A Preliminary Study off the “r1” coil sets for LI383

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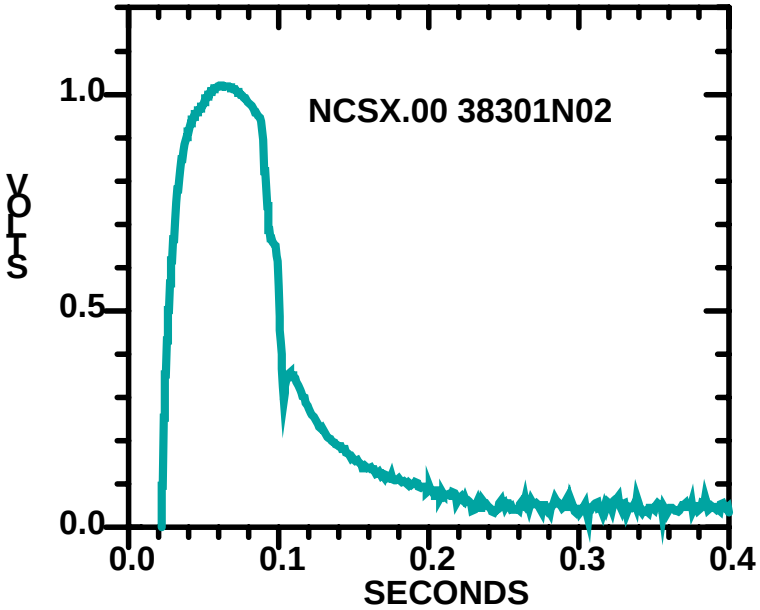
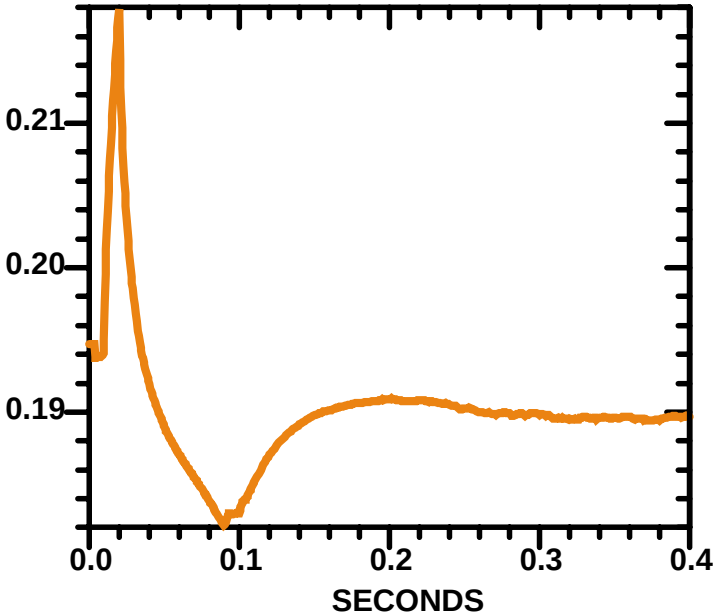
Outline All Results are for B = 1.2 T

- **The li383_328 target is used to model the discharge evolution with TRANSP**
  - **Balanced beams used to eliminate beam driven current**
  - **The plasma current of 150 kA is higher than the bootstrap current of 125 kA**
- **The TRANSP current and pressure profiles are used to generate a sequnece of VMEC input files**
  - **Free boundary equilibria generated for modular and saddle options.**
  - **Criterion adopted is to match the “a3” saddle, and “a4” modular shapes generated by the Coil Group.**
    - **Chi-Sq 3D Shape-RMS <Weight> = 1000.**
    - **Chi-Sq R-Btor <Weight> = 10. (keeps overall plasma size form changing)**
    - **Chi-Sq Iota (1/q) <Weight> = 3.2 (keeps optimizer believing it has enough constraints)**
    - **Sequential processing is very time consuming, each result (coil currents) is used as initial guess for next time slice. (Process automated on Nirvana.)**
- **Re-optimization of new boundary with li383_328 fixed boundary optimization, but starting with “a3” shape.**
  - **Leads to a second chance to produce a more desirable shape and generate with these coil sets.**
- **No effort as yet to obtain similar results with restrictions on coil currents**
  - **It may be that different combinations of coil currents will result in essentially the same results and have less variation in the coil currents.**
  - **It may also be that optimizing physics parameters would change the results somewhat.**
  - **Hence, preliminary results**

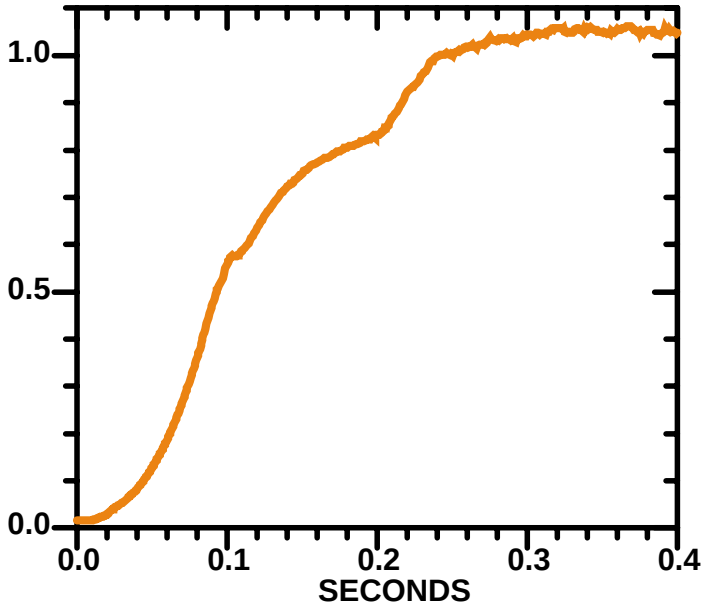
Results from 2-D TRANSP Simulation - Assumed Profiles - Balanced Beams



