Coil Design for Candidate Configurations

NCSX Project Meeting

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Overview

- At last Project Meeting (Feb 23-24, ORNL) High Coil Current density was identified as perhaps the most critical issue affecting coil design for the c82 family of plasmas
- Work plans were put in place to address this issue on a number of parallel fronts.

Paths to Reducing Coil Current Density

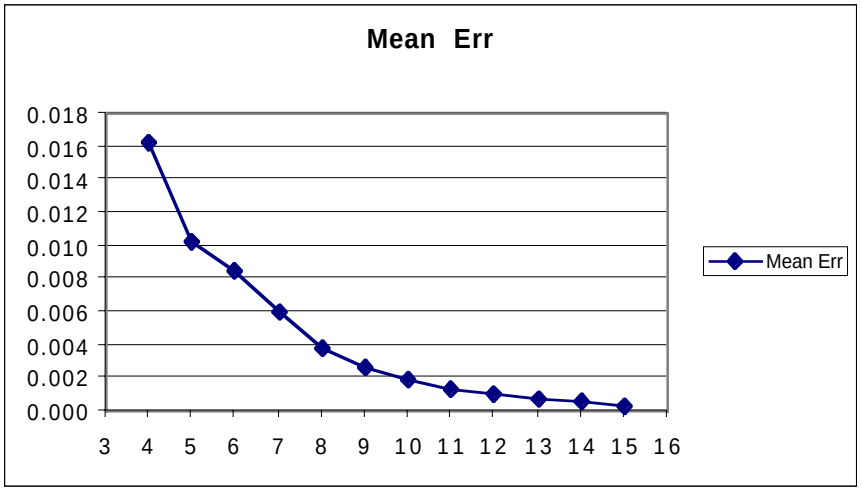
- Plasma Engineering Level
  - Incorporate NESCOIL into VMEC Optimization (Ku -> c85)
- Current Sheet Level
  - Scan Weights retained in NESCOIL SVD Solution (Valanju)
  - Scan Modes retained in standard NESCOIL
  - Scan Itor
  - Target Current density in NESCOIL (TBD)
- Coil Cutting Level
  - Reduce current density by reducing number of coils via contour level and current optimization. Because of fixed “dead” space between coils, fewer is better . (Pomphrey, Miner, Hirschman)
- Brute Force
  - Displace coils in regions of high current density to increase coil separation

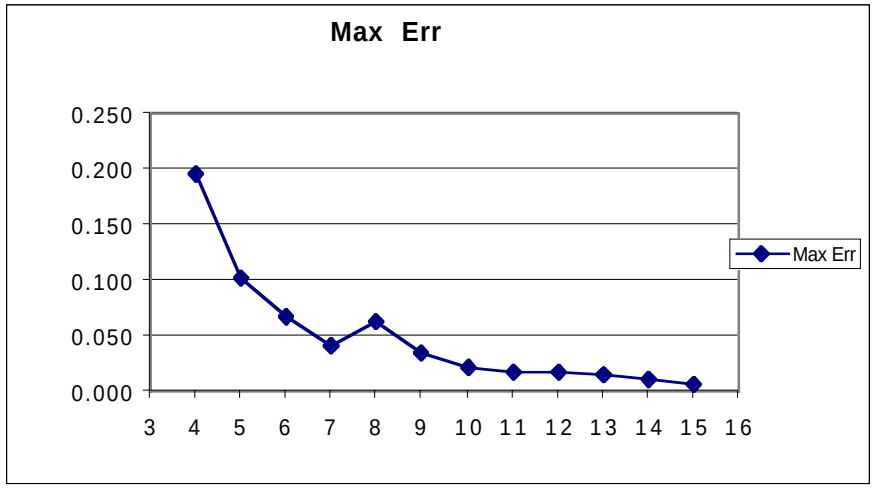
Reducing Coil Current Density at Current Sheet Level

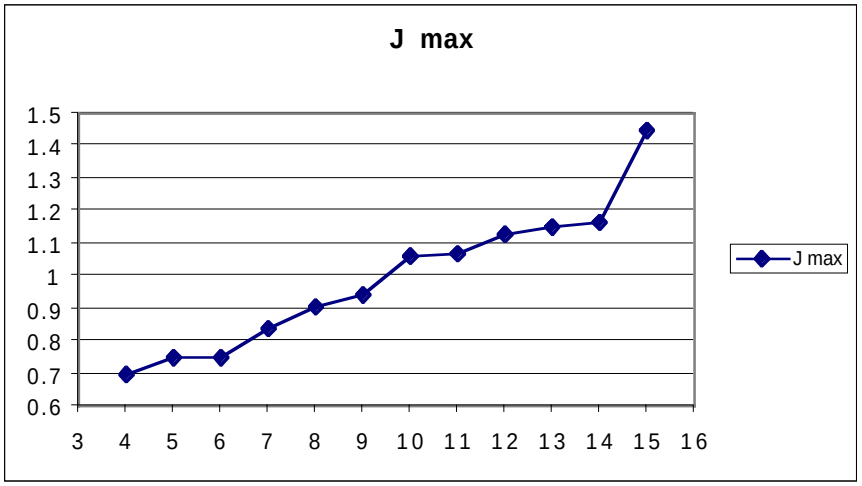
- Mode Scan
  - As expected, current density along with coil complexity can be reduced at the expense of field errors.
  - At < 10 modes field errors degrade plasma reconstruction (based on previous experience)
- SVD Scan
  - Results qualitatively similar to mode scan
  - At constant jmax,Standard Nescoil results in lower mean field errors on 18 cm surface. Presently investigating why.
- Itor Scan
  - Minimum current density (for c82) occurs at Itor=~0.

