STELLOPT and REGCOIL Integration

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Background about REGCOIL[1,2], 1

- 'Regularized NESCOIL' (REGCOIL) finds the current potential, Φ, on a winding surface such that the following function is minimized:
$$\chi^2 = \chi_B^2 + \lambda\chi_K^2$$
- Normal component of B on the *plasma surface:* $\chi_B^2 = \int d^2a\, B_{normal}^2$
- Current density on the winding surface: $\overrightarrow{\boldsymbol{K}} = \hat{n}\times\nabla\Phi$
- Surface−average−squared current density $K^2 = |\boldsymbol{K}|^2$ on the *winding surface*
$$\chi_K^2 = \int d^2a'\, K^2$$
- Inverse distance between coils (proxy): $K = \left|\overrightarrow{\boldsymbol{K}}\right|$
- Regularization parameter: λ
  - Larger λ (more regularization) leads to less complicated current potential contours ('less harmonic content'), but χ_B^2 increases

[1] M. Landreman, Nuclear Fusion **57**, 046003 (2017).

[2] https://github.com/landreman/regcoil

Background about REGCOIL, 2

- REGCOIL has several execution options.
- ‘General option=5’
  - User specifies the plasma-coil separation distance, ‘SEP’
  - User specifies a desired χ_K^2 (the ‘target’)
  - REGCOIL creates a winding surface and finds the current potential on that winding surface with the desired ‘K’ that minimizes χ_B^2

- Specify SEP and |K|, get back achieved χ_B^2 and λ

Background about STELLOPT[1], 1

- Multi-dimensional non-linear curve fitting algorithm to optimize 3D MHD equilibria to a set of target physics parameters encompassing stellarator design and 3-D equilibrium reconstruction
- Modified Levenberg-Marquardt algorithm
- Genetic algorithm
- Differential evolution (particle swarm?)
- Hyperplane mapping
- Minimization (or mapping) of

$$\sum \chi_i^2 = \frac{\left(f_i^{target} - f_i^{equilibria}\right)^2}{\sigma_i^2}$$

[1] http://vmecwiki.pppl.wikispaces.net/STELLOPT and all references therein

Background about STELLOPT, 2

➢Targets*

Aspect Ratio, Beta, CURTOR, PHIEDGE, R0, RBTOR, Stored Energy, Volume, EXTCUR, Line_NE, Faraday, PRESS, NE, TE, TI, LINE_TE, LINE_TI, IOTA, BROPE, FLUXLOOP, ROGOWSKI (DIAGNO), VESSEL, SEPARATRIX, BALLOON(COBRAVMEC), KINK, BOOTSTREAP, NEO, HELICITY, JSTAR, ORBIT(BEAMS3D), COIL_BNORM

* These lists are not necessarily complete

➢Variables*

Almost anything that describes the equilibrium (think ‘VMEC input parameters)

- Current and pressure profiles, external coil currents, enclosed flux, etc.

