Status Report on Xerror Targeting

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Goals: For each VMEC plasma under consideration

- Design filamentary coils which satisfy the following criteria:

  A. PIES free boundary reconstruction shows surfaces that are "almost as good" as original VMEC plasma

  B. Coils are "acceptable" from engineering viewpoint

Methods Available Today:

- **Nescoil-Svd-Xerr** for surface currents and discrete coils
- **PIES** reconstruction from discrete coils
- Island-width estimation and targeting with **Curropt**
- Xerr targeting with **Coilopt** discrete coils on variable surface

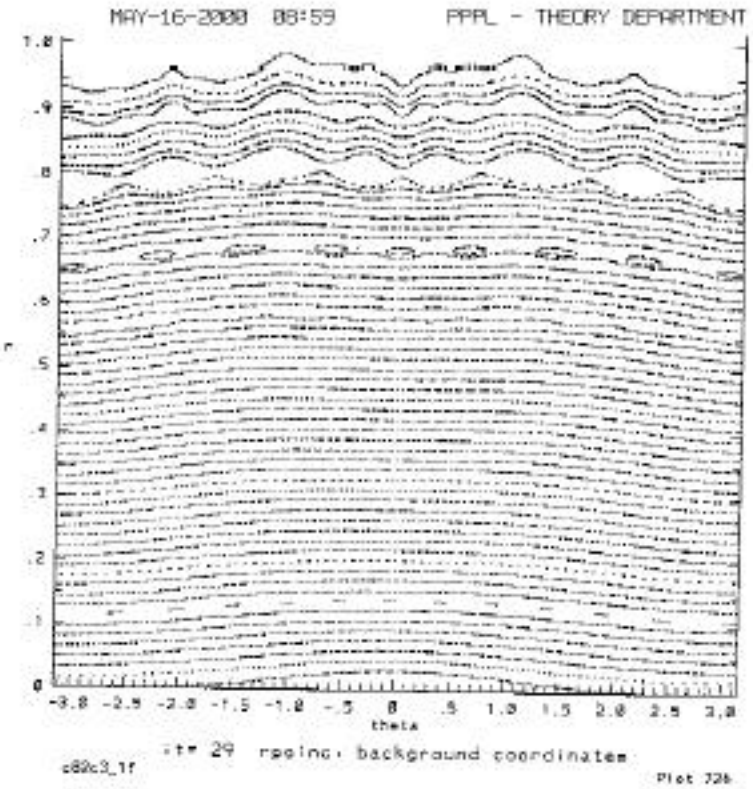
C82 Xerror Targeting Status

Efforts completed for c82:

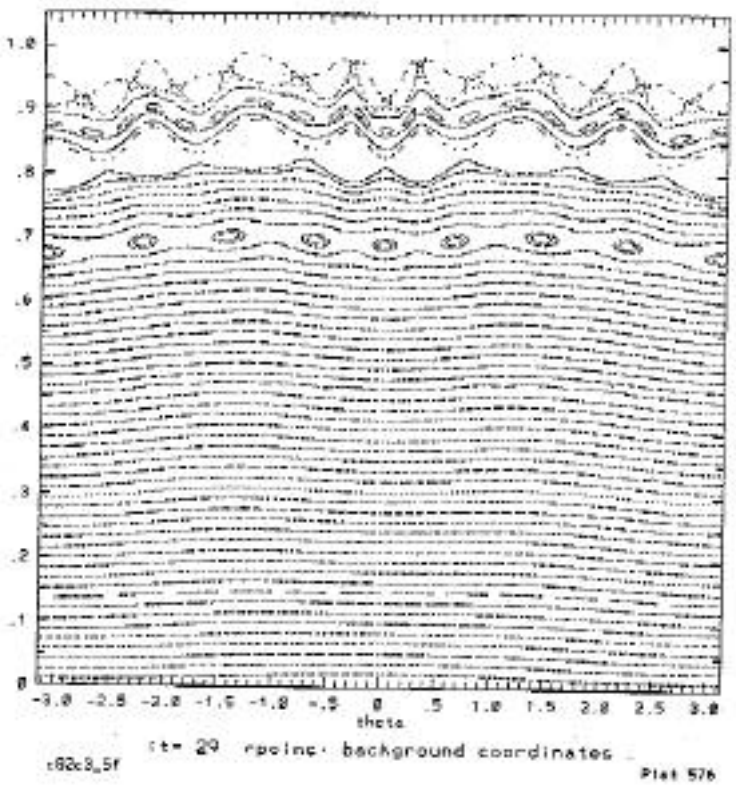
- Xerr and Berr targeted nescoil-svd optimized surface currents and 5,10,15,30 coils/period calculated and given to PIES
- PIES reconstruction for 30 coils/period shows better surfaces near plasma edge for Xerr targeting than Berr
- Small reduction of islands inside plasma - as expected because Xerr is calculated on plasma surface
- Zero beta full current case (has acceptable PIES plasma)
- Conformal 18 cm fixed surface was used.
- Xerr was not optimized by moving coil surface.
- Xerr down, Berr up => VMEC plasma surface moves?