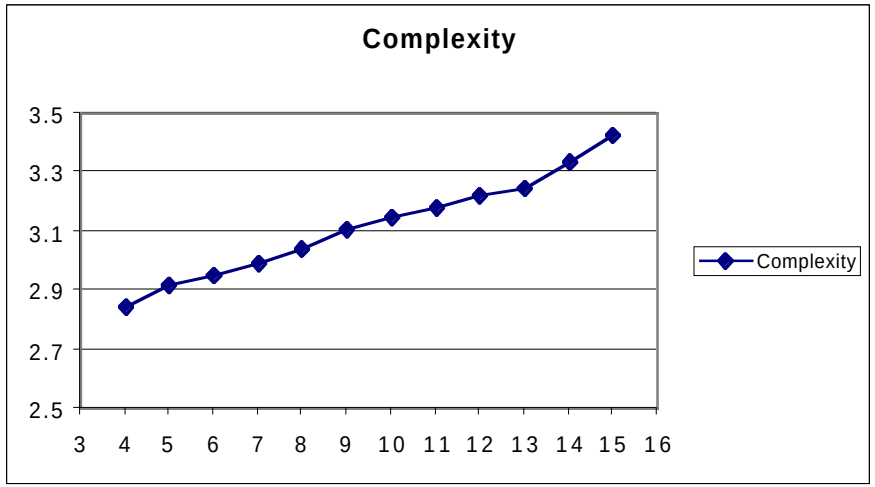
Mode Scan in Standard NESCOIL

Current Sheet Solution for c82 on 18 cm Surface, mf=nf



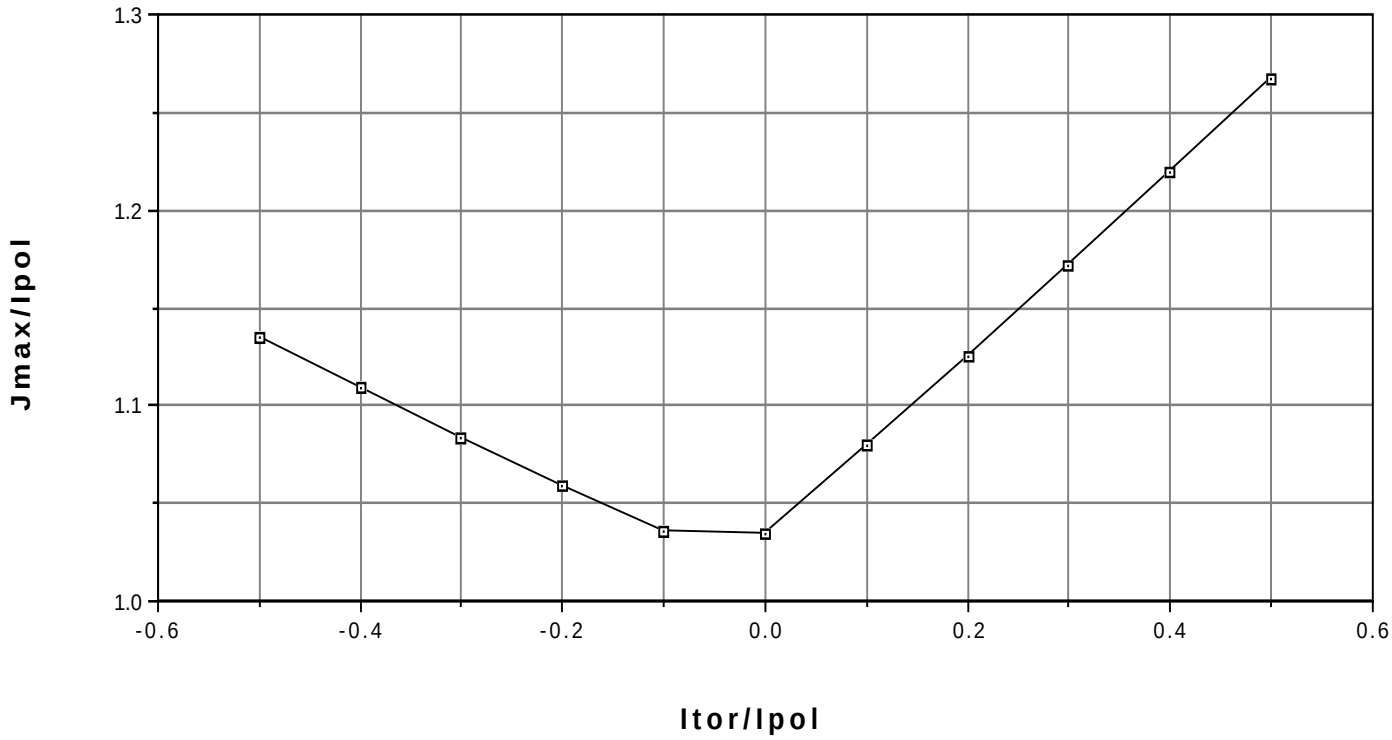






Already operating at minimun jmax
No further benefit found in varying Itor

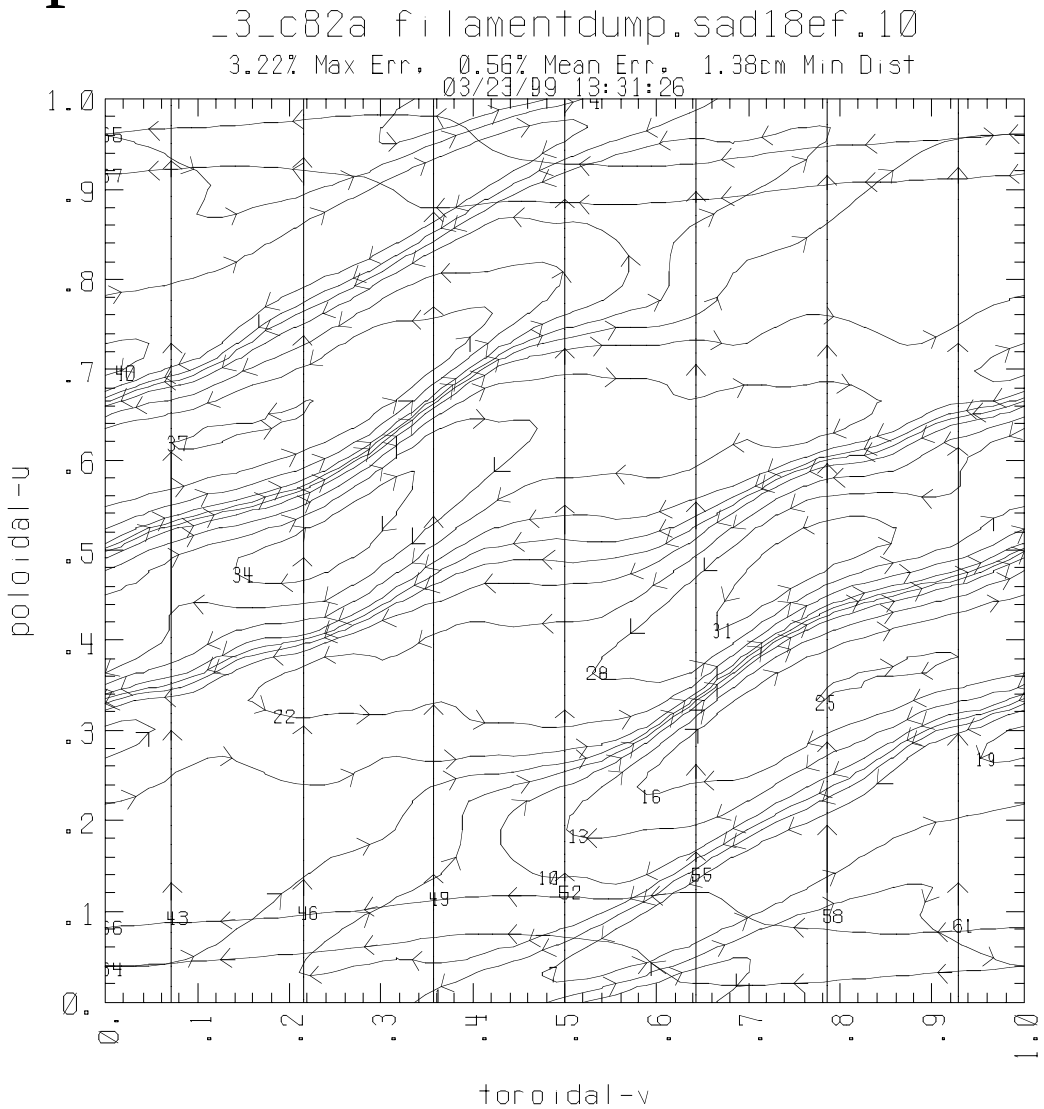
Current Sheet Solution for c82 on 18 cm Surface



