Coil Design Status for the QAS3_c10 Reference Plasma Configuration

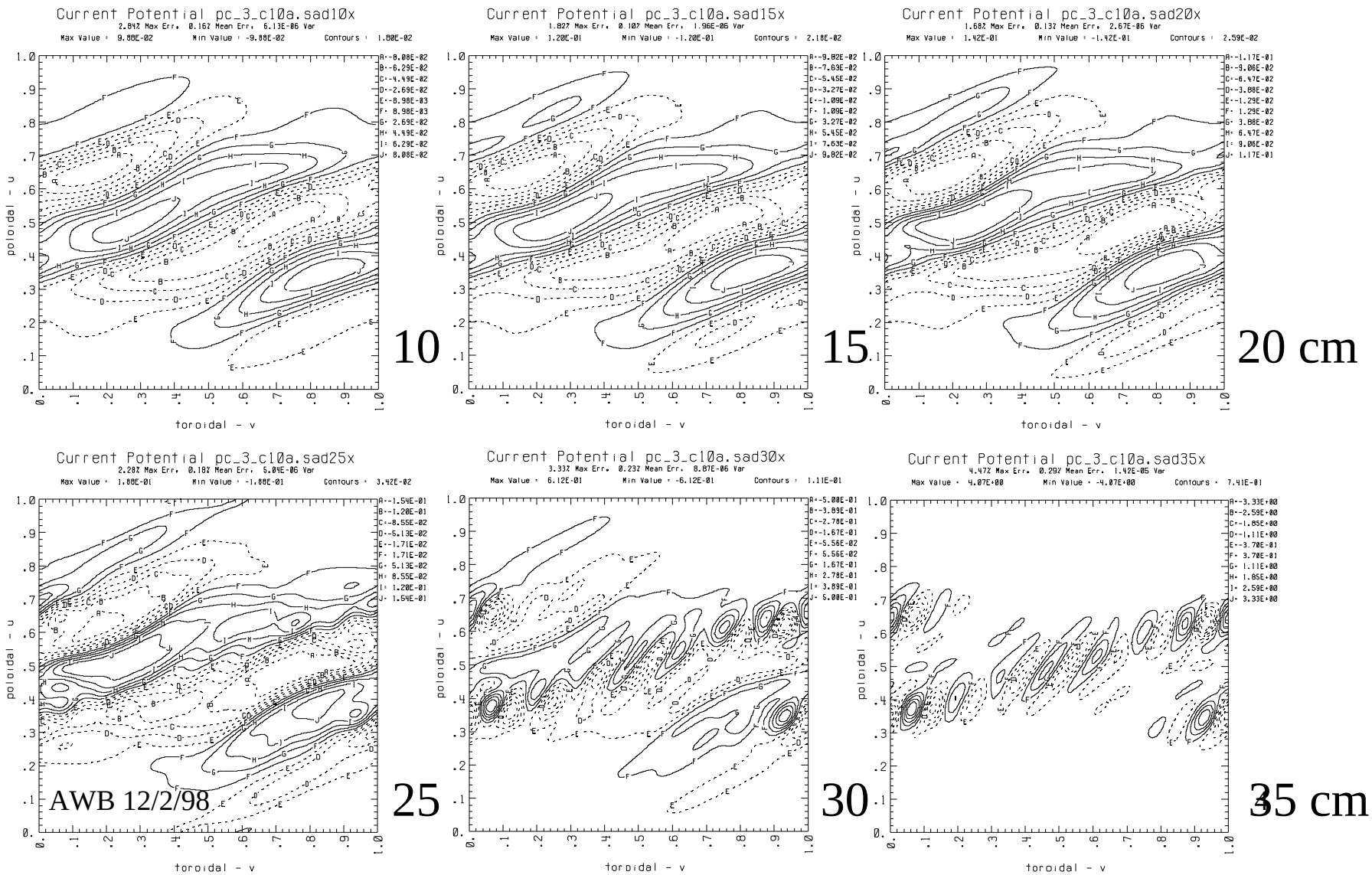
Overview

- Design Considerations
  - Coil to Plasma Separation (reactor scalability)
  - Current Density (pulse length)
  - Coil Complexity (manufacturing and ultimately cost)
  - Number of Coils (machine accessibility)
- Plasma Reconstruction Issues
  - Current Sheets
  - Discrete Coils
- Reversed Engineered Coils for the QAS_3_c10 Plasma
  - Saddle Coils for the in PBX option
  - Modular Coils for the New Machine Option

Design Considerations

- Current Sheet to Plasma Separation has significant effect on coil complexity and maximum current density (i.e. coil size)
  - Current sheets want to be *close* to plasma to reduce both coil complexity and maximum current density
  - Current contours can be smoothed by reducing number of fourier modes used to represent potential but sacrifices accuracy of fit
- Discrete Coil to Plasma Separation affect number of coils needed to overcome ripple effects
  - Coils want to be *further away* from the plasma to reduce number of coils
  - Finite build coils shown to improve accuracy of fit in most cases