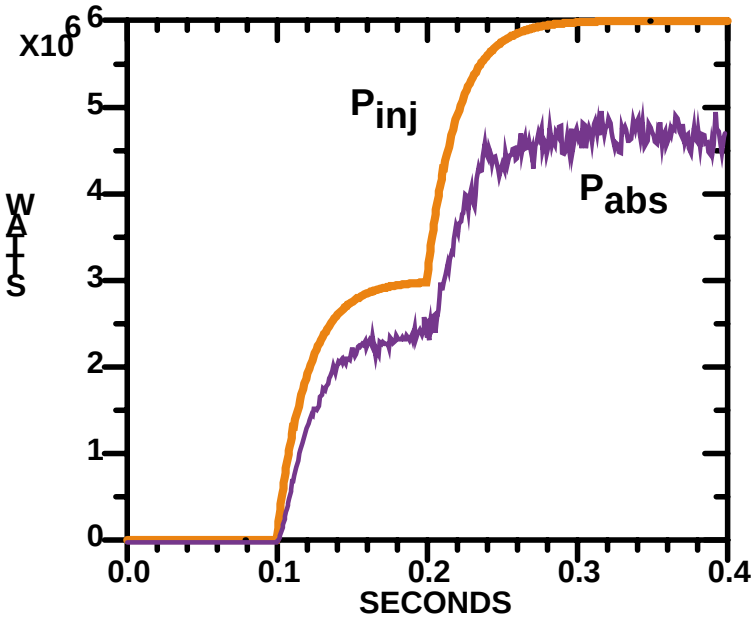
CALC.AVG. SURFACE VOLTAGE (VSURC) VS TIME



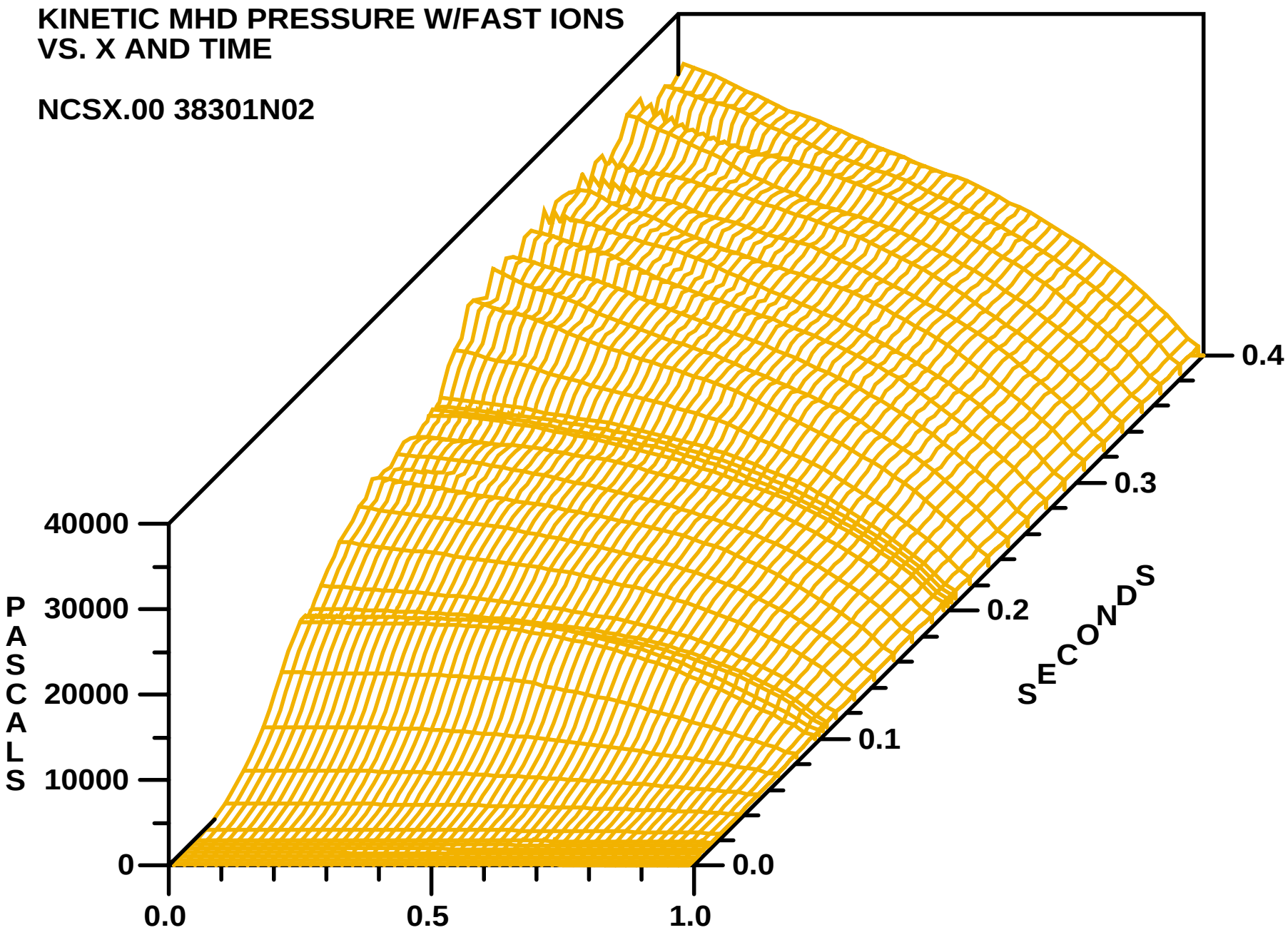
LI/2 (COMPUTED FROM J PROFILE) (LIO2C) VS TIME

