Configuration Development
-- High and Intermediate Iota Configurations --

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Recap of May Project Meeting

- We introduced a new family of QA configurations having
  - higher stellarator rotational transform (~ 0.4 to 0.6)
  - aspect ratios between 4.5 and 5.5
  - good MHD stability and transport properties
  - attractive figures of merit important to coil designs

- We laid out work plans to address critical issues needed to more completely characterize these configurations
  - surface quality
  - bootstrap current consistency
  - reconstructability

- We also emphasize the needs to broaden the search space to find better and further improved configurations.
  - number of field periods, aspect ratios
  - other configuration space having different characteristics

Accomplishments Since May Project Meeting

- PIES calculations have been carried out for many of the configurations.
  - surface integrity maintained at reference β and Ip
  - low order islands are large, occupying >15% of the plasma (without taking into account the neoclassical effects in the presence of bootstrap currents)

- Search domain has been broadened and new configurations developed.
  - 3 field-period configurations with lower aspect ratios, A~4.3-4.4
  - 2 field-period configurations with C82-like ι and A

- Bootstrap current consistency has been checked using KBSC code (with only axi-symmetric fields included) for some of the configurations.
  - current levels assumed consistent if density profiles are very broad
  - attempts made to increase Ip in newer configurations to accommodate more variations in density and temperature profiles

- Preliminary efforts were made to correlate surface quality, D_r and magnetic shear.
  - work presented in weekly physics meeting on June 8
  - results so far inconclusive; controlled numerical experiments planned

- Selected configurations were incorporated into the list on June 26 for consideration of picking a “reference” for detailed engineering studies.
  - “high” ι configurations: II75, II378, II379
  - “intermediate” ι configurations: LI65, LI383
  - 2 field period configuration: II283

Concerns of the Present Configurations and Progress Made to Address These Concerns

- For “high” iota configurations
  - “good” configurations are not “compact”.
  - coil current densities are too high for aspect ratios judged to be acceptably “compact”.

- For “intermediate” iota configurations
  - waist maybe too thin in the narrowest section.
  - strong shaping to attain desired MHD stability involves square and pentagonal terms, which may be hard to reconstruct from coils.
  - beta limit needs to be higher.

- For A=3.3, 2 field-period configuration
  - beta is not up to 4% for II283.
  - maximum B error is too high for coils.
  - surface quality is “weak.”

“High” ι configurations: Attempts to reduce coil current density for II378 only achieve modest improvement.

- Target Jmax in optimization for II378
  - Jmax is reduced from 1.12 to 0.97 in current sheet solution.
  - Further reduction requires stronger triangular shaping, resulting in failures in Terpsichore calculations for kink stability.

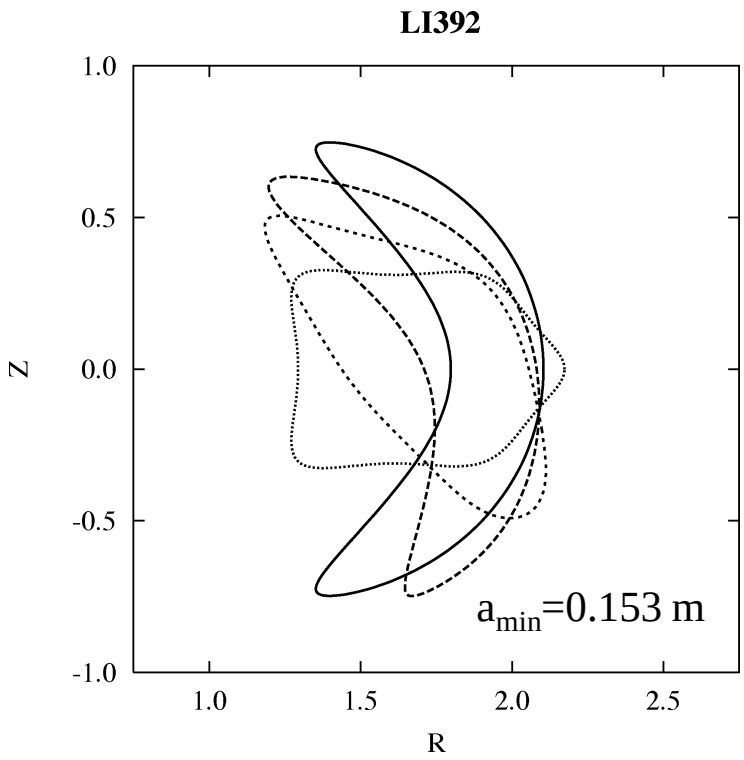
- Higher aspect ratios, although judged to be not “compact”, may lead to an overall much better configuration and thus are worthy further exploration.
  - work started to search for β~5%, $\iota > 0.5$ everywhere, and with less shaped outer surfaces.