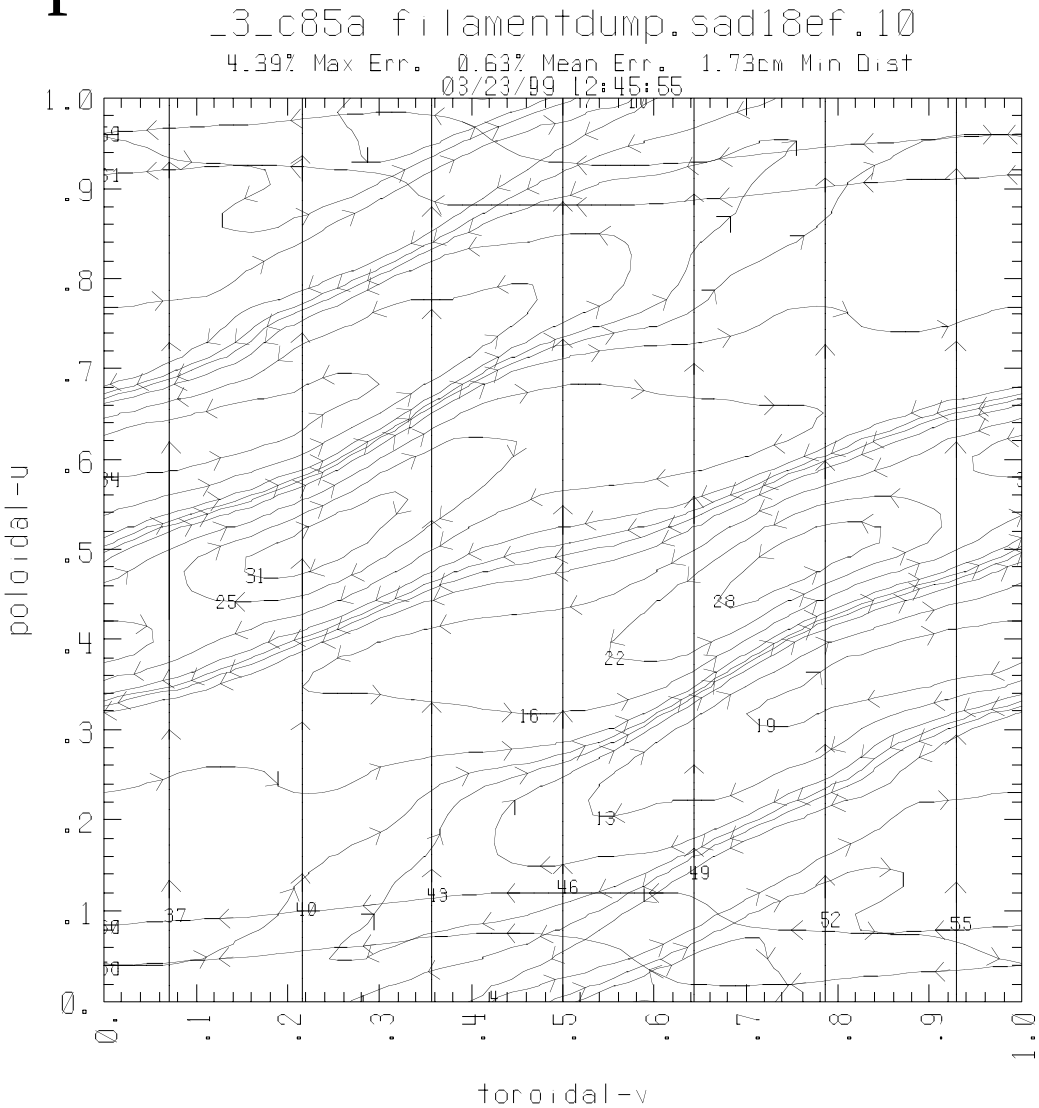
Reducing Current Density
Coil Cutting Level

- Optimized coil cutting code(s) have produced coil configurations with fewer coils at comparable field errors and reconstructions
- Fewer coils alone should lead to lower current density just because coils are further apart and the fixed allowance for intervening structure represents a smaller fraction of coil spacing: $j=I/(d-d_{fixed})$
- Lower current density not always achieved
- Codes are not optimizing directly to minimize current density