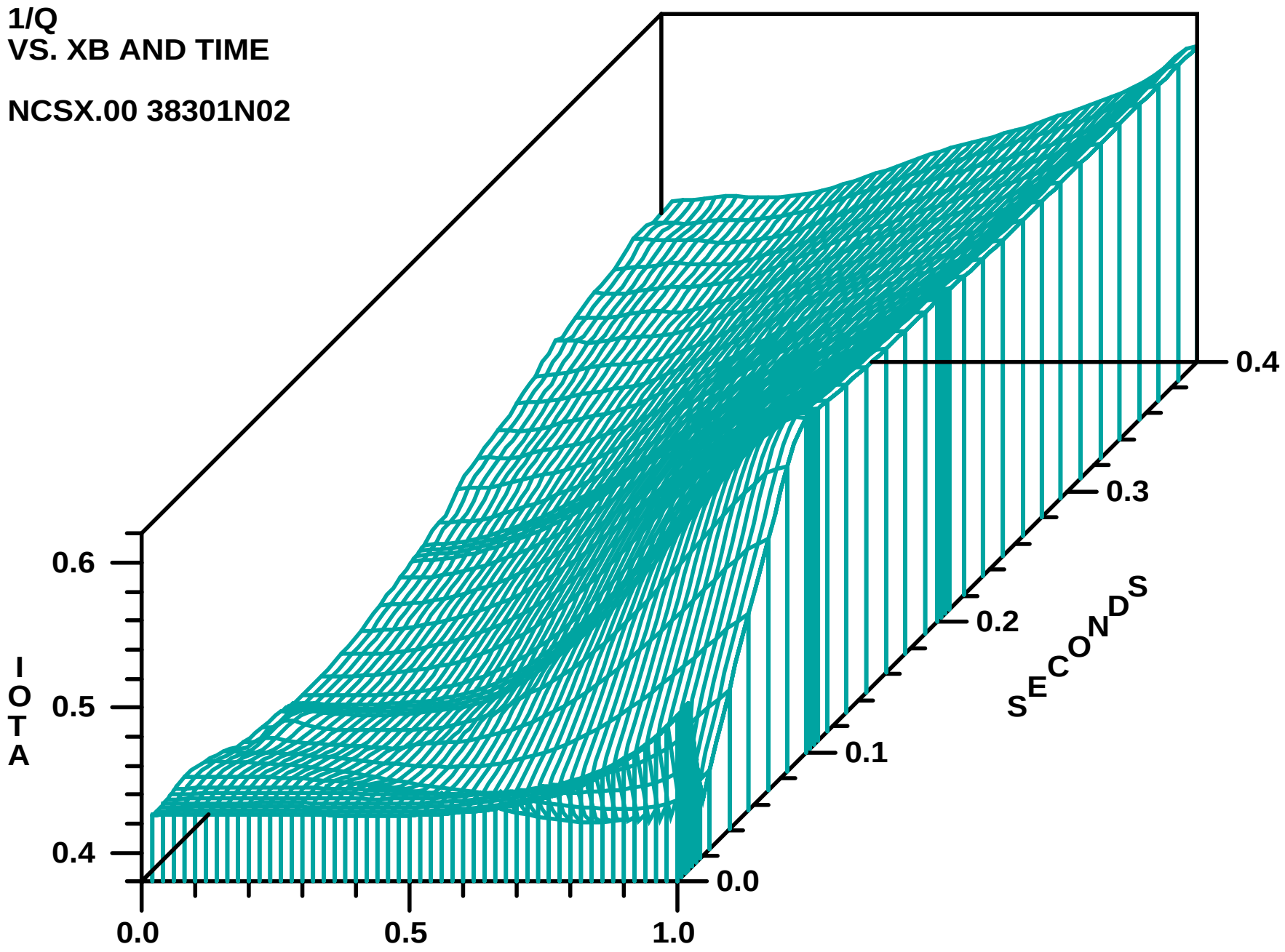


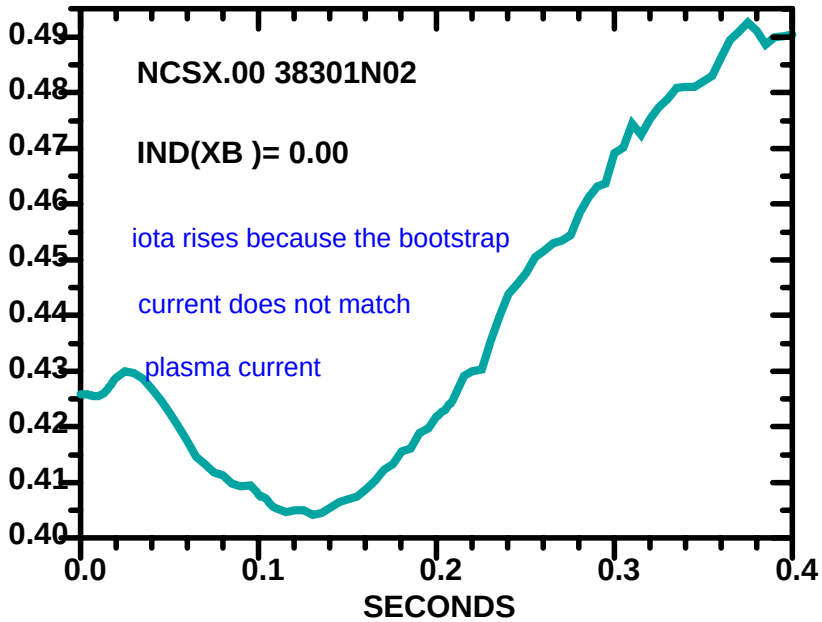
EQUILIBRIUM BETA(POLOIDAL) (BPEQ) VS TIME