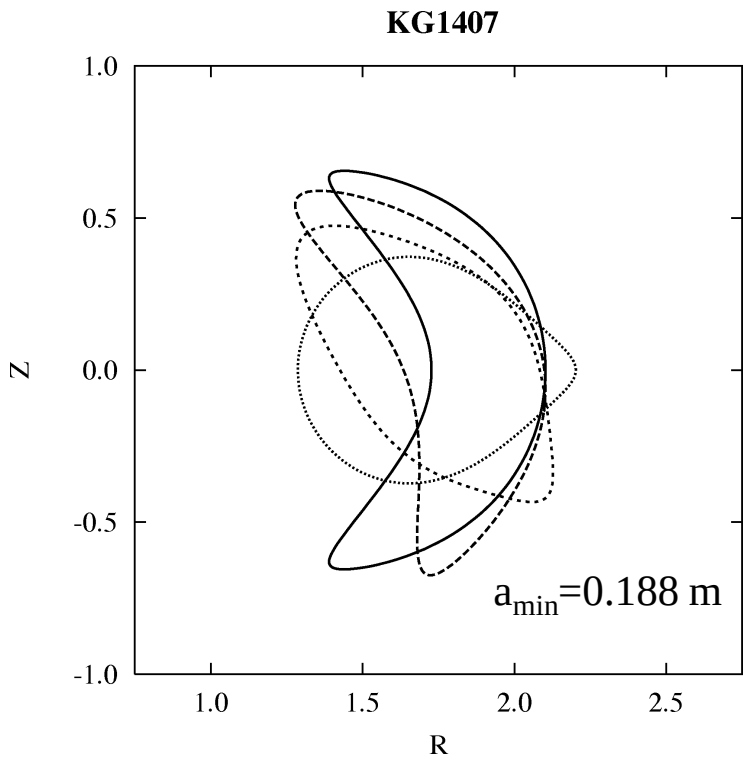
“Intermediate’ ι configurations: LI383, the favorite on June 26 list, has been improved to raise β to ≥ 4.6%. The thin waistline and strong high order surface shaping remain a concern.

- Two variants of LI383 are now available
  - LI392: β ~4.1%, with QA improved by 40% measured by χ^2 at s=0.5 surface and Jmax/Ipol reduced from 0.76 to 0.69 (next viewgraph).
  - LI394: β ~4.6%, QA slightly worse than LI392. The minimum half width at midplane is only 15 cm (C82 volume).

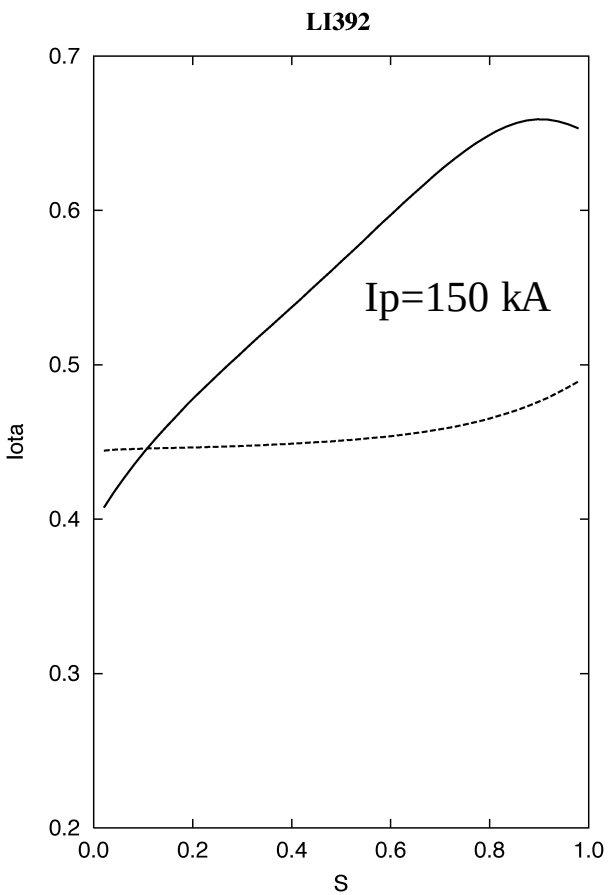
- To explore ways to improve surface shape, we have started to examine configurations with somewhat different characteristics -- a new KG family.
  - lower average stellarator transform, 0.38 vs 0.46, but higher shear
  - less shaping from higher order terms