Optimized Coil Filaments for c82



Optimized Coil Filaments for c85



Optimized Contours
Comparison of Results for c82 ,c85 & c10

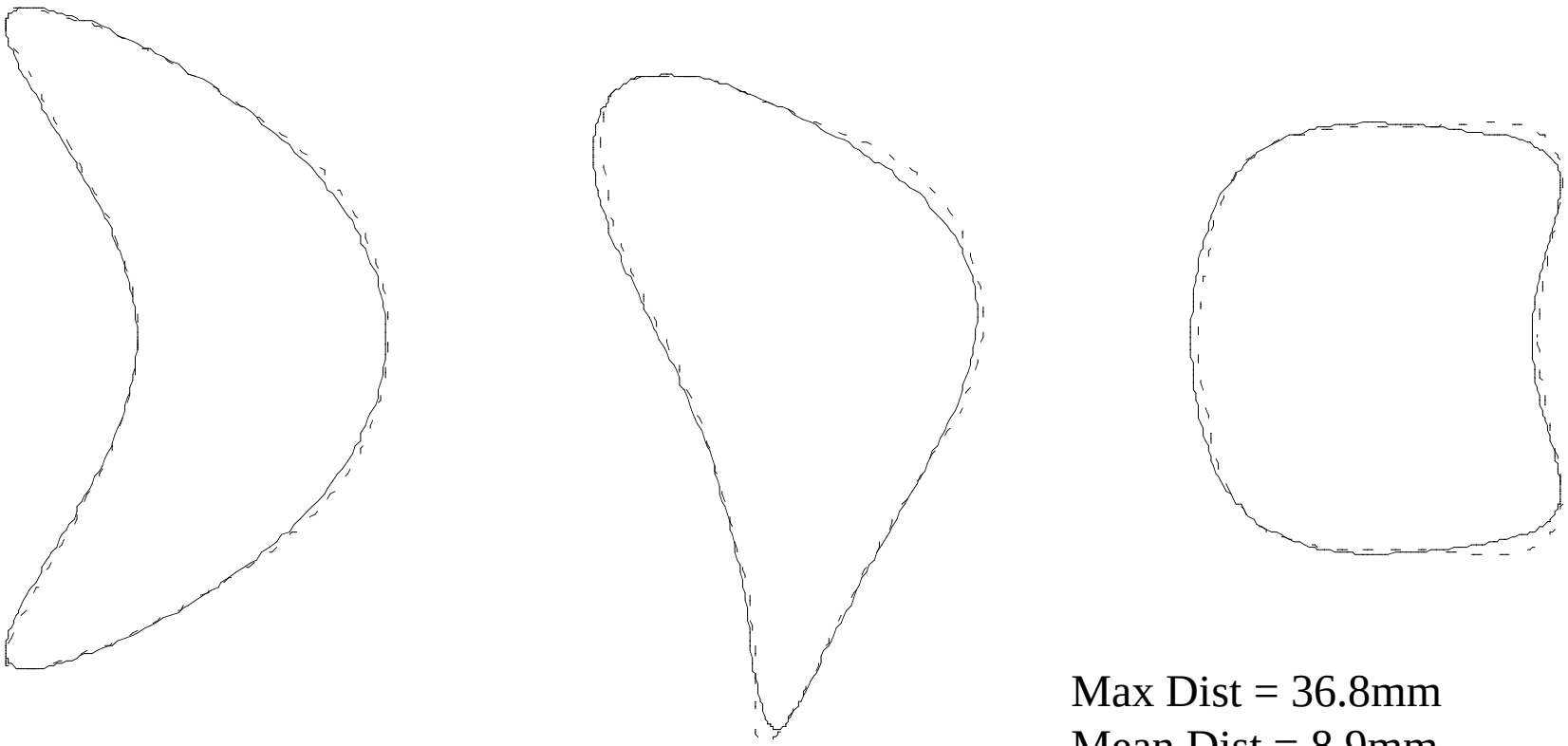
10 contours

Plasma	Coil Configuration	Free Boundary Separation, mm Max	Mean	Max Current Density* MA/m	Comments
c82					
	sad18ef.10	18.0	3.4	7.42	Optimized Contours
	sad18v.10.fbeta	36.8	8.9	3.93	Optimized Contours starting with Vacuum
	sad18_190.10	25.6	6.0	6.17	Optimized Contours from SVD
		(17.4)	(3.5)		Inproved Reconstruction
					by varing EXTCUR
c85					
	sad18ef.10	23.4	5.0	4.64	Optimized Contours
c10					
	sad18.10	13.4	2.9	3.92	Optimized Contours

* Assumes 8 mm ligament between coils. Does not include packing fraction

VMEC Free Boundary Reconstruction

c82 with 10 optimized vacuum contours, currents reoptimized for beta
sad18v.10.fbeta