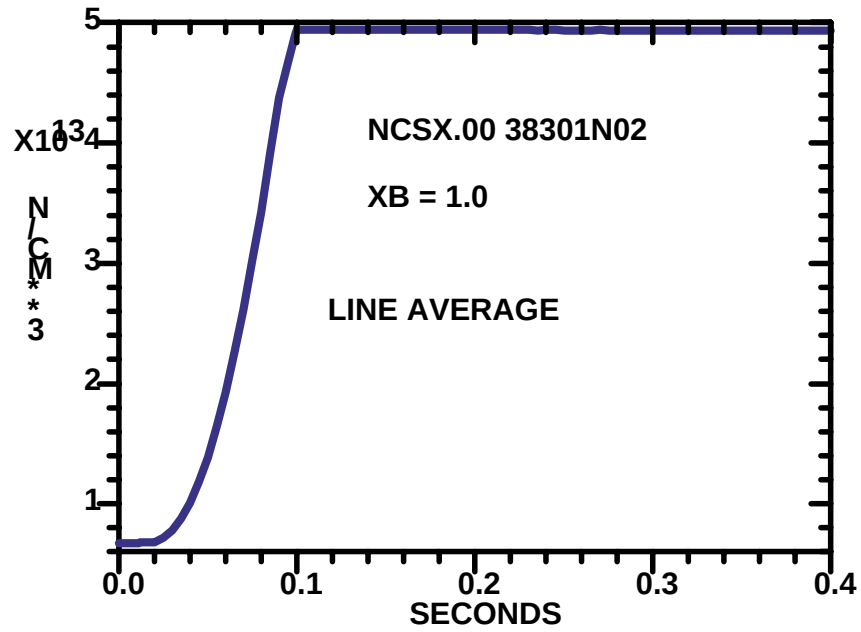
BEAM POWER INJECTED (PINJ) VS TIME


KINETIC MHD PRESSURE W/FAST IONS
VS. X AND TIME
NCSX.00 38301N02
PASCALS
40000
30000
20000
10000
0
0.0
0.5
1.0
0.0
0.1
0.2
0.3
0.4
SECONDS