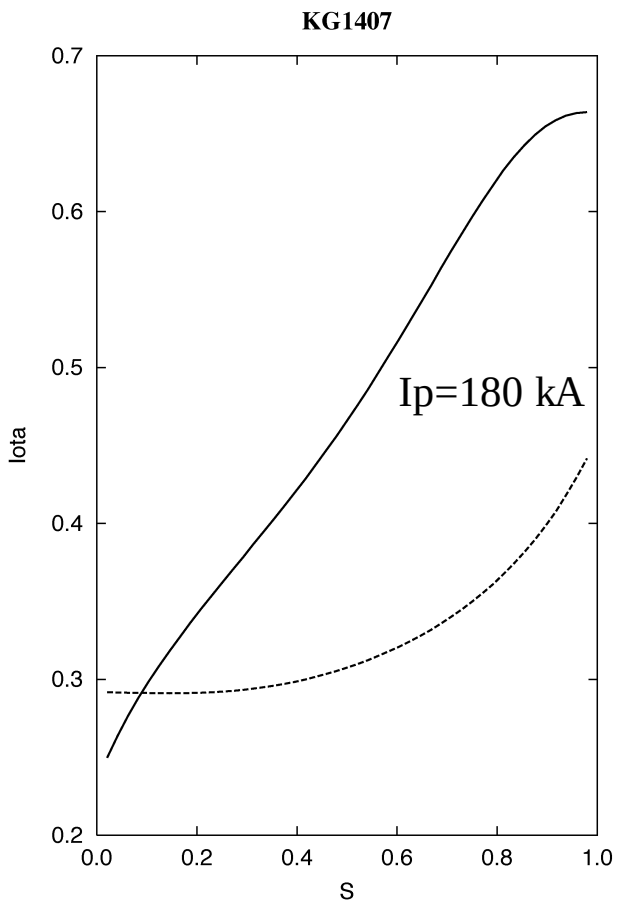
LI392 and KG1407: A=4.4 and stable at 4% β