Current Sheets for Saddle Coils More Complex With Increased Plasma Separation



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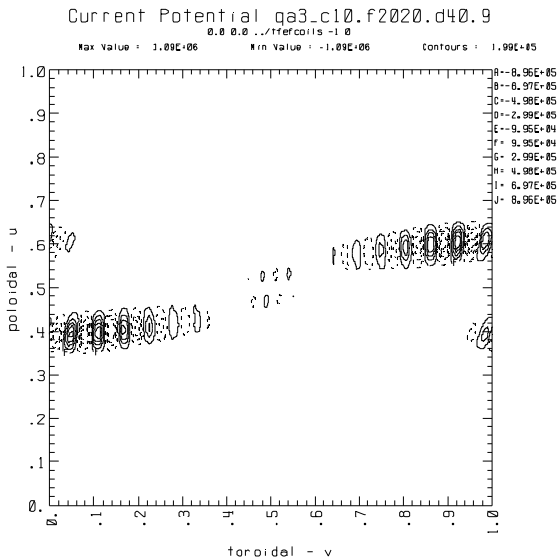
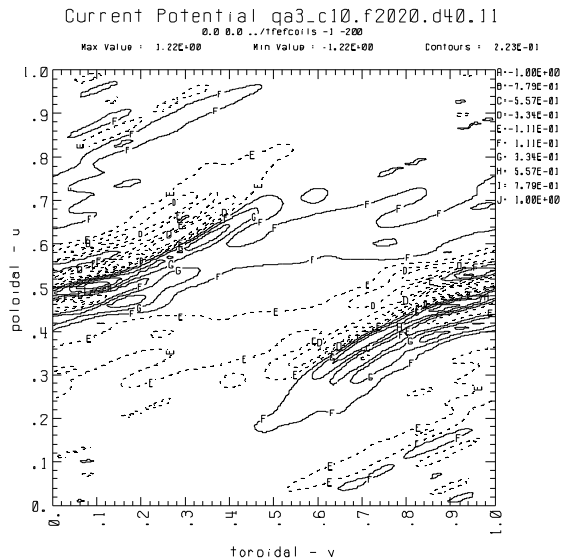
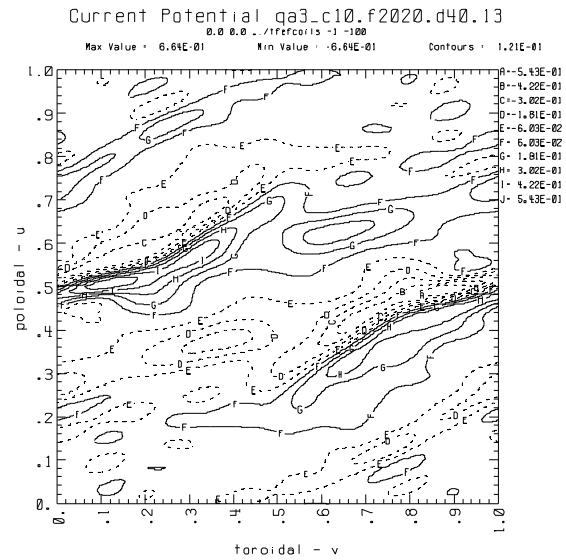
SVD can improve things without significant loss in accuracy







