NCSX DAY-1 EXPERIMENT - Stabilization by 3D shaping

Recall $I_p - \beta$ scan Table from Jan 30-31 Proj Mtg:

I_p[kA]	β[%]	0.0	1.0	2.0	3.0	4.0	5.0
0							
62.5			i0625b10.rstrt2 $\lambda_K = 0$ $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0369$	i0625b20 $\lambda_K = 0$ $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0259$	i0625b30.rstrt3 $\lambda_K = 0$ $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0350$		
125				i1250b20.rstrt1 $\lambda_K = 0$ $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0309$	i1250b30.again.rstrt3 $\lambda_K = 0$ $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0260$	i1250b40 $\lambda_K =$ -1.8e-5 $\lambda_B =$ unstable $\chi^2_{Bmn} = 0.0231$	
187.5				i1875b20 $\lambda_K = 0$ $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0204$	i1875b30.rstrt1 $\lambda_K = 0$ $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0303$	i1875b40.again.rstrt4 $\lambda_K =$ -1.9e-6 $\lambda_B =$ unstable $\chi^2_{Bmn} = 0.0167$	
250		s2.001.again $\lambda_K = 0$ $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0337$	i25000b10 $\lambda_K =$ -2.8e-5 $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0219$	i25000b20 $\lambda_K =$ -1.0e-5 $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0245$	i25000b30 $\lambda_K =$ -5.8e-6 $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0221$	i25000b40 $\lambda_K =$ -2.8e-6 $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0239$	i25000b50.rstrt1 $\lambda_K =$ -4.6e-5 $\lambda_B = 0$ $\chi^2_{Bmn} = 0.0515$

Table 3: $I_p - \beta$ performance scan using baseline current and pressure profiles

The $I_p - \beta$ scan numerical experiments presented in Table 3-pomphrey can be used to show, in a more explicit way, the effect of MHD stabilization by 3D shaping. The present measure used for stability in the free-boundary optimizer cost function is a weighted sum of the square of the maximum unstable kink mode eigenvalue and the sum (over ballooning unstable surfaces) of the maximum ballooning mode eigenvalue. It follows that any stable "final state" of the optimizer is a state of marginal stability.

Consider now two states from the $I_p - \beta$ scan that have the same value of plasma current but different values of beta. For example the cases $I_p = 62.5$ kA, $\beta = 1.0\%$, and $I_p = 62.5$ kA, $\beta = 3.0\%$. Overlays of the plasma boundaries for these two configurations, and of their calculated $\iota(s)$ profiles, are shown in Fig.5-pomphrey. Axis and edge iota values are:

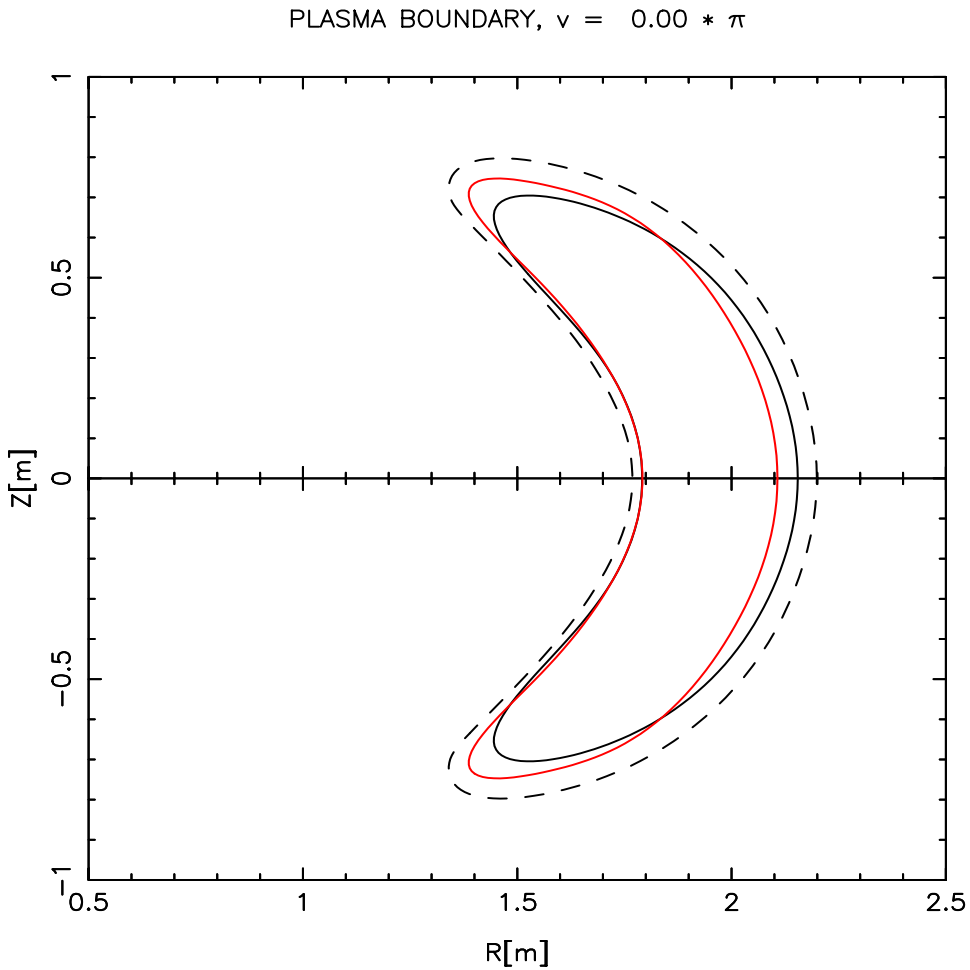
$$\iota(0) = 0.44, \iota(1) = 0.50 \textbf{ for } I_p = 62.5 \textbf{ kA}, \beta = 1.0\%;$$
$$\iota(0) = 0.40, \iota(1) = 0.44 \textbf{ for } I_p = 62.5 \textbf{ kA}, \beta = 3.0\%.$$