Includes non-VMEC quantities

- Te,Ne and Ti,Ni profiles, Zeff

Boundary of plasma

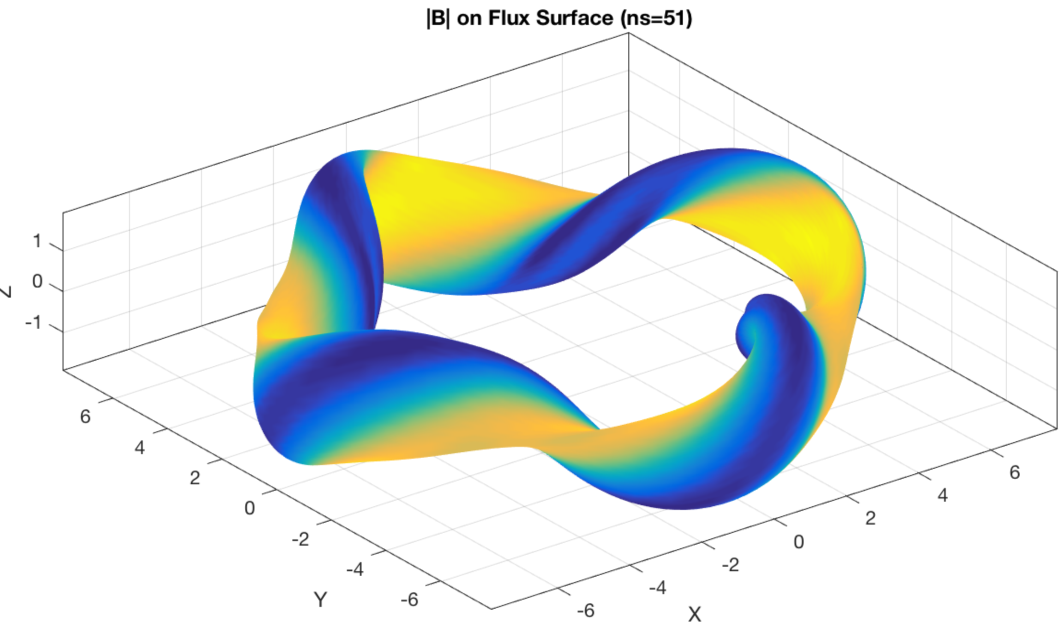
- RBC, ZBS (VMEC)
- RHOMN (Hirshman/Breslau)
- DELTAMN (Garabedian)

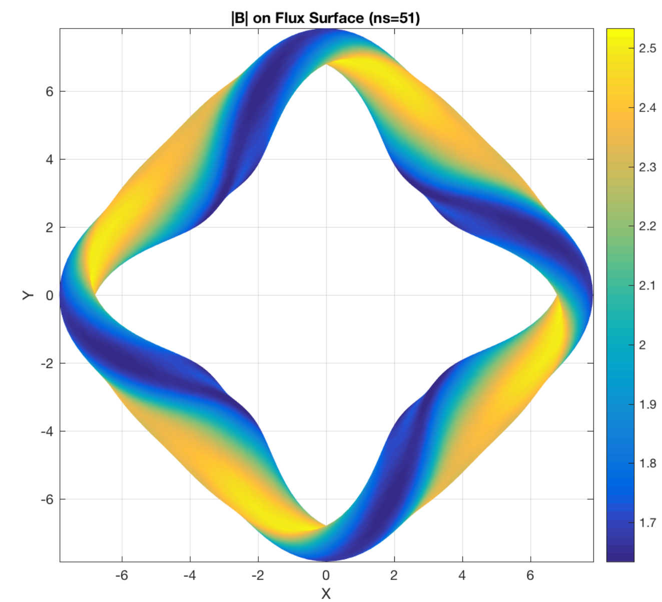
STELLOPT now uses REGCOIL vary SEP to minimize χ_B^2 while meeting a desired |K|

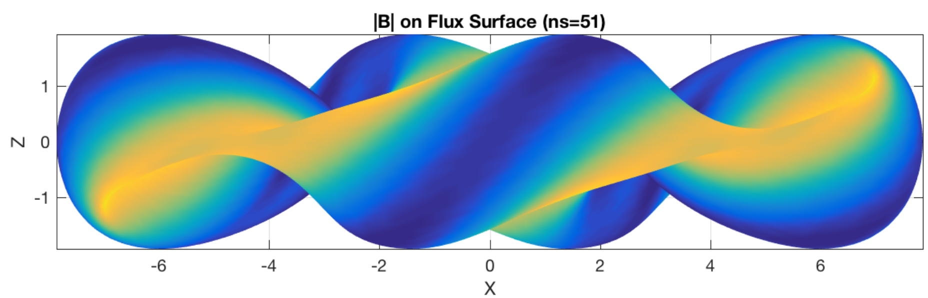
- REGCOIL does this:
  - Specify SEP and |K|, get back achieved χ_B^2 ~~and λ~~
- STELLOPT was modified[1] to include REGCOIL in its optimization loop
  - Given a specified target RMS-current-density, |K|, find the optimal plasma-coil separation, SEP, that minimizes the residual on the plasma surface, χ_B^2
- Goal #1: Help find plasma shapes compatible with distant coils.
  - 1st step: Use QHS46 as an initial test case to understand behavior of coupled code base
- Goal #2: Document the steps necessary to implement new targets and variables in the newest version of STELLOPT[1]
  - Permit rapid expansion of the flexibility of STELLOPT to new targets and variables.
  - For instance, see B. Faber's recent work on turbulence optimization.

