Physics Evaluation of Coil Designs

L. P. Ku

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Physics Evaluation of Reconstructed Plasmas -- Part II

- Continue to evaluate coil designs as they become available
  - Methodology of evaluation outlined in last Project Meeting.
  - Configurations from both “as received” and “current modified” (for further optimization) are examined.

- Three classes of designs for the modular coils
  - Coil symmetry plane: $\zeta = 0$

    09_07 (M2); 10_17 (M3-NBI); 01_05 (M8-NBI)
  - Coil symmetry plane: $\zeta = \pi/3$

    11_15 (M4); 12_19 (M7)

- Coils symmetry planes: $\zeta = 0$ and $\zeta = \pi/3$, 6 coils/period
  - 12_07 (M5); 12_15 (M6)

- In this presentation, we compare (only the S3 state):

  - M7 to M4, showing M7 “as received” offers very good reconstruction.
  - M6 to M5, showing 6 coils/period may be a possibility.
  - M8 to M3, showing M8 offers reasonable reconstruction and also the possibility to access regimes of lower aspect ratios as well as C82-like pressure profiles.

- We have also briefly examined the convergence of reconstruction with respect to the poloidal and toroidal modes used in VMEC
  - m=9 and n=5 are the minimum number of modes required to give adequate convergence in routine analysis (These are the modes used in most of reconstruction and analyses).
  - Sensitivities to the modes used need to be understood.

Comparison of Physics Properties, M4 versus M7

Coil symmetry plane: $\zeta = 60$

	LI383	LI383M4.3-K00 (11_15_b8) (As Received)	LI383M7.3-K00 (12_19_a6) (As Received)	LI383M4.3-Z09 (11_15_b8) (Optimized)	LI383M7.3-K01 (12_19_a6) (Optimized)
A	4.36	4.32	4.37	4.47	4.35
β	4.19	4.36	4.17	4.25	4.17
R (m)	1.734	1.733	1.735	1.752	1.758
<a> (m)	0.397	0.401	0.397	0.392	0.404
R-min (m)	1.209	1.206	1.210	1.242	1.232
R-max (m)	2.173	2.165	2.161	2.188	2.216
Z-max (m)	0.764	0.765	0.759	0.772	0.754
Min. Plasma-VV Distance (cm)	1.14	0.83	1.08	1.89	1.34
$\iota(0)$	0.394	0.401	0.399	0.399	0.386
$\iota(a)$	0.655	0.647	0.649	0.648	0.659
ι Max.	0.662	0.656	0.657	0.660	0.666
λ, Kink ($\times 10^4$)					
n=1	Stable	0.85	Stable	Stable	Stable
n=0	Stable	2.5	0.84	Stable	Stable
λ, Ballooning					
$\zeta = 0$	0.85-0.88; (0.06)	0.91-0.93; (0.09)	0.91-0.93; (0.08)	Stable	Stable
ζ=60	0.91-0.96; (0.11)	0.91-0.96; (0.17)	0.91-0.96; (0.15)	Stable	Stable
χ^2, Bmn ($\times 10^4$)					
S=0.3	0.5	0.7	0.6	0.6	0.8
S=0.5	1.7	2.1	1.9	1.9	2.3
S=0.8	6.9	7.7	7.0	7.8	8.4
$\varepsilon_{eff}^{2/3}$ ($\times 10^4$)					
S=0.3	1.0	2.8	2.3	3.5	4.2
S=0.5	5.6	8.4	7.5	10	14
S=0.8	32	36	33	46	64
τ^{NC} (ms), thermal D 1.2 T, $e\phi/kT=1$, $nR/T^2=0.22$	28		27		20

Best reconstruction among as-received coil sets.

The only case where improvement of stability also leads to better χ^2_{Bmn}, but the effective ripple is increased.

Improvement of MHD stability often leads to deterioration in QA. Use multipoles for PF instead of coils in next phase study.

Interior ripple worse, but does not harm GTC result.