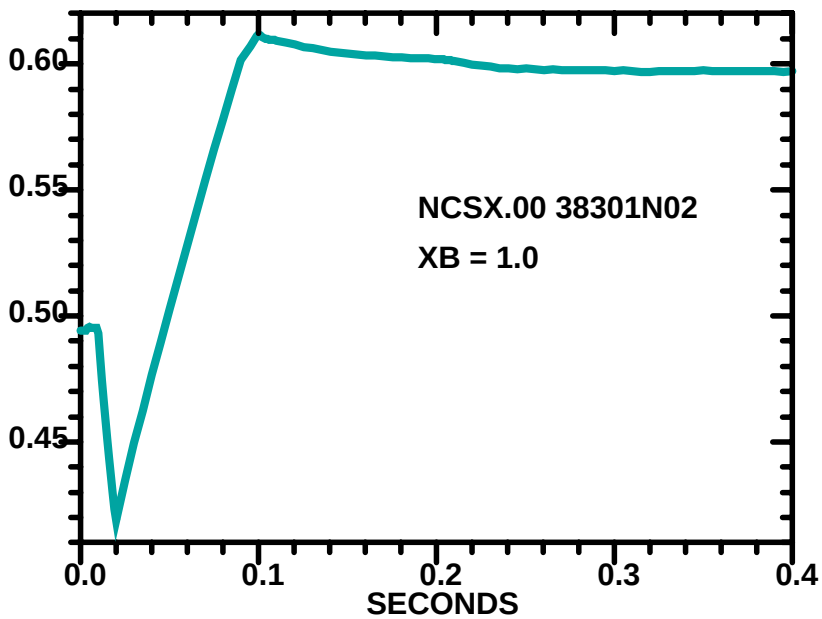

1/Q
VS. XB AND TIME
NCSX.00 38301N02
IOTA
0.6
0.5
0.4
0.0
0.5
1.0
0.0
0.1
0.2
0.3
0.4
SECONDS



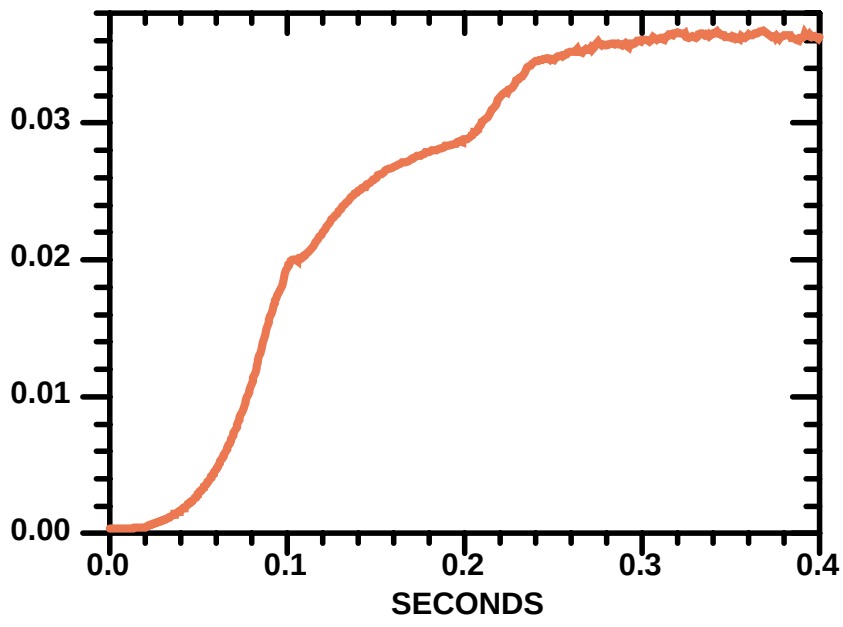
ι (0) VS TIME



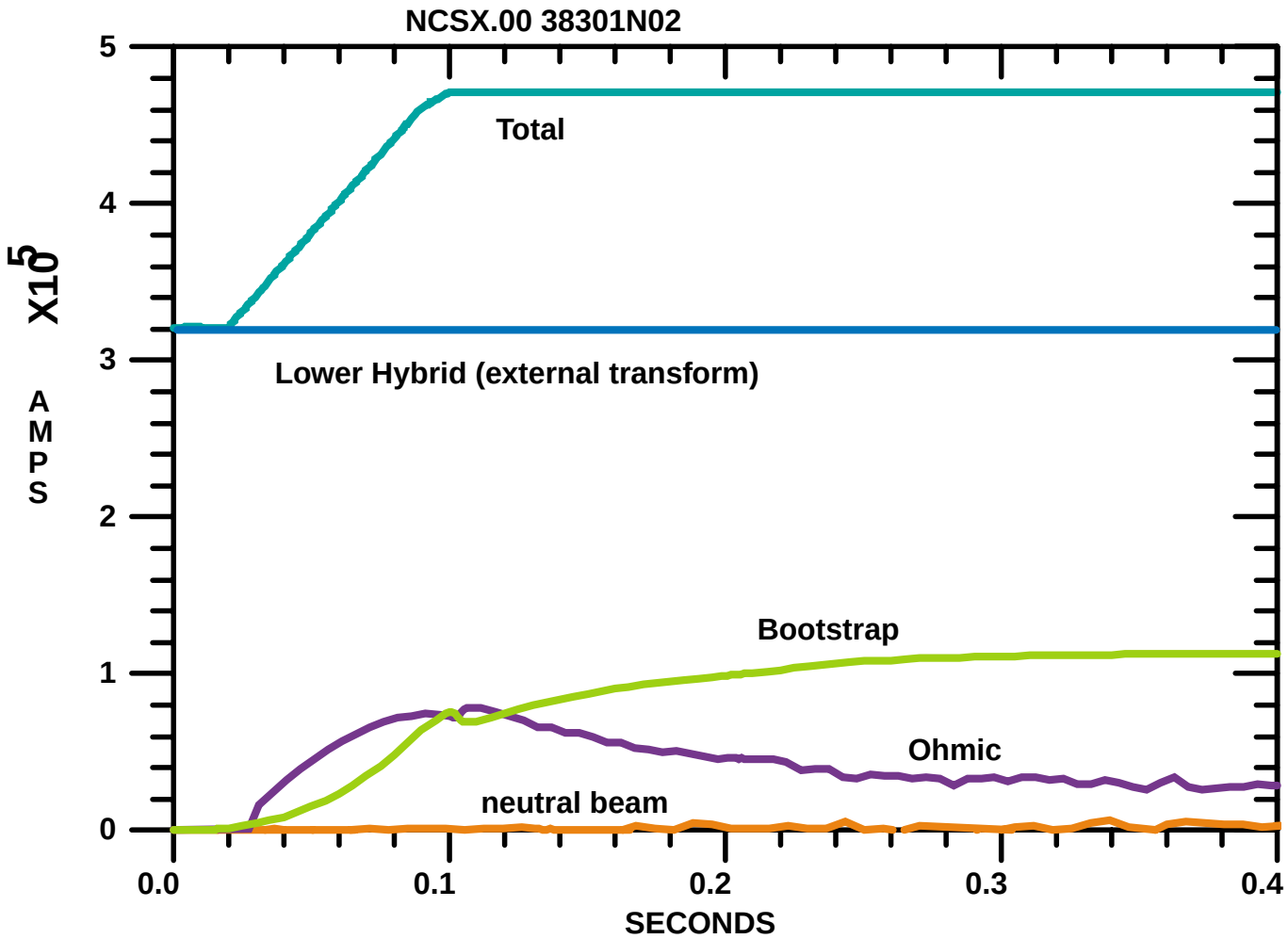
ELECTRON DENSITY (RMC00) VS TIME



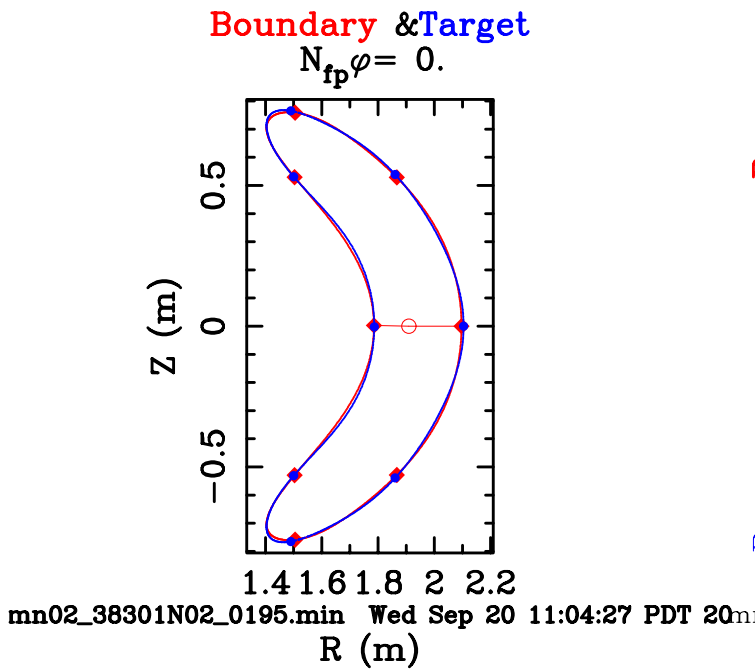
ι (1) VS TIME

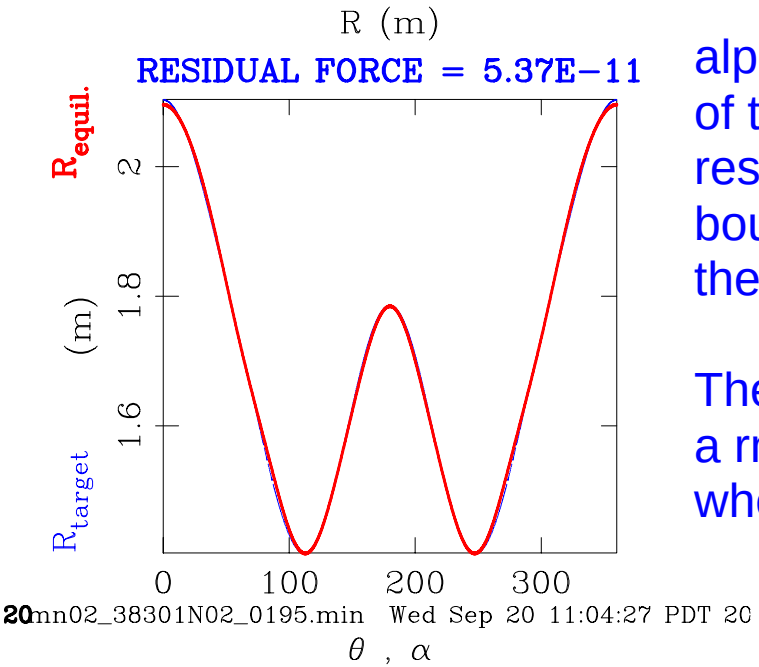


EQUILIBRIUM BETA(TOROIDAL) (BTEQ) VS TIME