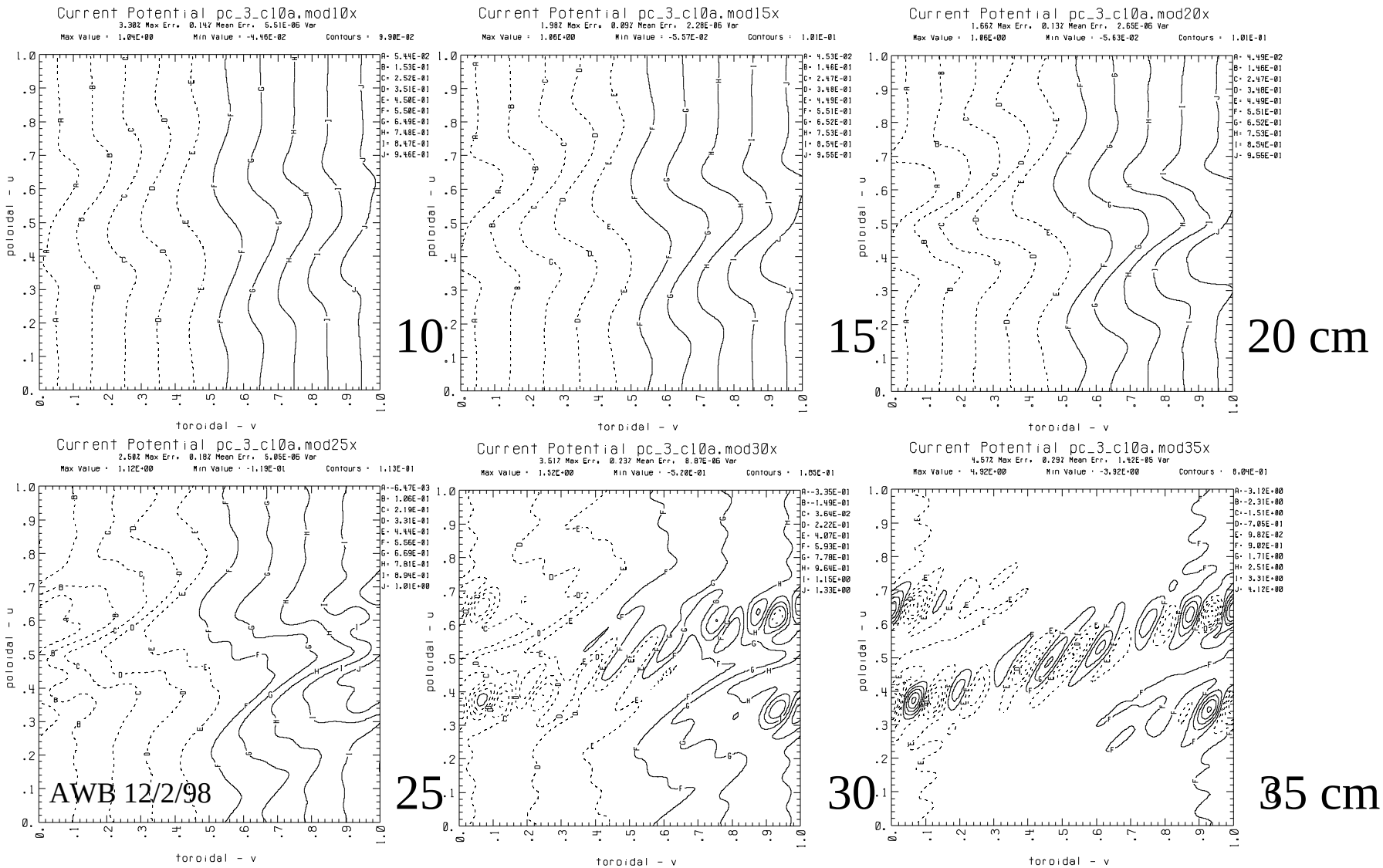
Max Err = 0.34%
Mean Error = 0.02%
861/861

Max Err = 1.60%
Mean Error = 0.16%
200/861

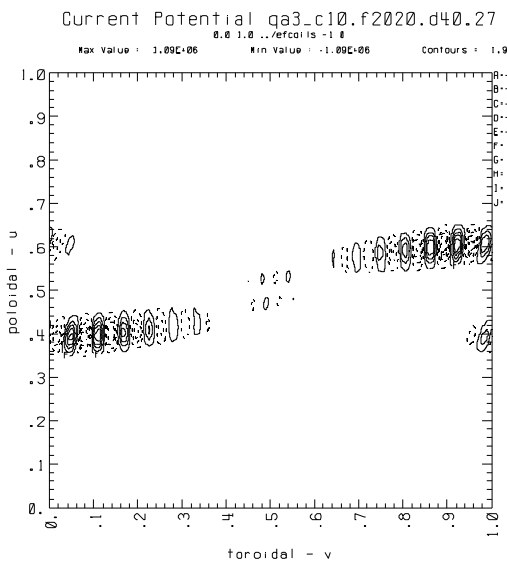
Max Err = 3.18%
Mean Error = 0.63%
100/861