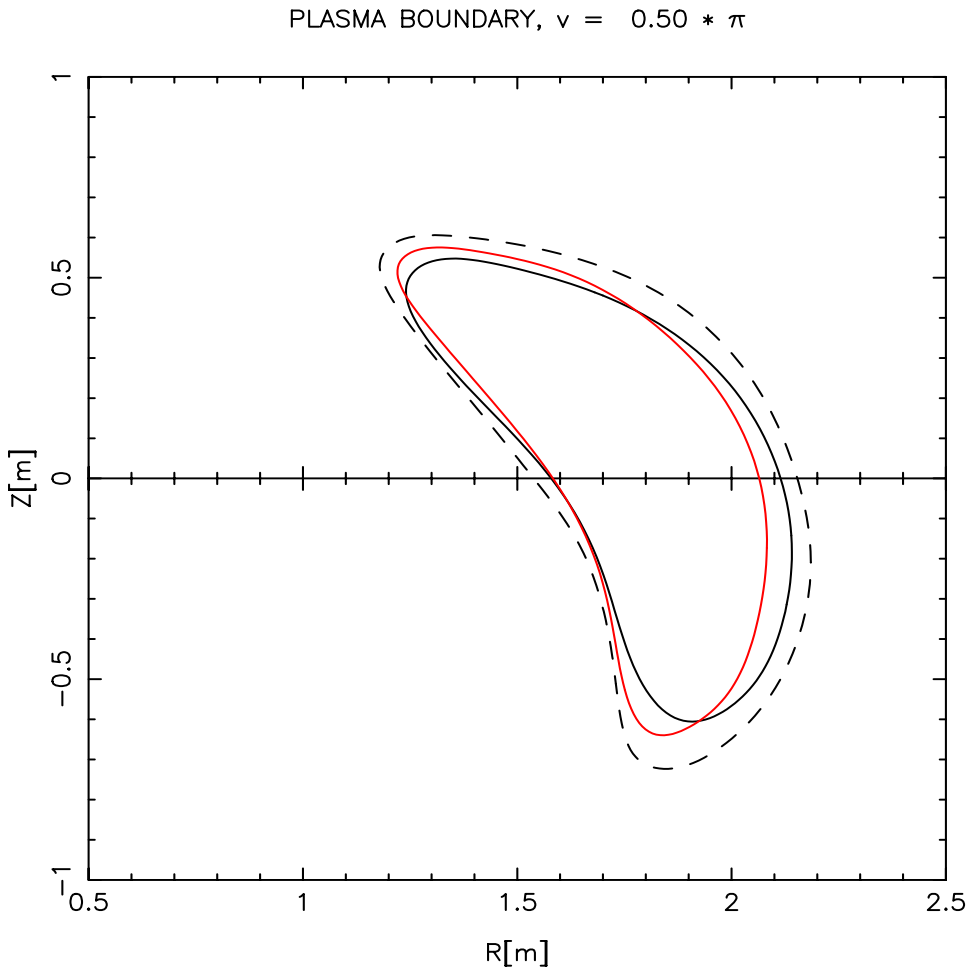
Coil currents calculated by the optimizer for these configurations are presented in Table 5-pomphrey.