Comparison of Iota Profiles





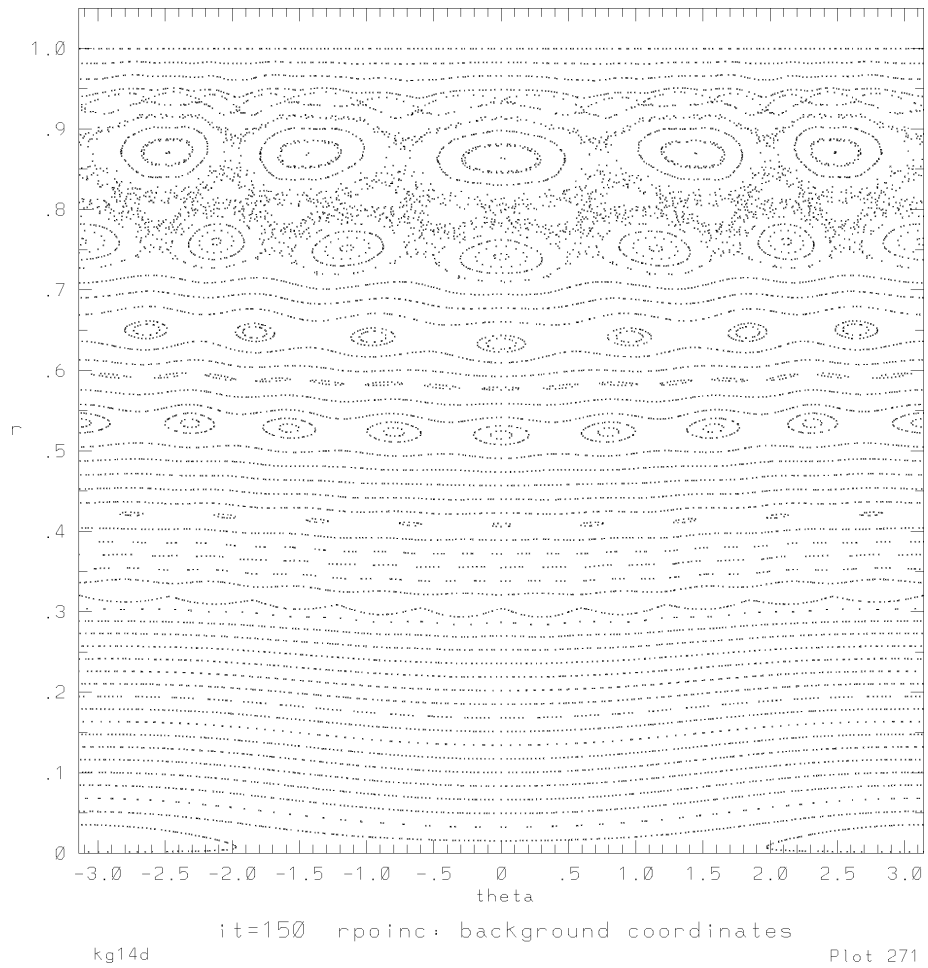
Comparisons of transport measures show that with restricted degrees of freedom for boundary optimization KG1407 is not able to achieve as good a QA as LI392.

	LI392	KG1407
χ^2 (s=0.3) (x10^{-4})	0.3	0.6
χ^2 (s=0.5)	1.2	2.1
χ^2 (s=0.8)	6.3	9.4
τ_E (ms) for D, 1.26T	29	21
Fast Ion Energy Loss Fraction, H, 40 keV, 2T	17	19

KG1407 also has poorer figures of merit important to coil designs.

	LI392	KG1407
Coil complexity	2.09	2.35
Max. B error (%)	1.8	1.7
Mean B error (%)	0.13	0.10
Jmax/Ipol	0.686	0.766
Jmax (MA/m)	2.37	2.54

KG1407 has poor surface (or lack of it) between ι=0.5 and 0.6. Is this because of the spacing between these two surfaces (due to the higher shear) or because this configuration has inferior D_r?



To better understand the flux surface issue and the limitation on the optimization due to shaping constraints, we have started to:

- carry out numerical experiments to examine flux surface quality
  - configurations of similar characteristics but without optimization with respect to QA and stability
  - systematic variation of ι, ι', magnetic well, and p'
- examine the subspace between KG family and LI family (and perhaps beyond)
  - gradual relaxation of shaping constraints
  - different levels of stellarator transform

Low A, N=2 configurations: Search for "good" two field-period configurations has so far yielded limited progress.

- II283 has been upgraded to II289
  - MHD stable at β~4% (from 3.7%)
  - reduced fast ion loss, from 19.2 to 17.3%.
  - less (marginally) coil complexity and Jmax, but much larger Bmax error (7.7% vs 6.6%)
  - study of surface quality yet to be complete.

- Search for A=3 configurations has led to LI281
  - for C82 volume, R=1.34 m, $\langle a \rangle$=0.443, and a_{min}=0.204
  - at β=4%, χ2 is similar to II289, but neoclassical confinement is only 19 ms (22 ms for II289).

- very high coil current density (Jmax/Ipol=1.2, current sheet, 0.18 m coil surface displacement), but lower Bmax (3.7%)
- very poor surface quality

- Due to the potential of achieving a very “compact” configuration and avoiding crossing ι=0.5, the present work plan is to continue exploring the two field-period configuration space.
  - complete the analysis of A=3.5 and 3.7 configurations
  - target Bmax, Jmax in optimization
  - give up a_{min} consideration and increase stellarator transform with lesser shear