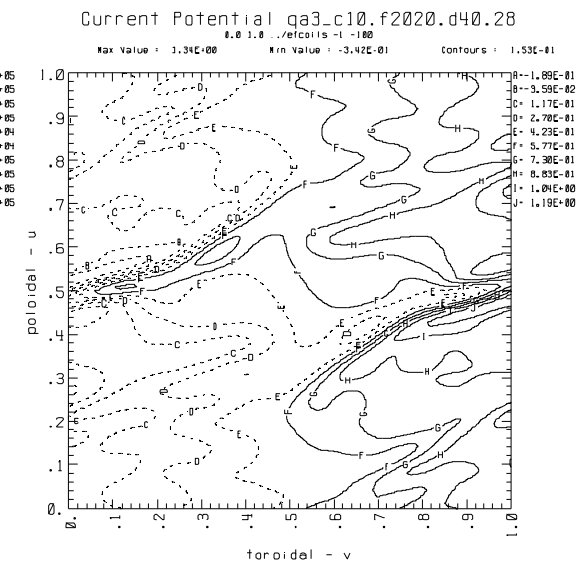
All on 40 cm Surface Offset

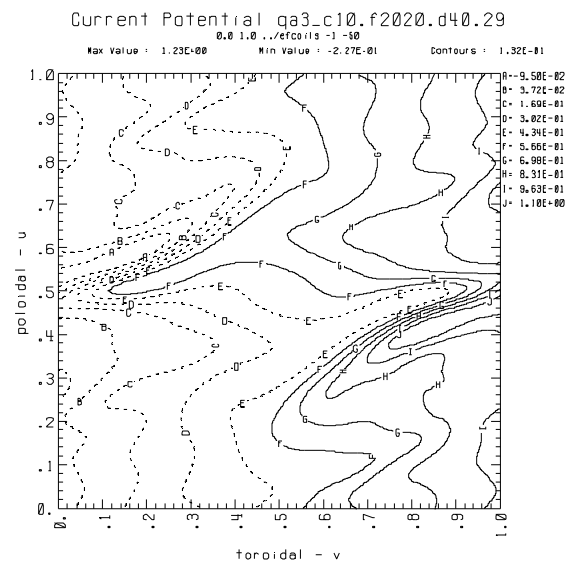
Current Sheets for Modular Coils More Complex With Increased Plasma Separation



Again, SVD can improve things without significant loss in accuracy







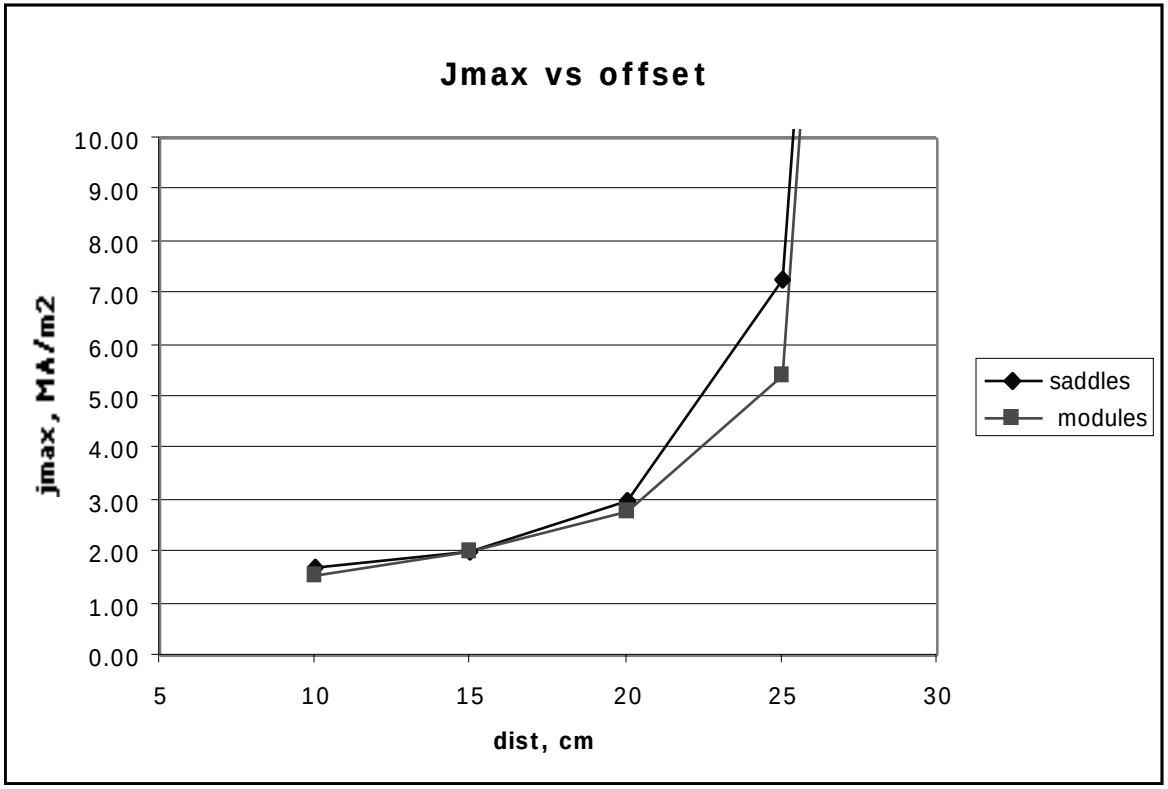
Max Err = 0.34%
Mean Error = 0.02%
861/861