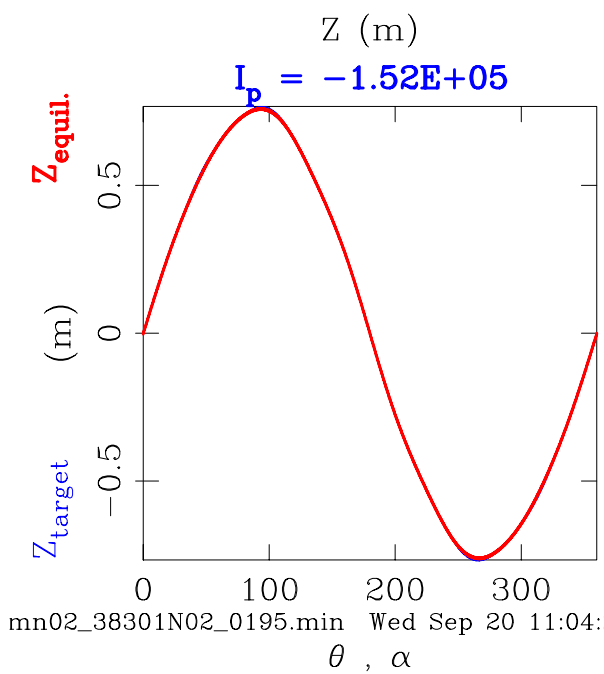
CALCULATED PLASMA CURRENTS VS TIME

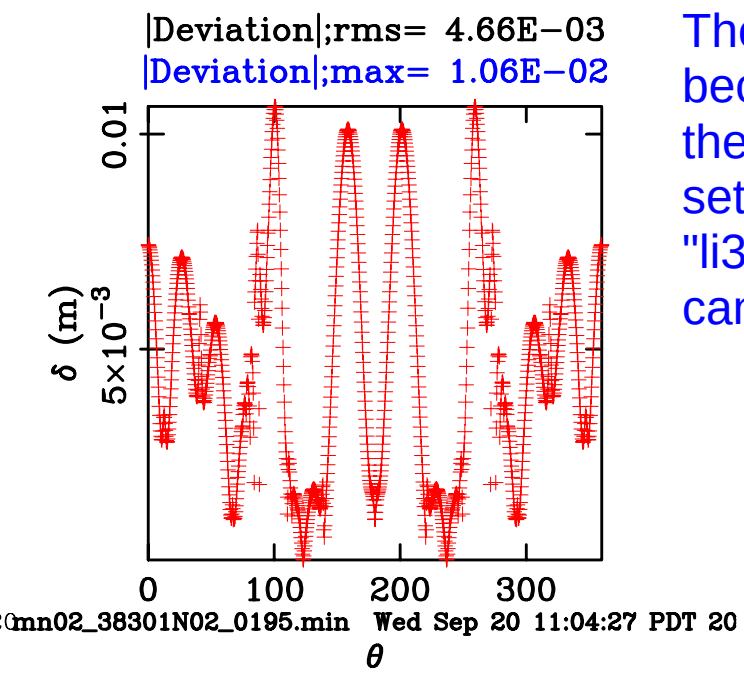




alpha is the poloidal angle of the target shape which results in points nearest the boundary: alpha=alpha(theta), theta is the usual poloidal angle.

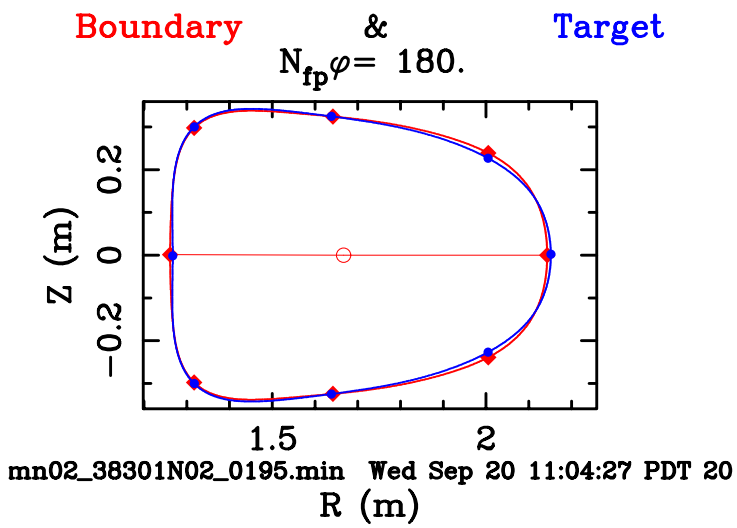
The calculation results in a rms deviation ~ 1 mm (error) when the agreement is exact.