[1] http://vmecwiki.pppl.wikispaces.net/Stellopt_Adding_new_code

QHS46 Configuration: “6-m HSX”

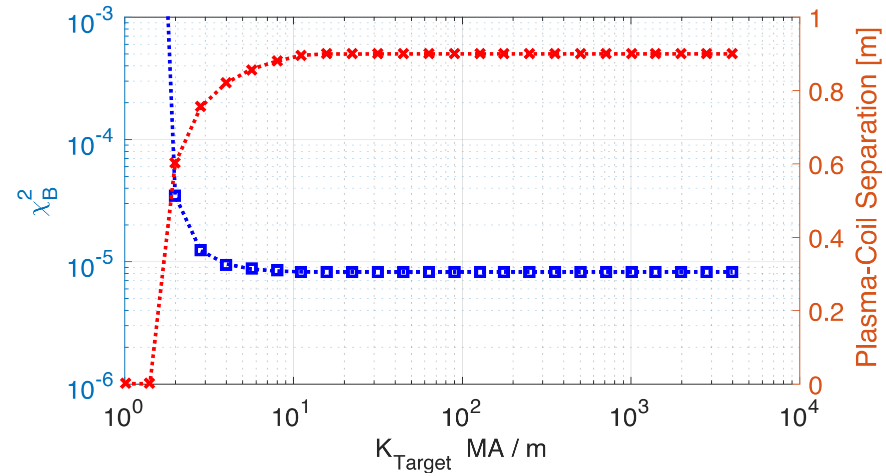


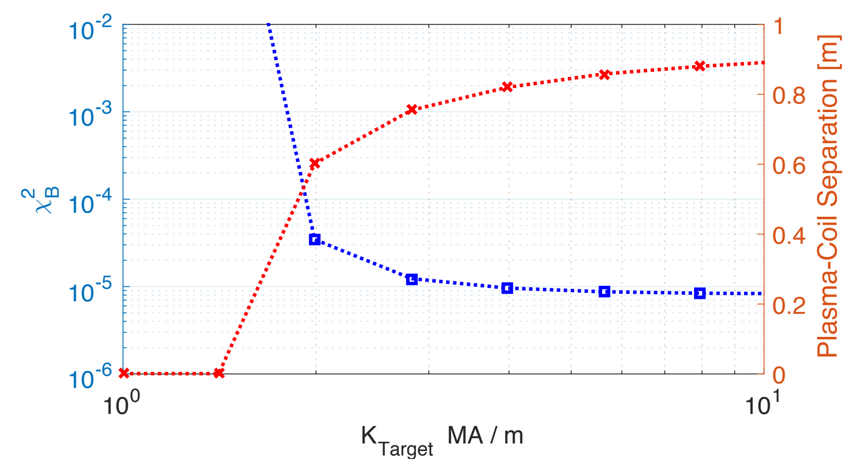




'Target K' –scan results for QHS46 Show that optimal separation and χ_B^2 asymptote for $K \geq 8$ MA / m