Max Err = 3.14%
Mean Error = 0.60%
100/861

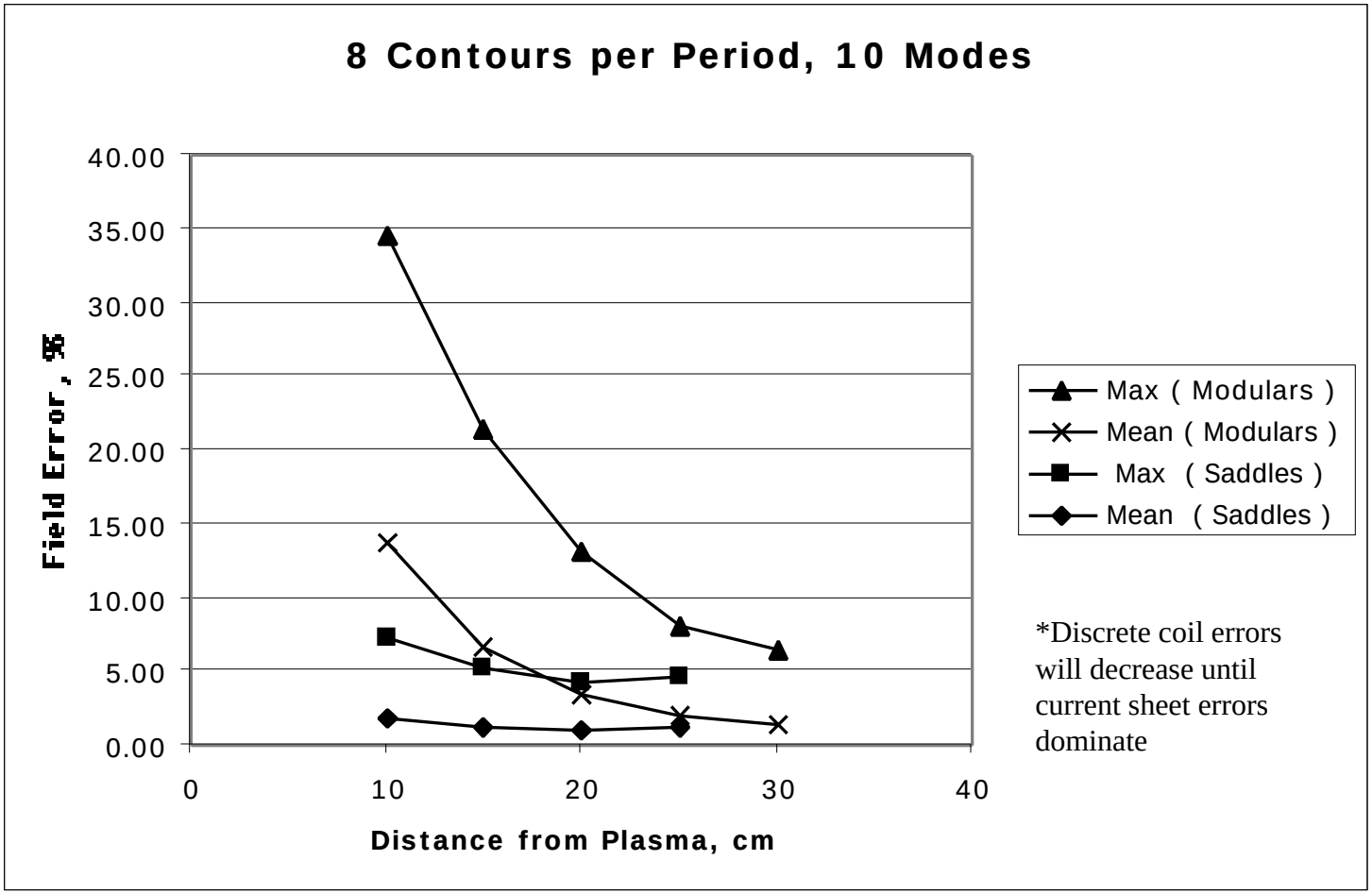
Max Err = 5.11%
Mean Error = 0.94%
50/861

All on 40 cm Surface Offset

Current Density Increases Significantly with Offset from Plasma



Field Errors from Discrete Coils Decrease* with Offset from Plasma



*Discrete coil errors will decrease until current sheet errors dominate

Plasma Reconstruction Status

- Successfully reconstructed plasma from saddle, modular and ‘helical’ current sheet solutions (on 20 cm Surface)
  - Provides reassurance that Fix Boundary VMEC to Bnorm_code to NESCOIL to Free Boundary VMEC loop is working properly
  - Difficulty lies with coil discretization effects
- Reconstructed plasma using large number of discrete filament coils for modular, saddle and helical designs
  - Demonstrates that with large numbers of coils current sheet solution can be approached
  - However, needed to fully cover surface with coils. Reconstruction not successful when coil to coil spacing large.

Plasma Reconstruction Status, cont'd

- Using more reasonable numbers of coils has failed to reconstruct even in cases where max/mean errors are comparable to current sheet solution.
  - These are the max/mean errors coming out of standard NESCOIL

- Resonance Errors at Plasma Surface believed to be cause
  - First, need to verify this using tools presently under development.
  - Next, need to modify coil design codes to suppress resonance error terms.