Comparison of Physics Properties, M5 versus M6

Coils symmetry planes: $\zeta = 0$ and $\zeta = 60$

	LI383	LI383M5.3-K00 (12_07_a5) (As Received)	LI383M5.3-K36 (12_07_a5) (Optimized)	LI383M6.3-K00* (12_15_b4) (As Received)
A	4.36	4.36	4.23	4.37
β	4.19	4.15	3.96	4.16
R (m)	1.734	1.730	1.761	1.732
<a> (m)	0.397	0.396	0.417	0.397
R-min (m)	1.209	1.210	1.217	1.213
R-max (m)	2.173	2.148	2.256	2.159
Z-max (m)	0.764	0.755	0.779	0.755
Min. Plasma-VV Distance (cm)	1.14	0.65	-0.33	0.93
$\iota(0)$	0.394	0.404	0.389	0.403
$\iota(a)$	0.655	0.650	0.660	0.651
ι Max.	0.662	0.660	0.663	0.659
λ, Kink ($\times 10^4$)				
n=1	Stable	5.0	Stable	0.45
n=0	Stable	5.0	Stable	Stable
λ, Ballooning				
$\zeta = 0$	0.85-0.88; (0.06)	0.91-0.93; (0.09)	Stable	0.91-0.93; (0.09)
ζ=60	0.91-0.96; (0.11)	0.91-0.96; (0.19)	0.92-0.96; (0.06)	0.91-0.96 (0.10)
χ^2, Bmn ($\times 10^4$)				
S=0.3	0.5	1.4	1.4	0.7
S=0.5	1.7	3.1	3.6	2.1
S=0.8	6.9	8.6	12.1	7.4
$\varepsilon_{eff}^{2/3}$ ($\times 10^4$)				
S=0.3	1.0	6.5	8.7	3.3
S=0.5	5.6	13	29	9.7
S=0.8	32	40	141	36
τ^{NC} (ms), thermal D 1.2 T, $e\phi/kT=1$, $nR/T^2=0.22$	28			

Variable currents and include 5 PF

Very poor QA and kink unstable in the first design

Substantial improvement in the 2nd design, but the effective ripple is still large in the core.

Comparison of Physics Properties, M3 versus M8

Coil symmetry plane: $\zeta = 0$

	LI383	LI383M3.3-K00 (10_17_a2) (As Received)	LI383M8.3-k00 (01_05_c2) (As Received)	LI383M3.3-Z03 (10_17_a2) (Optimized)	LI383M8.3-K01 (01_05_c2) (Optimized)
A	4.36	4.36	4.36	4.16	4.24
β	4.19	4.15	4.15	4.10	4.10
R (m)	1.734	1.728	1.728	1.738	1.746
<a> (m)	0.397	0.396	0.397	0.418	0.412
R-min (m)	1.209	1.208	1.209	1.196	1.211
R-max (m)	2.173	2.145	2.137	2.208	2.209
Z-max (m)	0.764	0.755	0.759	0.775	0.764
Min. Plasma-VV Distance (cm)	1.14	0.52	0.61	-0.80	0.22
$\iota(0)$	0.394	0.406	0.408	0.413	0.407
$\iota(a)$	0.655	0.651	0.652	0.653	0.657
ι, Max	0.662	0.660	0.661	0.659	0.664
λ, Kink ($x10^4$)					
n=1	Stable	0.23	Stable	Stable	Stable
n=0	Stable	7.3	6.2	Stable	Stable
λ, Ballooning					
$\zeta = 0$	0.85-0.88; (0.06)	0.91-0.93; (0.06)	0.91-0.93; (0.05)	Stable	Stable
ζ=60	0.91-0.96; (0.11)	0.91-0.96; (0.17)	0.91-0.96; (0.16)	Stable	Stable
χ^2, Bmn ($x10^4$)					
S=0.3	0.5	0.8	0.6	0.8	0.7
S=0.5	1.7	2.2	1.9	2.5	2.3
S=0.8	6.9	7.1	7.0	10.3	9.3
$\varepsilon_{eff}^{2/3}$ ($x10^4$)					
S=0.3	1.0	2.0	1.5	3.0	3.1
S=0.5	5.6	6.4	4.8	12	13
S=0.8	32	30	23	63	61
τ^{NC} (ms), thermal D 1.2 T, $e\phi/kT=1$, $nR/T^2=0.22$	28	30	29	21	21

Presently used in engineering design and flexibility studies.

M7 & M3 are very similar. M7 offers better fit and QA.

Best case in QA and effective helical ripple.

Good QA lost when MHD modes stabilized.