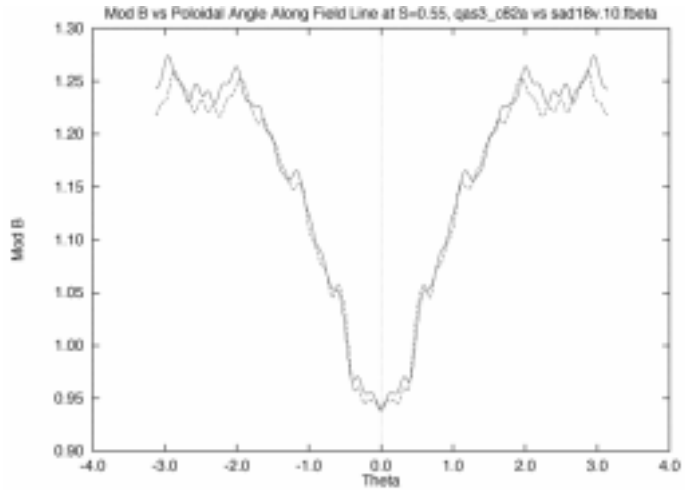
Max Dist = 36.8mm
Mean Dist = 8.9mm

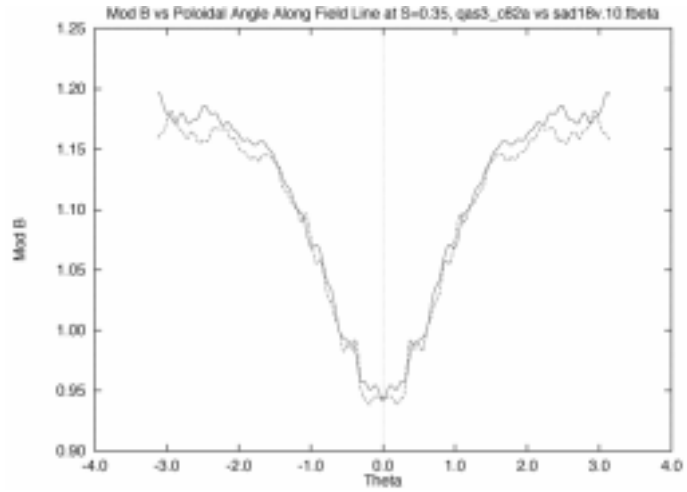
Post Reconstruction Evaluation

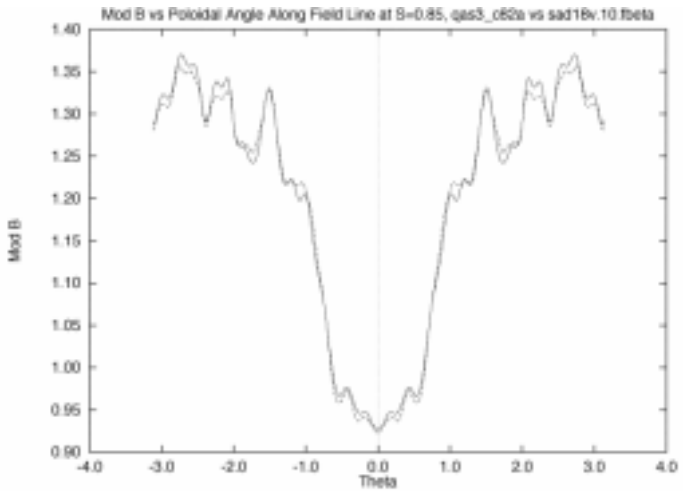
- The change in Chi-sq of the Mod B spectrum (sum[Bmn^2]) has been examined for all coil configurations reported and found to deviate less than 25%
- Kink Stability was evaluated for the worst case (c82 - sad18v.10.fbeta) and found to be acceptable (Ku)
- Transport evaluation (to my knowledge) has not yet been initiated.

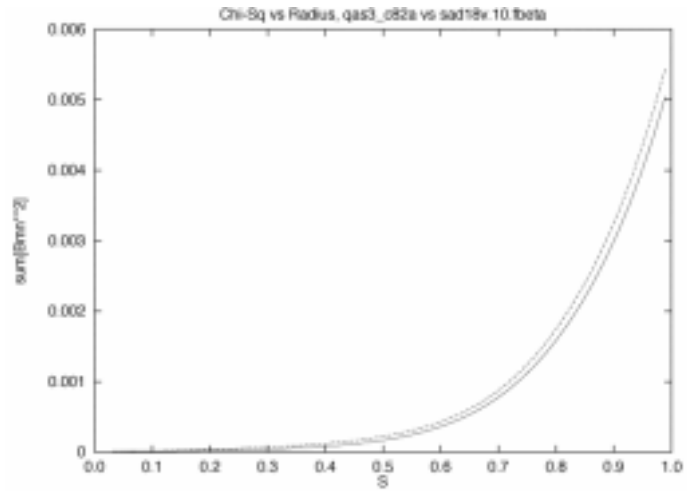
Mod B for Free Boundary

c82 with 10 optimized vacuum contours, currents reoptimized for beta
sad18v.10.fbeta









Brute Force Approach to reducing current density

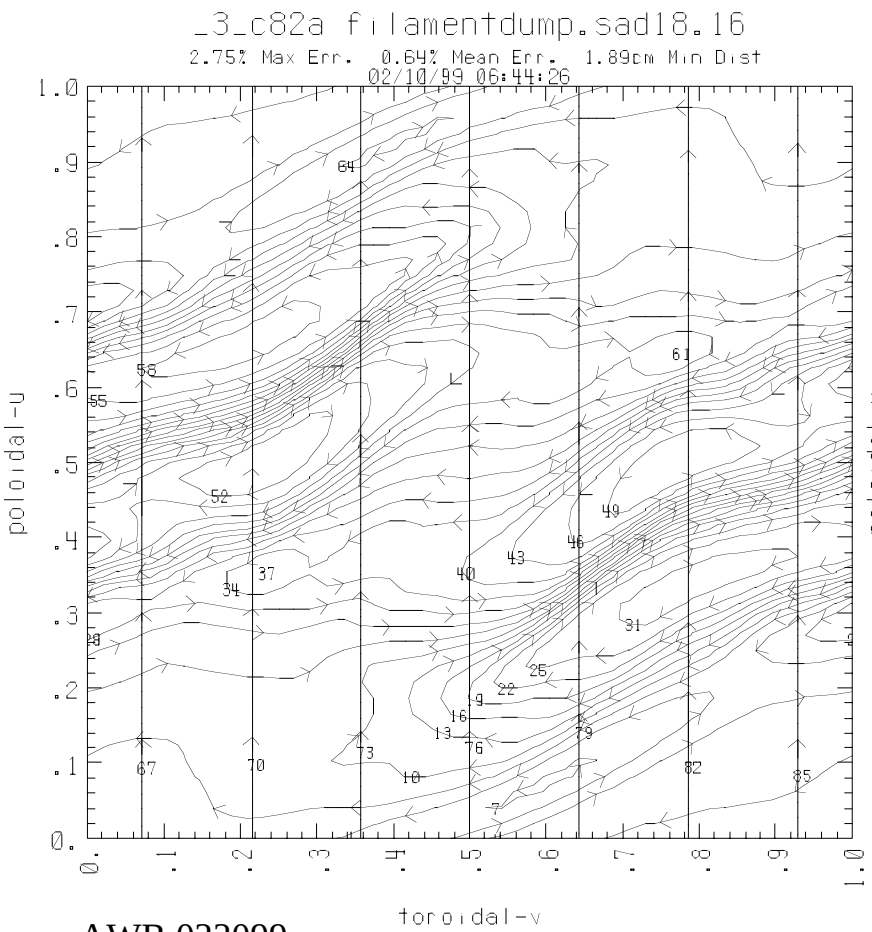
- Conductors are spread out along coil surface in regions of High Current Density.
- Consequently, conductors in these regions no longer follow contours lines
- To facilitate this, coil filaments are first mapped back to "u-v" space on coil surface. Underlining current potential used to determine degree of movement:
  - Conductors moved in direction of steepest gradient
  - Magnitude of imposed displacement given by:

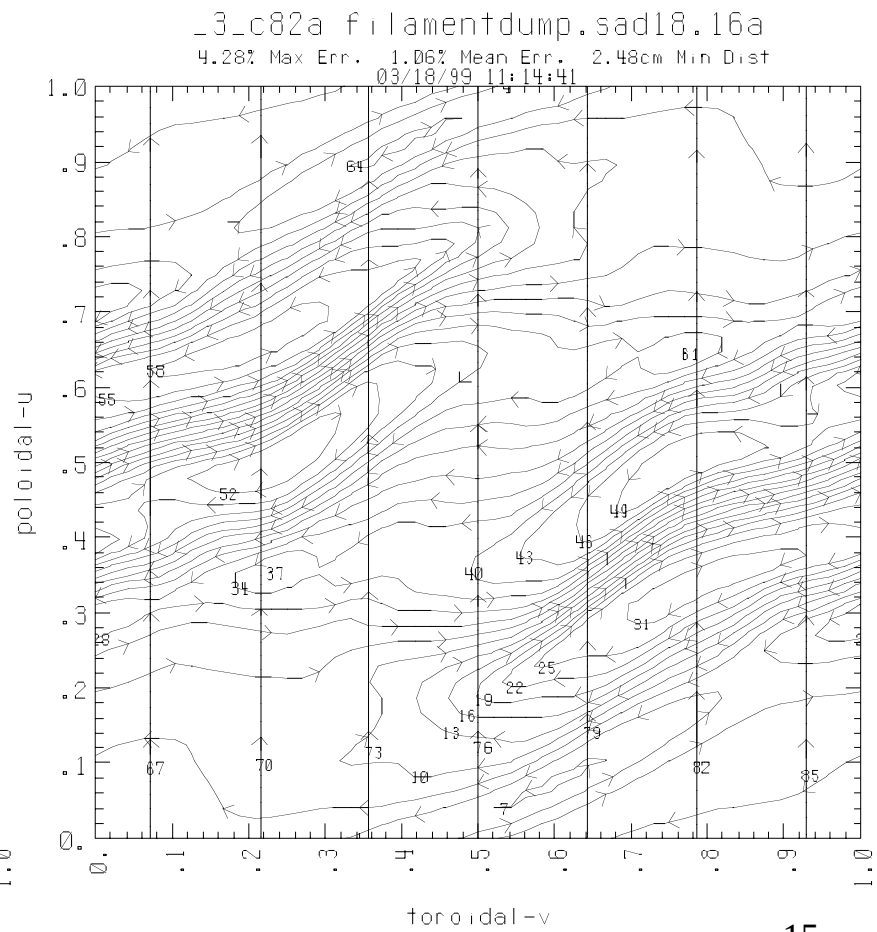
    $\delta=\delta_{max}*(\Phi/\Phi_{max})*(j_{abs}-j_{lim})/(j_{max}-j_{lim})$

    δ_{max} , and j_{lim} are manually adjusted until it "looks good"