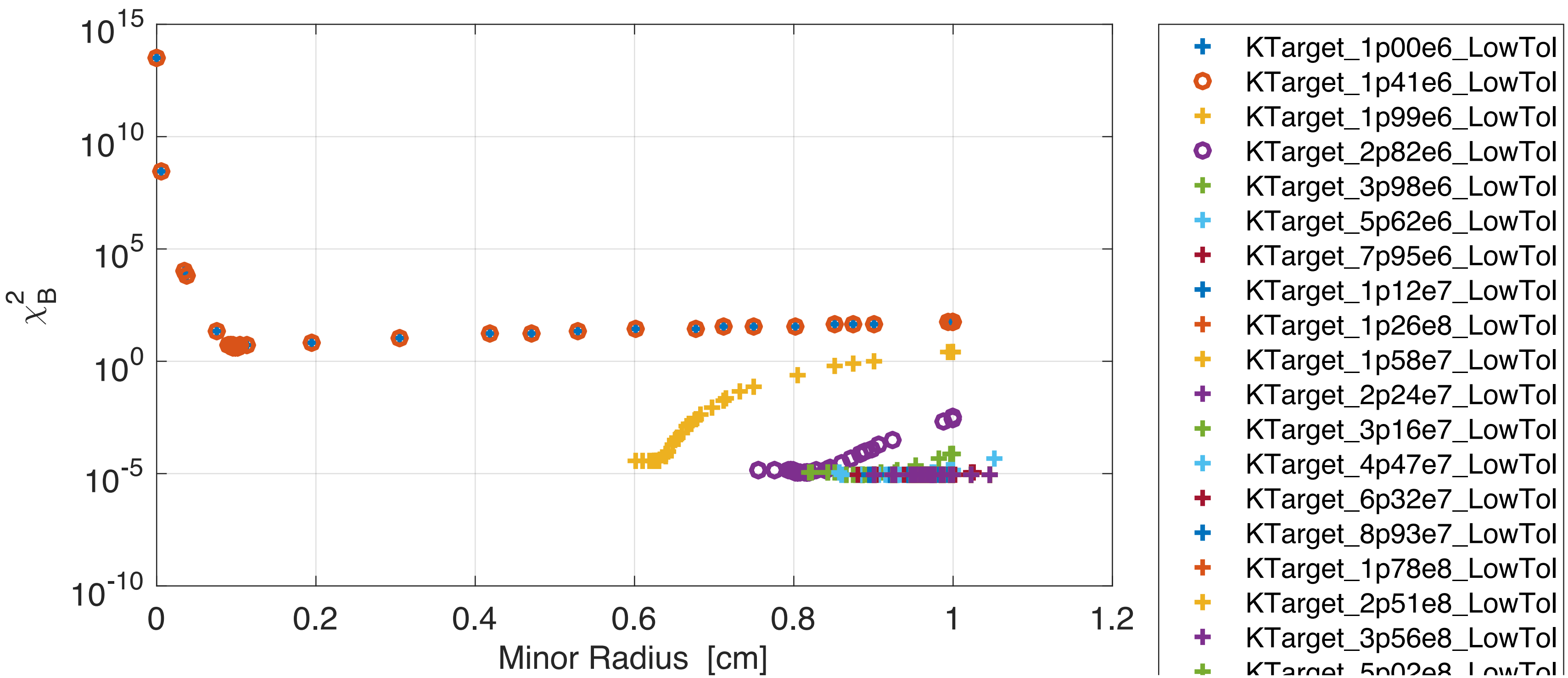
- Recall that the seperation is a 'constant' on the entire surface.
- Scan just completed
  - Details have not been fully analyzed
  - 'Cut coils' are not shown (to do)
  - Winding surface may have geometric difficulties for separation > 0.93





A deeper look into the data shows similar behavior for $\chi_B^2(sep)$ for many K

- Lower boundary on χ_B^2 is beginning to be mapped
- Can fill in the scan with mapping option (stellopt)



Next steps

- PPPL LDRD activities for FY ‘18
  - Continue to explore QHS/QAS configurations with new target option. ‘Cut’ coils from several surfaces for comparisons.

  - Target χ_K^2.
  - Add a cost-function (‘target’) that penalizes/excludes plasma shapes that have sharp ’cusps’ which cause problems with self-consistent uniformly spaced winding surfaces.
  - Add a coil-cutting routine in REGCOIL (Fortran) to generate initial coil shapes compatible with other coil optimization routines (COILOPT++, FOCUS, NESCOIL).
  - Generalize the winding surface for non-uniform separation between it and the plasma surface.

- WISTELL
  - Discussion