Comparison of Physics Properties, Configurations Based on M8

	LI383	LI383M8.3-K01 (01_05_c2) (Bmn Optimized)	LI383M8.3-K01F (01_05_c2) ($\varepsilon_{eff}^{2/3}$ Optimized)	LI383M8.3-K15 (01_05_c2) (Low-A Optimized)	LI383M8.3-K26 (01_05_c2) (C82 p & J Optimized)
A	4.36	4.24	4.26	4.02	4.09
β	4.19	4.10	4.07	4.36	3.31
R (m)	1.734	1.746	1.743	1.720	1.734
<a> (m)	0.397	0.412	0.409	0.427	0.424
R-min (m)	1.209	1.211	1.211	1.161	1.189
R-max (m)	2.173	2.209	2.195	2.185	2.212
Z-max (m)	0.764	0.764	0.762	0.789	0.802
Min. Plasma-VV Distance (cm)	1.14	0.22	-0.17	-3.48	-1.52
$\iota(0)$	0.394	0.407	0.411	0.426	0.423
$\iota(a)$	0.655	0.657	0.655	0.651	0.650
ι, Max	0.662	0.664	0.663	0.655	0.663
λ, Kink ($x10^4$)					
n=1	Stable	Stable	Stable	Stable	Stable
n=0	Stable	Stable	Stable	Stable	Stable
λ, Ballooning					
$\zeta = 0$	0.85-0.88; (0.06)	Stable	Stable	Stable	Stable
ζ=60	0.91-0.96; (0.11)	Stable	Stable	Stable	Stable
χ^2, Bmn ($x10^4$)					
S=0.3	0.5	0.7	0.7	0.9	1.3
S=0.5	1.7	2.3	2.2	3.0	3.6
S=0.8	6.9	9.3	9.0	13	13
$\varepsilon_{eff}^{2/3}$ ($x10^4$)					
S=0.3	1.0	3.1	2.4	1.9	5.2
S=0.5	5.6	13	10	8.4	16
S=0.8	32	61	51	51	81
τ^{NC} (ms), thermal D 1.2 T, $e\phi/kT=1$, $nR/T^2=0.22$	28	21	21	25	

MHD stable state with C82 profiles has lower β and poor QA.

A lower A, higher β regime, though has poor QA, has better $\varepsilon_{eff}^{2/3}$ and thermal ion confinement, but the present vessel boundary is violated.

20-30% improvement in $\varepsilon_{eff}^{2/3}$ does not change GTC results.

Comparison of Coil Currents (A) for M3 and M8 Configurations

	LI383M3.3-K00 (10_17_00) (As Received)	LI383M3.3-Z03 (10_17_00) (Optimized)	LI383M8.3-K00 (01_05_c2) (As Received)	LI383M8.3-K01 (01_05_c2) (Optimized)	LI383M8.3-K15 (01_05_c2) (Low-A Optimized)	LI383M8.3-K26 (01_05_c2) (C82 p & J Optimized)
Modular 1	**-8.122e+5**	**-8.221e+5**	**-7.815e+5**	**-7.882e+5**	**-7.649e+5**	**-8.317e+5**
Modular 2	**-8.122e+5**	**-8.103e+5**	**-8.075e+5**	**-8.128e+5**	**-7.816e+5**	**-8.065e+5**
Modular 3	**-8.122e+5**	**-8.425e+5**	**-8.229e+5**	**-8.365e+5**	**-8.104e+5**	**-9.903e+5**
Modular 4	**-8.122e+5**	**-8.152e+5**	**-8.615e+5**	**-8.778e+5**	**-8.293e+5**	**-6.850e+5**
TF		**-3.717e+4**		**4.036e+4**	**-6.105e+3**	**2.220e+4**
PF 1		**1.472e+6 (*)**		**-5.855e+5**	**-1.492e+6**	**-1.591e+6**
PF 2		**1.472e+6**		**-1.535e+6**	**-7.645e+5**	**6.219e+5**
PF 4		**1.267e+6**		**-2.130e+5**	**1.792e+5**	**-5.999e+5**
PF 6		**1.130e+5**		**9.389e+3**	**4.763e+3**	**8.026e+4**
PF 7		**-6.700e+4**		**-7.992e+4**	**-3.964e+4**	**-1.216e+5**

Note: (*) regularized

Organization of Data from Reconstruction

- Large amounts of data from reconstruction are now available for various modular coil designs. We are in the process of
  - compiling a spreadsheet data base, and
  - establishing a common directory for sharing input, output, equilibrium interface and magnetic spectrum data files.

    /u/ftp/pub/lpku/NCSX/QAS3_HI.F/DATA

Sensitivity of Plasma Reconstruction to Number of Fourier Modes in Boundary Representation and Equilibrium Calculation

- Wide range of variations observed in χ^2, which measures the goodness of reconstruction, with different number of modes used in VMEC (M2-S3 used in the study).

- Increasing n from 5 to 6 improves the reconstructability of aspect ratio, RB_t, and kink stability by as much as 50% in χ^2 in some cases.

- QA improves as modes increase, but the decrease in χ^2 is not monotonic.

- The ballooning stability shows pattern of swing between near stable and unstable states as m increases for α=0.

- Overall, m=9, n=5 that we used seems adequate, but the lack of convergence with respect to the modes needs to be understood.