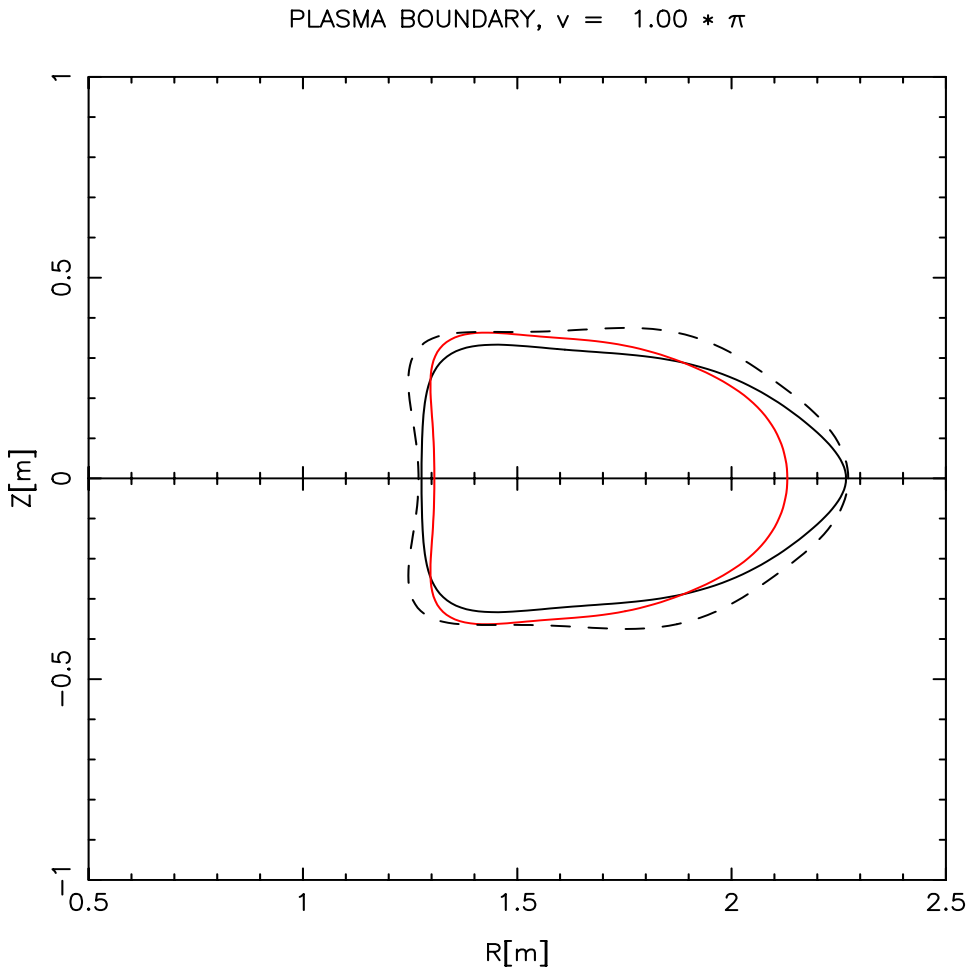
	$I_p = 62.5$ kA, $\beta = 1.0\%$	$I_p = 62.5$ kA, $\beta = 3.0\%$
Aux TF [A]	-4.472e+2	+8.614e+3
Mod 1 [A]	-8.116e+5	-8.031e+5
Mod 2 [A]	-8.270e+5	-8.283e+5
Mod 3 [A]	-7.558e+5	-8.202e+5
Mod 4 [A]	-9.110e+5	-7.834e=5
PF Quad	+8.419e-1	+4.377e-1
PF Dipole	+1.319e-0	-1.771e-1
PF Hexapole	-8.837e-1	+1.044e-0
PF Octapole	+2.032e-0	+2.244e+0