C82, zero beta full current 18cm Xerr vs Berr nescoil-svd targeting

30 coils/period (almost same as surface current)

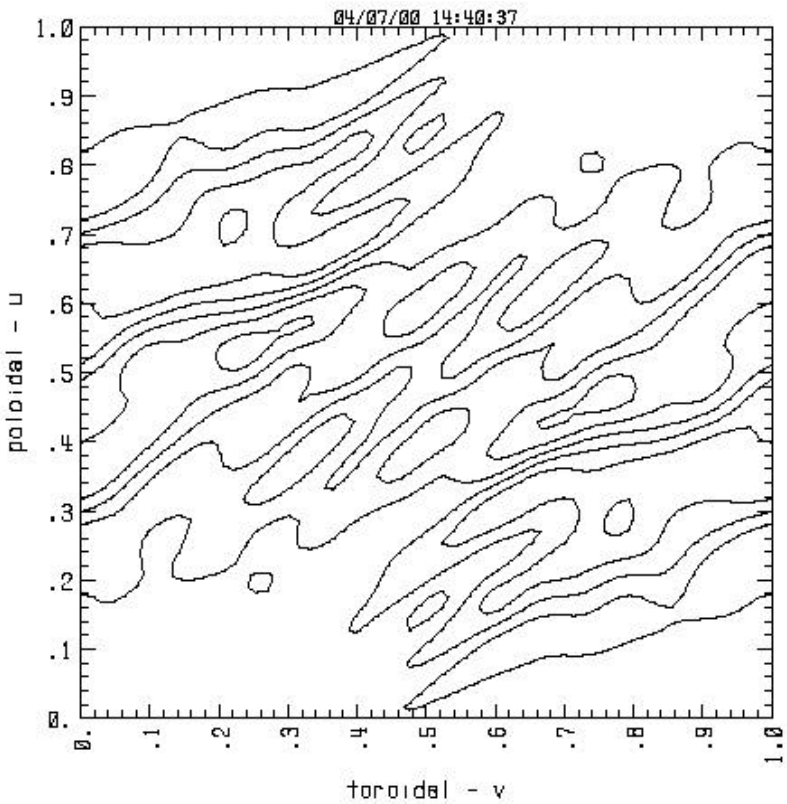


Case 100 : Xerr target

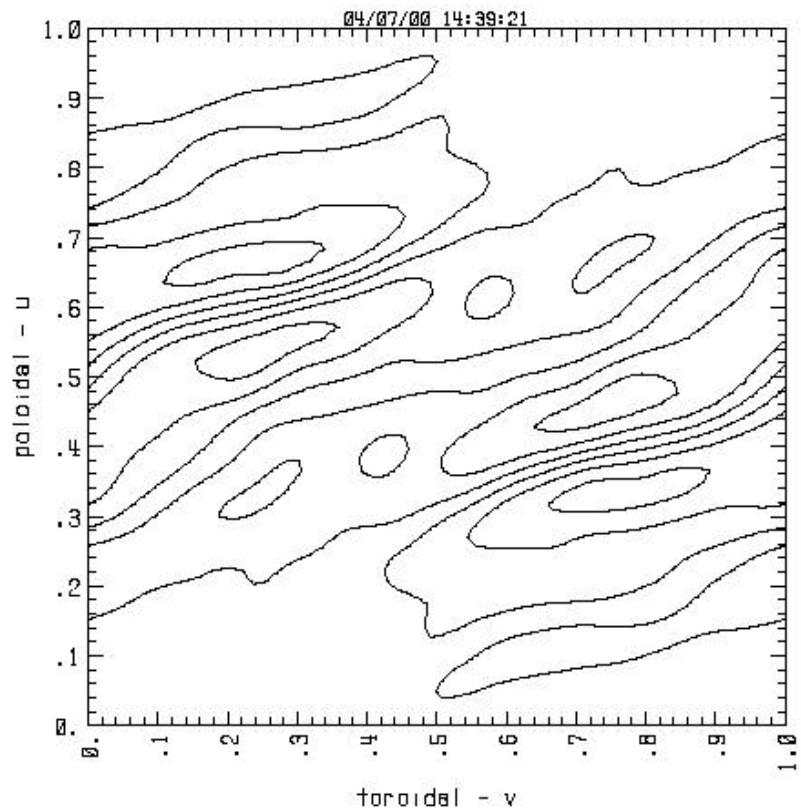


Case 98 : Berr target

#, Target	<Berr>	<Xerr>	Jmax	**Complexity**	**Max D cm**	**Ave D cm**
98: Berr	0.6003	0.1451	0.8316	3.119	1.64	0.32
100: Xerr	1.087	0.0201	1.632	4.046	3.46	0.31
Ratio > 1	1.811	7.219	1.962	1.297	2.11	0.97