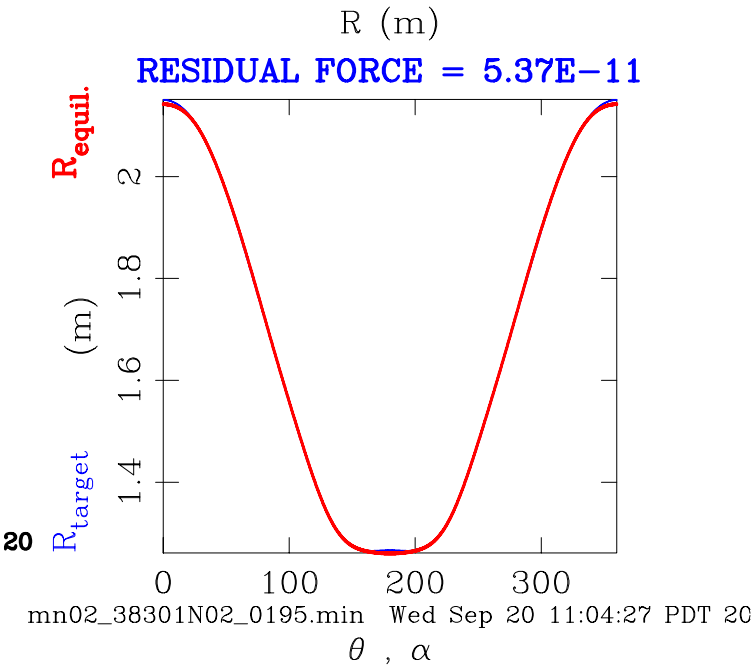


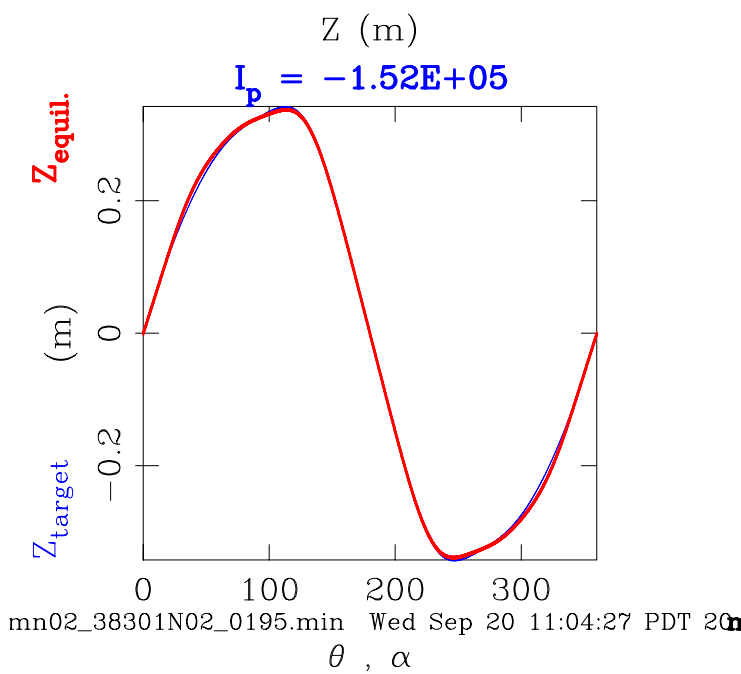


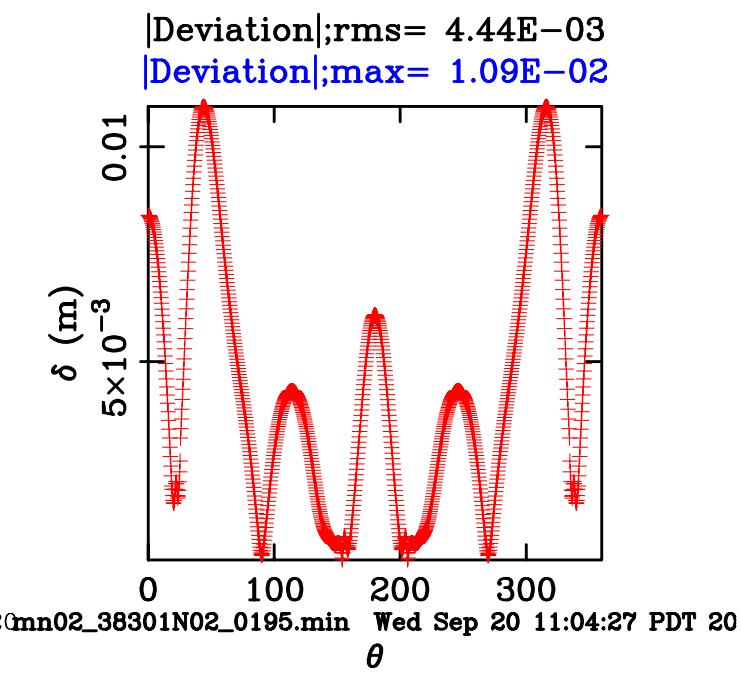
The agreement is good because we are comparing to the "a4" shape, which the coil set can make, not the "li383_328" shape which it cannot make.

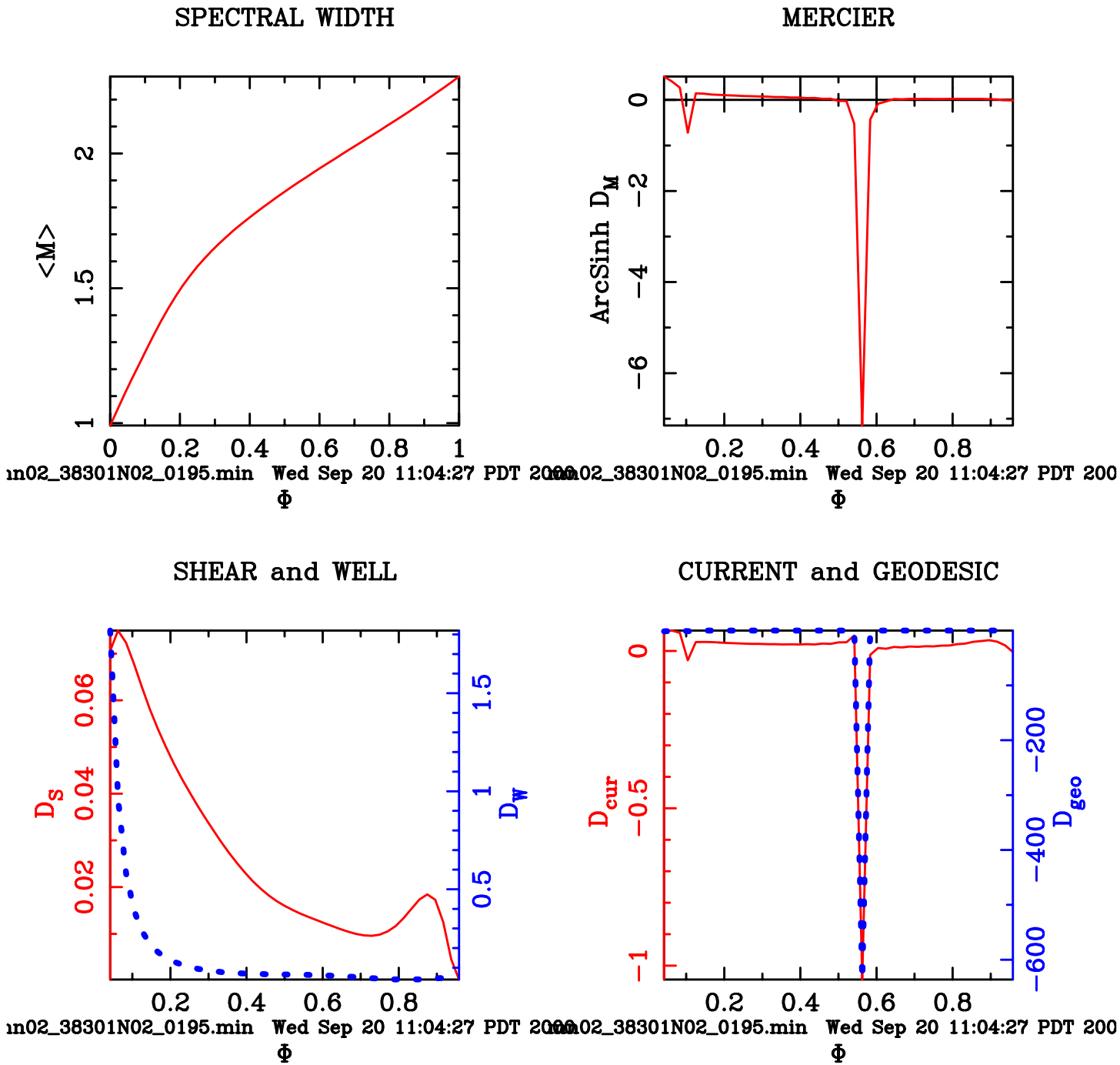
Typical results for the modular coil set.