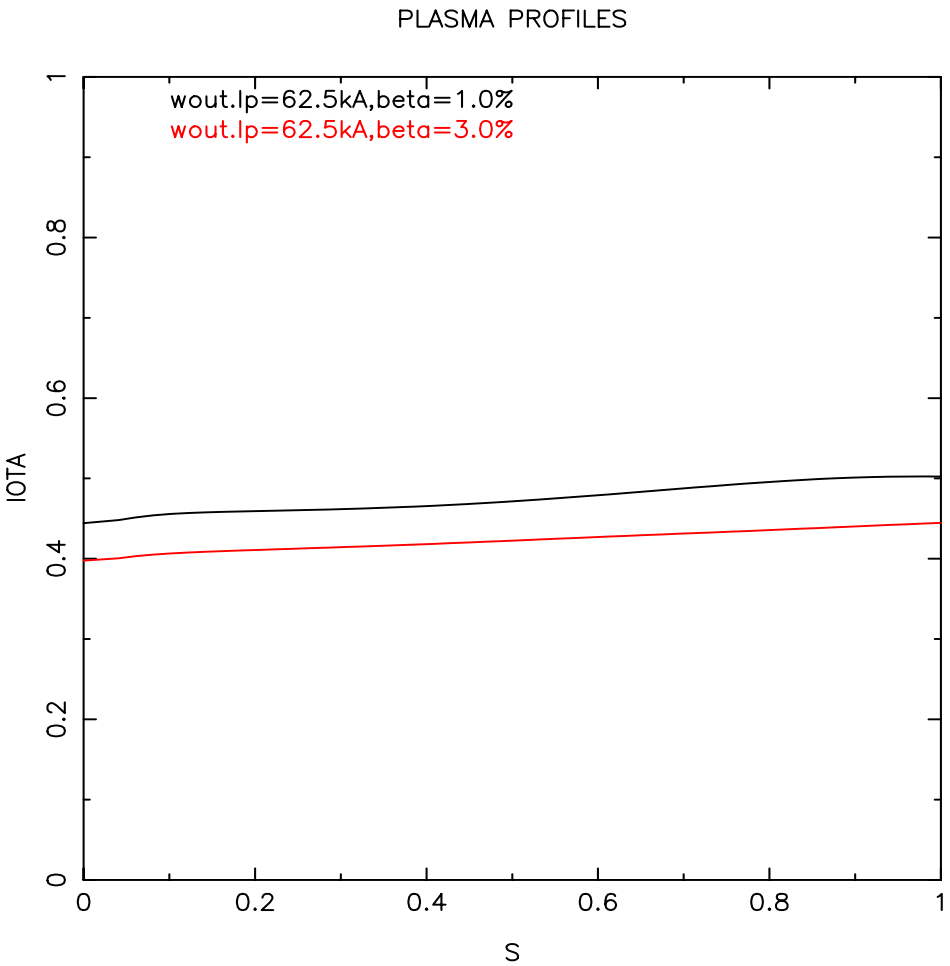
Table 5-pomphrey: Coil currents for case illustrating MHD stabilization by 3D shaping. Units for the Auxiliary TF and Modular coil currents are amps. Poloidal field "currents" are expressed as multipole moments.

Now take the $I_p = 62.5$ kA, $\beta = 1.0\%$ configuration and raise β keeping the plasma boundary fixed. The iota profile for this "virtual" configuration has $\iota(0) = 0.40, \iota(1) = 0.50$. It is found to be strongly unstable to kink modes, with an eigenvalue of $\lambda_K =$ -1.37e-3 (Ballooning modes are also found over the range of magnetic surfaces from $s = 0.14$ to $s = 0.33$, and the QA-ness measure increases to $\chi^2_{Bmn} = 0.0739$). Comparing the iota profile of the fixed boundary virtual configuration with the free boundary profiles shows that raising beta at fixed shape has predominantly changed the transform on axis, leaving the edge transform unchanged. It follows that the external transform provided by the coils in causing the shape change of the $I_p = 62.5$ kA, $\beta = 1.0\%$ free-boundary configuration to that of the $I_p = 62.5$ kA, $\beta = 3.0\%$ configuration ($\Delta\iota(0) = 0.00, \Delta\iota(1) = -0.06$) is responsible for the stabilization of the higher β configuration


PLASMA BOUNDARY, v = 0.00 * π
Z[m]
R[m]
1
0.5
0
−0.5
−1
0.5
1
1.5
2
2.5


PLASMA BOUNDARY, v = 0.50 * π
Z[m]
R[m]
1
0.5
0
−0.5
−1
0.5
1
1.5
2
2.5


PLASMA BOUNDARY, v = 1.00 * π
Z[m]
R[m]
1
0.5
0
−0.5
−1
0.5
1
1.5
2
2.5


PLASMA PROFILES
wout.Ip=62.5kA,beta=1.0%
wout.Ip=62.5kA,beta=3.0%
IOTA
S
0
0.2
0.4
0.6
0.8
1