSX

B-normal error for case c82a-0424a1



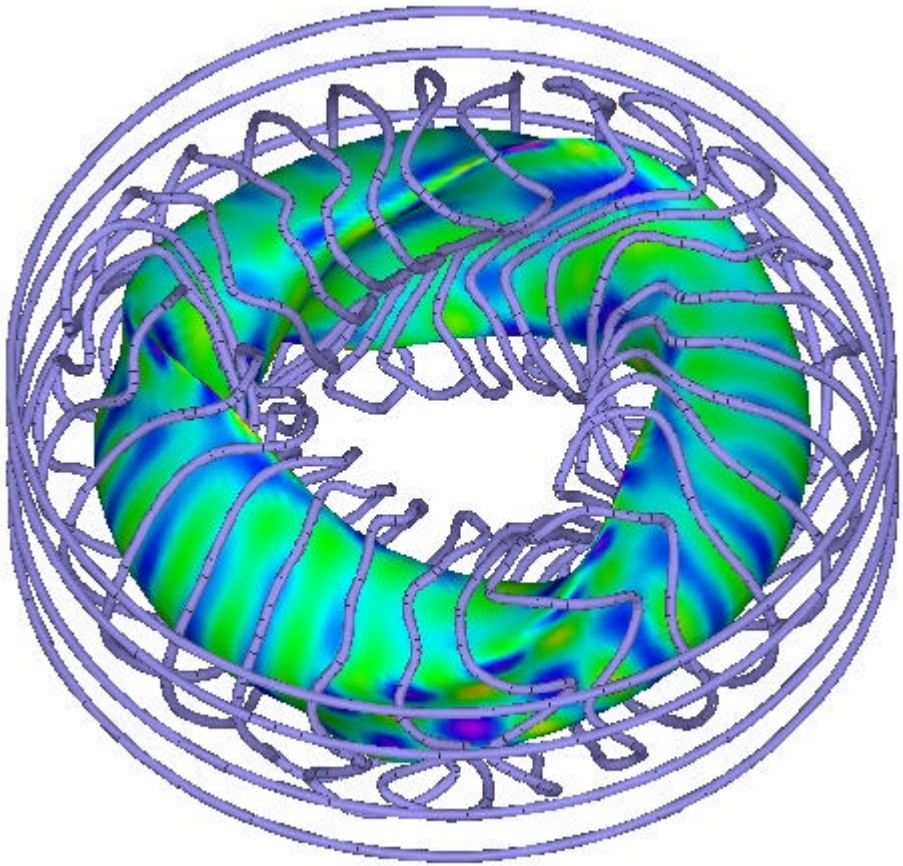
Modular Coils for NCSX

B-normal error for case c82a-0424a1



Modular Coils for NCSX

B-normal error for case c82a-0424a1



Summary

Modular coil optimization using COILOPT has led to a configuration with nine coils per period that accurately reconstructs the c82a reference equilibrium. Engineering feasibility with respect to conductor current density and plasma access is under investigation.