Coils Spread out in Regions of High Current Density

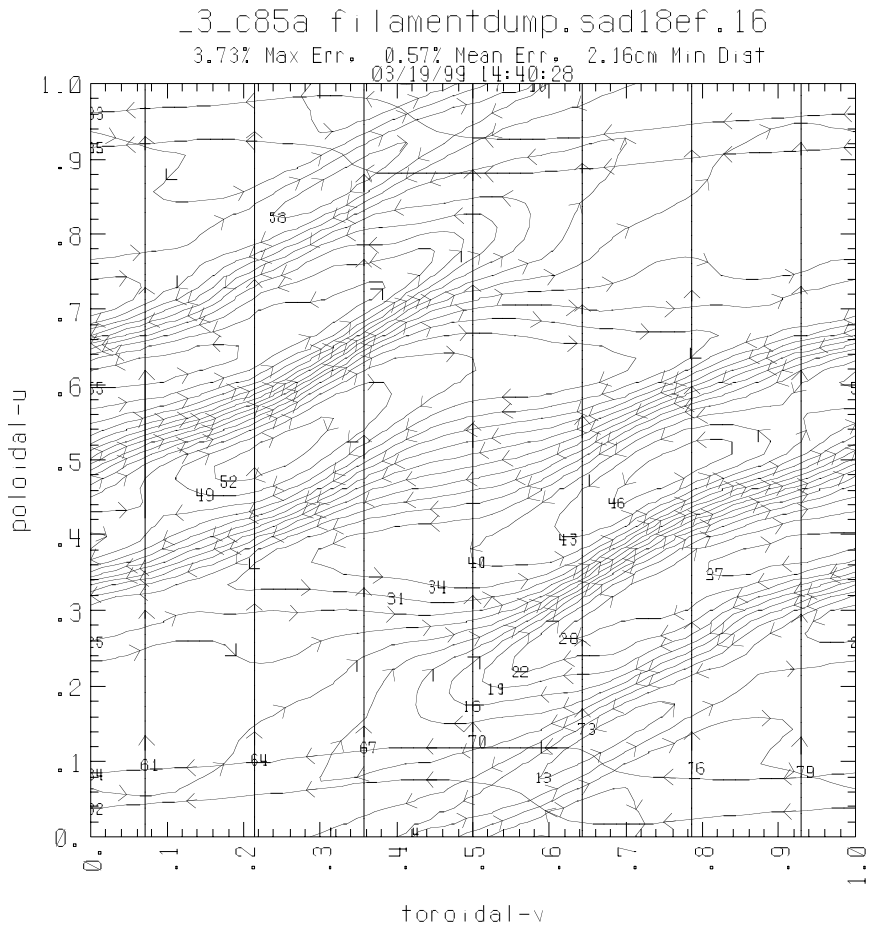
c82 with 16 uniform contours

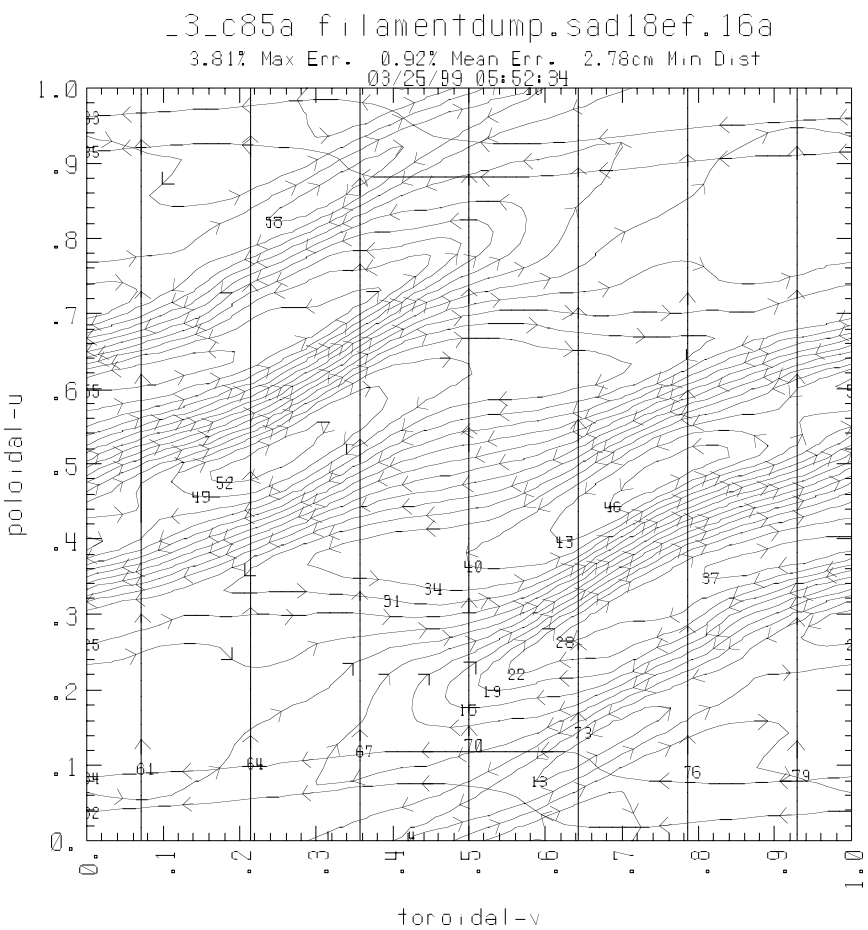




Coils Spread out in Regions of High Current Density

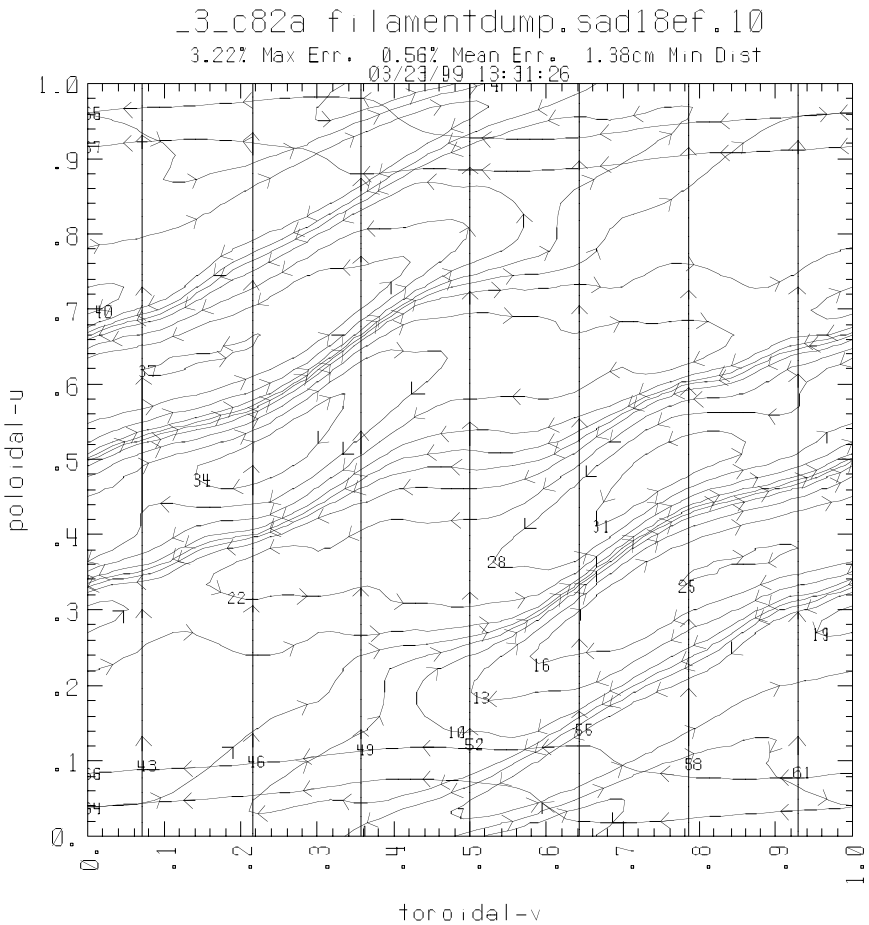
c85 with 16 uniform contours

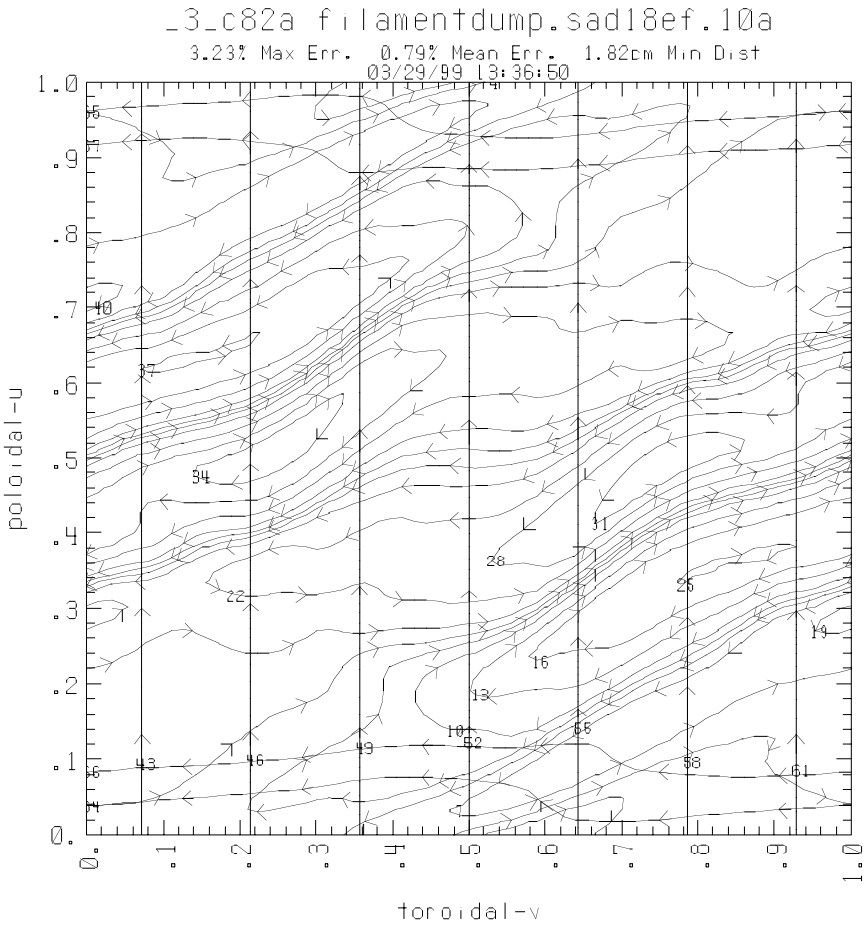




Coils Spread out in Regions of High Current Density

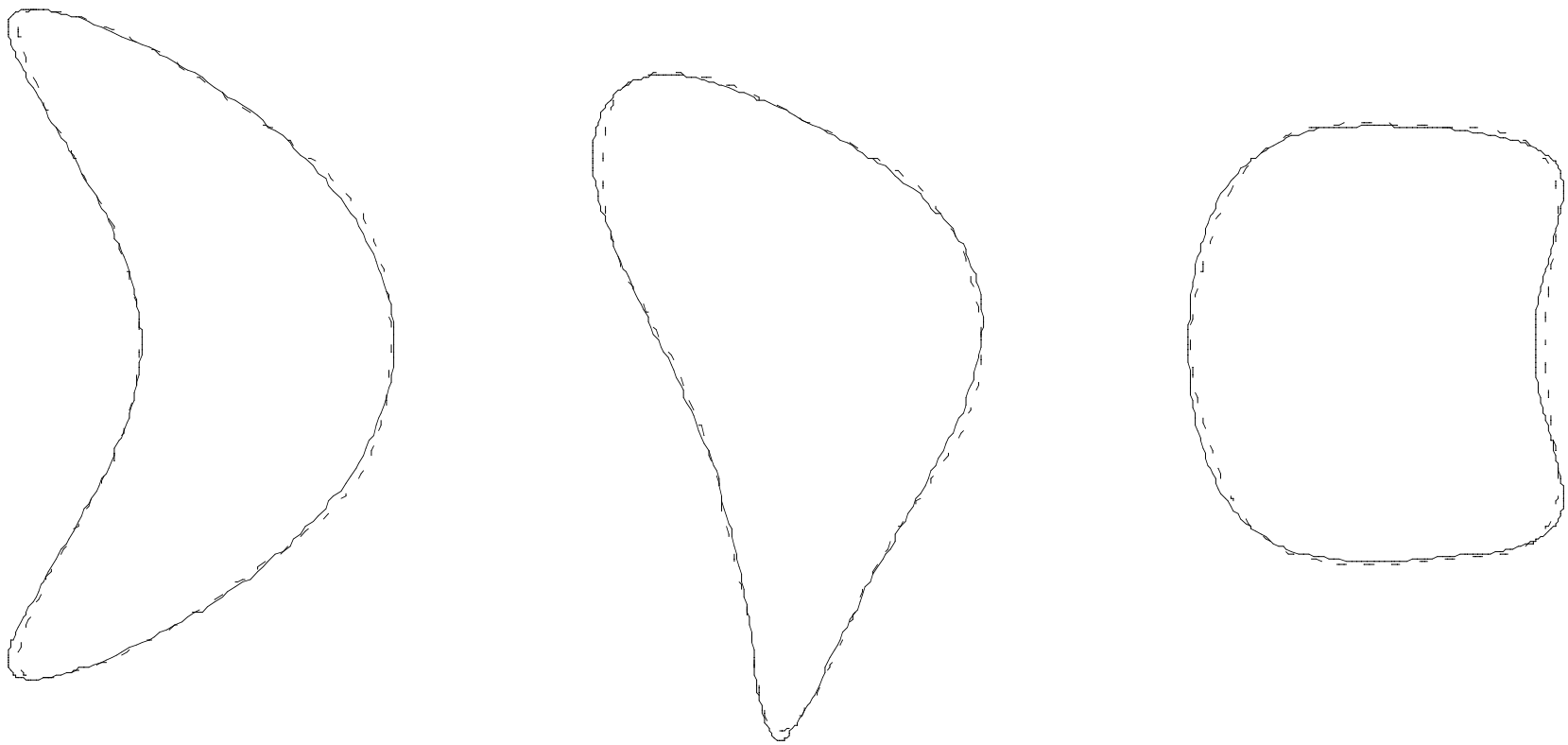
c82 with 10 optimized contours





VMEC Free Boundary Reconstruction

c82 with 10 optimized contours, then spread apart - sad18ef.10a



Spreading Coils Out
Comparison of Results for c82 & c85

Plasma	Coil Configuration	Free Boundary Separation, mm		Max Current Density*	Comments
		Max	Mean	MA/m	
c82					
	sad18.16	27.7	6.8	5.20	Uniform Contours
	sad18.16a	29.0	7.9	3.65	Uniform Contours Spread Apart
	sad18ef.10	18.0	3.4	7.42	Optimized Contours
	sad18ef.10a	23.1	6.2	3.90	Optimized Contours Spread Apart
c85					
	sad18ef.16	22.6	3.4	3.93	Uniform Contours
	sad18ef.16a	34.6	5.8	2.56	Uniform Contours Spread Apart

* Assumes 8 mm ligament between coils. Does not include packing fraction

Work Remaining

- The use of additional coils further away from plasma to handle some of the “low order modes” has not yet been addressed. The hope is this could further reduce current density
- We have returned in this exercise to targeting the full current, full beta point design. Other appropriate operating points need to be identified and evaluated for impact on current density
- Candidate coil configurations need further evaluation by physics

Summary

- By moving coils by hand, lower current densities relative to c10 have been achieved with 16 contours:
  - 3.92 MA/m in c10
  - 3.65 MA/m in c82 (or 3.90 MA/m with 10 contours)
  - 2.56 MA/m in c85
- By generating optimized coil contours in vacuum, and re-optimizing coil currents at full current, full beta, a comparable 10 contours solution has been obtained:
  - 3.93 MA/m in c82
- Again, other operating points need to be assessed