QAS3_c10 Reconstruction Status
(on 20 cm surface)

	#Coils	Errors, %		Reconstruction Status	
	(per)	Max	Mean	<M>	Remarks
Current Sheet					
Saddle	-	2.12	0.15	2.296	Very Good
Helical	-	2.12	0.15	2.310	Very Good
Modular	-	2.11	0.15		Did not try (expect very good)
Discrete Coils					
Modular	20	2.22	0.17	2.646	Fair (slightly Bumpy)
Modular	60	2.09	0.15	2.295	Very Good
Helical	14	2.16	0.19	4.107	Poor (Very Bumpy Surfaces)
Helical	30	2.34	0.23	2.276	Very Good
Saddle	11	4.41	0.79	2.776	Fair-Poor (moderately bumpy)
Saddle	30	2.25	0.32	2.460	Good (still visibly off)
Saddle	60	2.27	0.21	2.296	Very Good

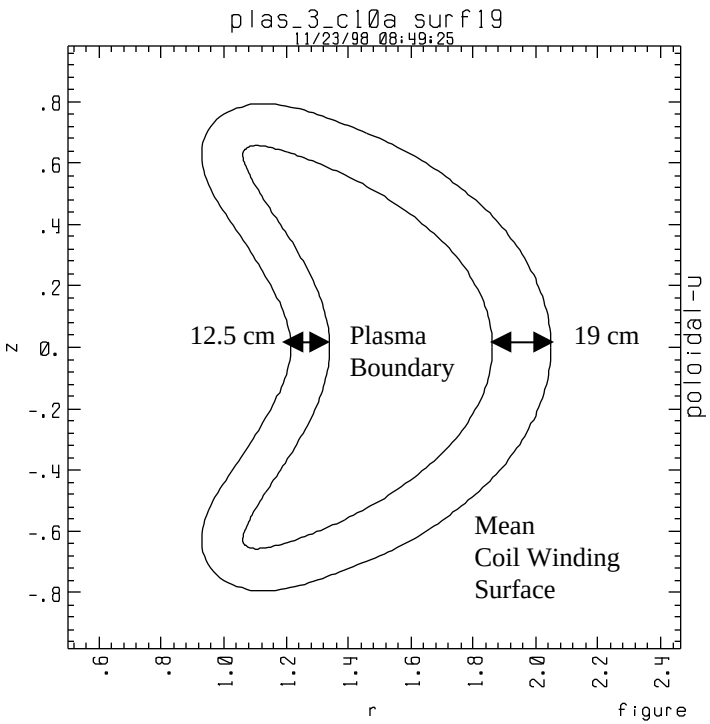
Reversed Engineered Coils for the QAS3_c10 Plasma

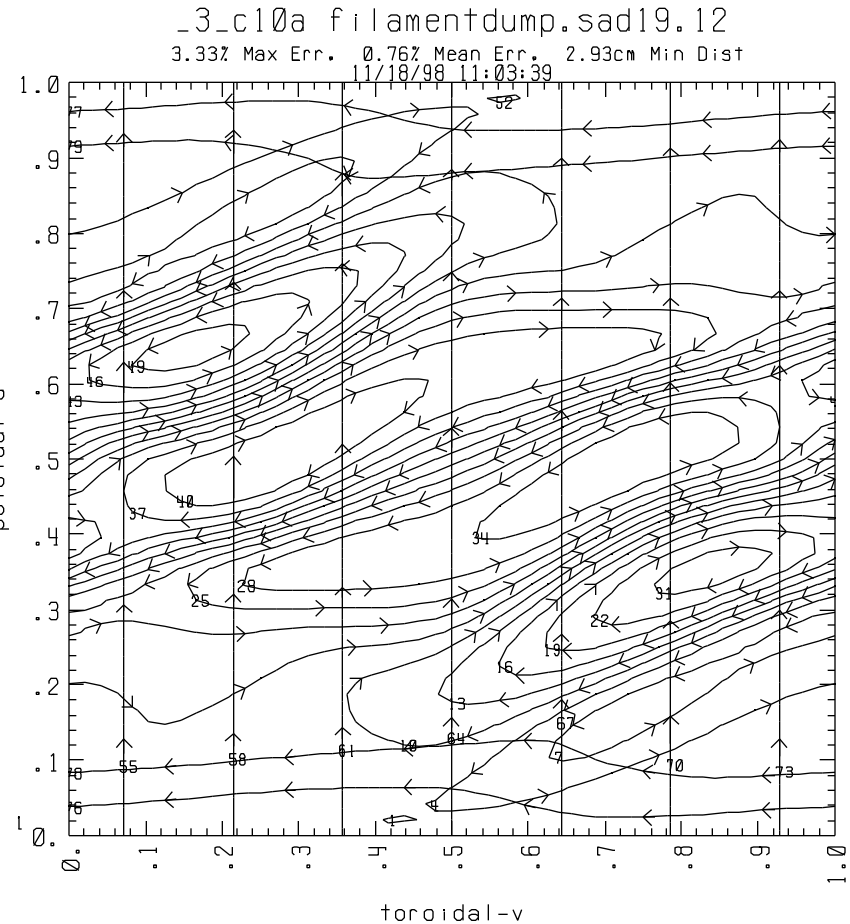
- In parallel to efforts to develop SVD and Resonance suppression tools, Design activities have forged ahead utilizing coils developed with the original version of NESCOIL
- Difficulties encountered with optimization tools have led us to manually search for improved surfaces, balancing the need for low field errors with simpler coil designs