Case 100 : Xerr target



Case 98 : Berr target

C82 Xerror Targeting Status

Summary of work last year:

- C10 nescoil xerr targeting showed correlation between low xerr and good VMEC recon (even with higher berr)
- Puzzling xerr minima found in number of coils scan
- PIES runs for PG1: island width targeted: limited success

Efforts currently underway:

- PIES Free Boundary reconstructions for 5 coils/period
- Do VMEC recon of xerr targeted surface and iterate
- Add Xerr targeting capability in GA

Efforts for near future (planned or desired):

- Modify and exercise xerr targeting capability in Coilopt
- Put Nescoil-svd-xerr in surface optimizer

Hurdles

At Starting Point:

VMEC Plasma is NOT a PIES Plasma:

- PIES Fixed Boundary (no coils involved) 3% beta c82 reconstruction shows big bad islands and stochastic regions
- Bootstrap model does not seem to heal islands as expected
- We have no PIES optimizer loop to heal islands - PIES too slow

At Coil Design Stage:

- We have no PIES-independent *quantitative* indicator of islands generated by a given coilset => optimizer loop not available
- Xerr targeted (nes)coils have high Jmax, Complexity => NOT acceptable from engineering standpoint => need surface variation
- No fast estimators for xerr for coils without stellarator symmetry

Summary, Ideas, and Questions

Plasma:

- At present only PIES can reliably judge island problem (VMEC?)
- Need many PIES runs in very near future (*)
- PIES improved, but still too slow for optimizer with coil codes (?)

Coil design:

- Do VMEC frb recon of C82 xerr: is new VMEC surface x-better?
- Try nescoil-xerr -> VMEC frb loop (+ surface variation)?
- Do Curropt optimization for C82 (like PG1)?
- Can Curropt island estimate be used in nescoil-svd?
- Can simultaneous nescoil targeting of Berr on plasma edge and Xerr inside plasma (for vacuum case) help?
- Extra freedom of surface variation may be essential for xerr control => need to put nescoil inside optimizer loop?
- New suggestions from Boozer and Hirshman need discussion

Discussion: Strategy for Optimizing Coils for Good Surfaces

Some TOUGH questions about this effort (better now than later):

- Is C82 acceptable from surface quality viewpoint (non-starter)?
- How much effort should go to non-C82 configurations and when?
- Are there any unresolved issues in PIES?
- Should any resources be diverted to get PIES production run capability going immediately?
- Should we work now on errors due to finite coils, leads, lack of stellarator symmetry etc. or can we expect nature will be kind?
- Which tasks should be done when?
- Should we divert some effort into trying the new ideas?
- What are REALISTIC time scales for the various tasks?

Procedure Being Pursued

- Start with generating a coil set
  - Presently still targeting B•n = 0. on plasma boundary
- Run VMEC free boundary
  - Extract VMEC surfaces to use as PIES background coordinates using vp code
- Run PIES
  - Extract PIES resonant surfaces (surface thru x and o points, in magnetic coordinates) and their associated iota, s, $d\Psi/ds$
- Run Curropt
  - Calculate Island Widths on Resonant Surfaces
  - Correlate with PIES field line plots
  - Try to suppress Islands by varying coil currents while preserving B•n = 0. on plasma boundary using SVD

Island Width Evaluation

Using s, θ, ϕ as the magnetic coordinates, island width given by :

$$ds = 4\left|\frac{C_{mn}(s)}{m\iota'(s)}\right|^{1/2}$$

where $C(s) \equiv \frac{B^s}{B^\phi} = \frac{B \bullet \nabla s}{B \bullet \nabla \phi}$

$\frac{B^s}{B^\phi}$ is evaluated by making use of

$$B^\phi = \frac{1}{J_{s,\theta,\phi}} \frac{d\Psi}{ds}$$

and $$\nabla s = \frac{1}{J_{s,\theta,\phi}} \left(\frac{\partial R}{\partial \theta} \times \frac{\partial R}{\partial \phi} \right)$$

leaving an expression which does not require explicit evaluation of the Jacobian and linear in B (and therefore coil currents)

$$\frac{B^s}{B^\phi} = \frac{B \bullet \left(\frac{\partial R}{\partial \theta} \times \frac{\partial R}{\partial \phi} \right)}{\frac{d\Psi}{ds}}$$

Summary

- Calculated Island width appears to correlate with islands observed in PIES field line plots when proper surface is targeted (for coil sets presented)
  - Further verification on larger islands desired (ie plasmas with larger iota profiles) and with plasma current
- Targeting of Islands in cases presented required large sacrifice in B•n on boundary to drive calculated island size down.
  - This distorts the initial boundary and resonant surface as well.
  - Targeted surfaces may need to be recalculated to be effective.
- Targeting of Islands within CURROPT may require different coils with stronger resonant coupling to minimize surface distortion.
  - Additional trim coils designed for resonance.
  - Produce different coils with NESCOIL by including island target
  - Add island target to background coil optimization