Coils for In PBX option

- Saddle Coil Configuration
- Reuses Existing TF and EF coils and Vacuum Vessel
- Saddle Coils located inside VV
- Coil Surface moved closer to plasma inboard to minimize current density
- Larger number of coils required (48) for comparable field errors
- Machine access provided by sparse coil coverage outboard

Saddle Coils for QAS_3_c10

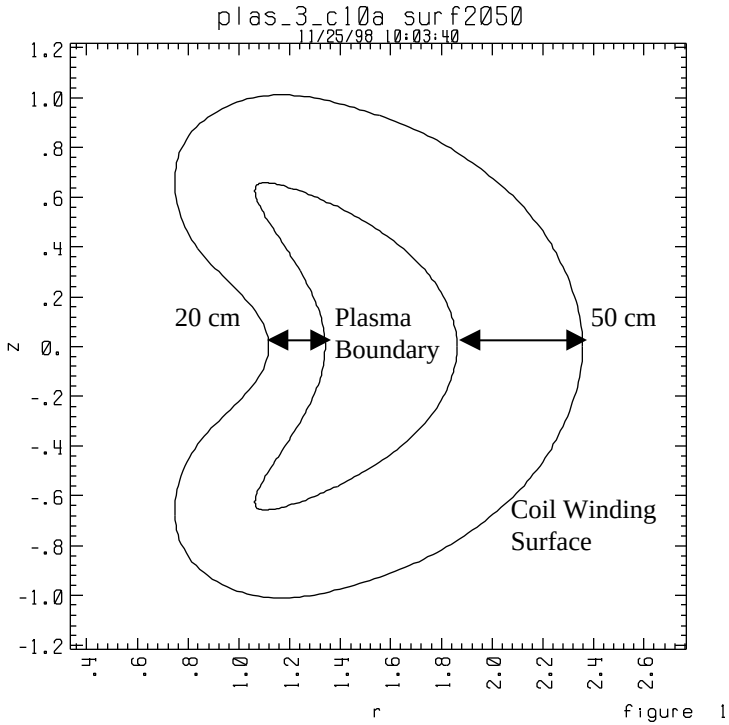


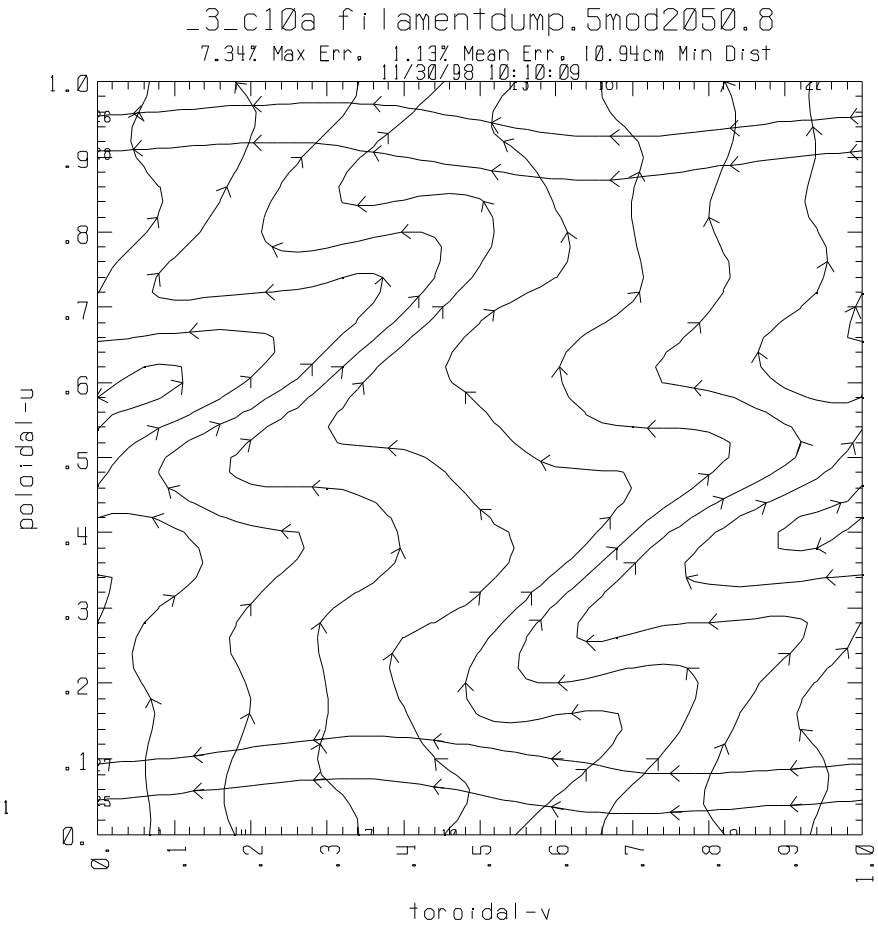


Coils for New Machine Option

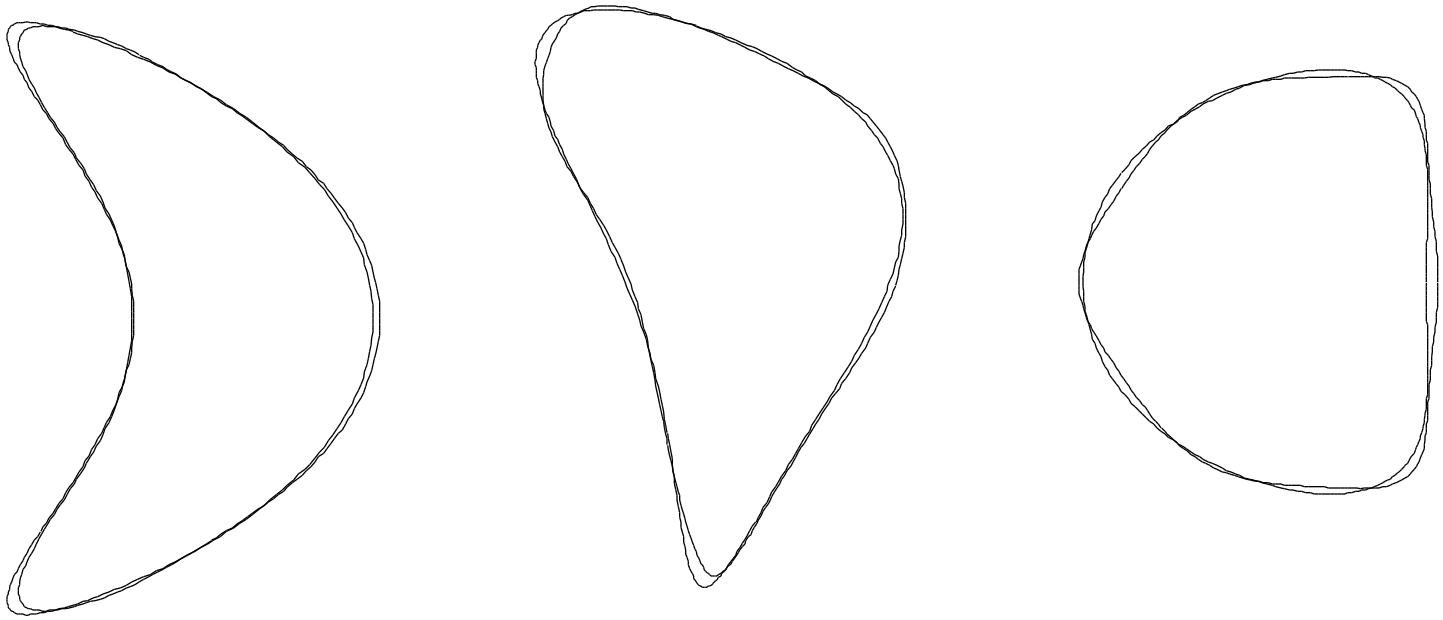
- Modular Coil Configuration
- All new coils (may be able to use some OH Coils)
- New Vacuum Vessel with coils external
- Coil Surface pushed away from plasma outboard to minimize number of coils (24) and maximize machine access
- Number of modes representing current potential reduced to smooth coils at expense of field errors

Modular Coils for QAS_3_c10





“Fair” Plasma Reconstruction with 8 Modular Coils per Period



	Radius, axis,	beta, %	Aspect Ratio	Volume, m3	iota(s=0)	iota(s=1)	R*Btor
Free Boundary	1.62	3.98	3.45	5.32	0.26	0.46	1.65
Fixed Boundary	1.61	3.93	3.43	5.27	0.26	0.47	1.65

(Similar Reconstruction with Saddle Coils for In PBX Option not yet achieved)

Summary

- Reverse Engineering process works.
  - Can generate coils of varying topologies which match field at plasma boundary
- Further code development expected to lead to simpler designs
  - SVD techniques to smooth coils
  - Resonance suppression to reduce number of coils needed for Plasma Reconstruction
  - Improvements in optimization routines