Boundary
&
Target
$N_{fp}\varphi$= 180.
Z (m)
0.2
0
−0.2
1.5
2
mn02_38301N02_0195.min Wed Sep 20 11:04:27 PDT 20
R (m)

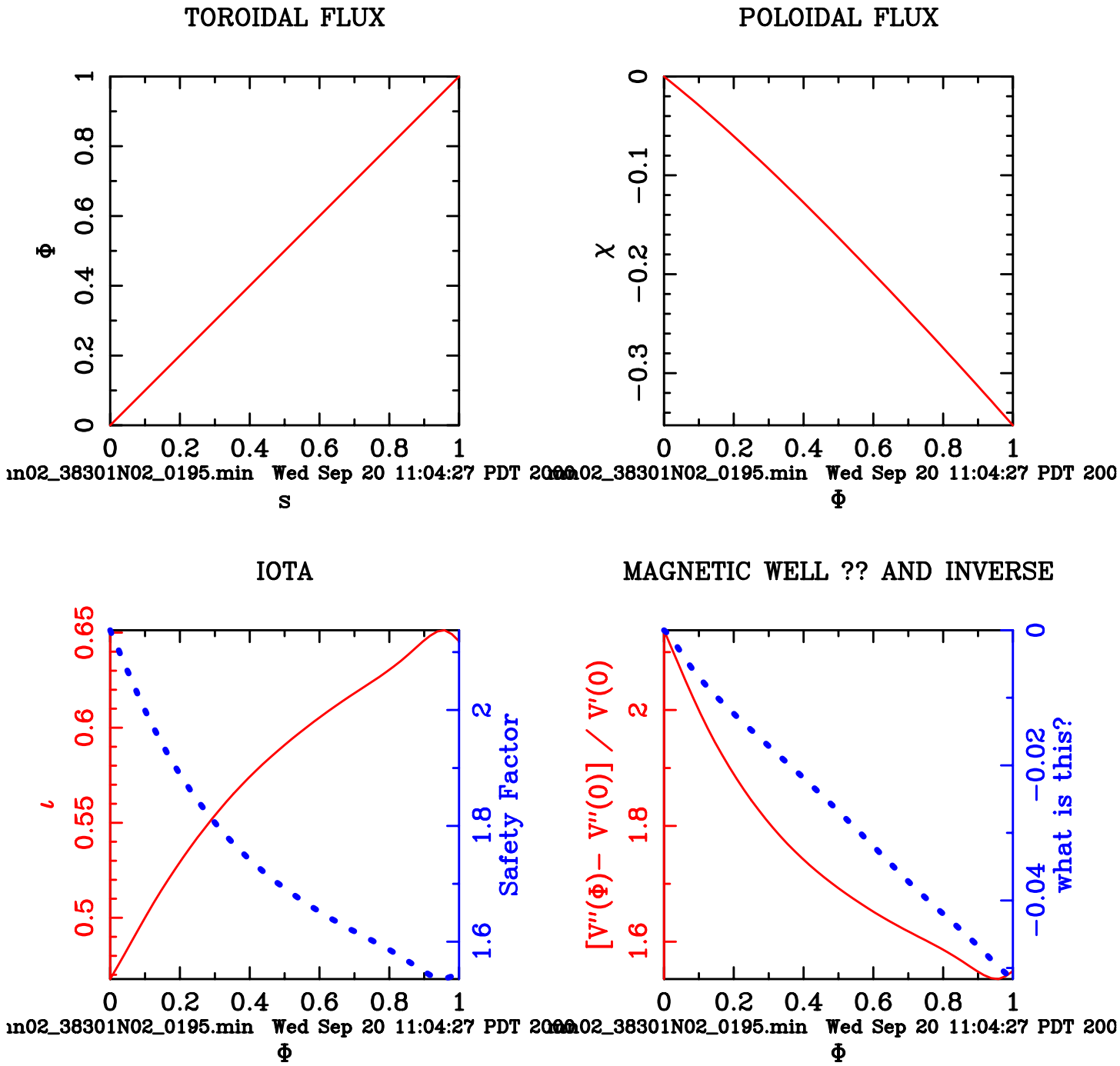

R (m)
RESIDUAL FORCE = 5.37E−11
$R_{equil.}$
R_{target}
(m)
2
1.8
1.6
1.4
0
100
200
300
mn02_38301N02_0195.min Wed Sep 20 11:04:27 PDT 20
θ , α


Z (m)
I_p = −1.52E+05
$Z_{equil.}$
Z_{target}
(m)
0.2
0
−0.2
0
100
200
300
mn02_38301N02_0195.min Wed Sep 20 11:04:27 PDT 20
θ , α


|Deviation|;rms= 4.44E−03
|Deviation|;max= 1.09E−02
δ (m)
0.01
5×10^{-3}
0
100
200
300
mn02_38301N02_0195.min Wed Sep 20 11:04:27 PDT 20
θ

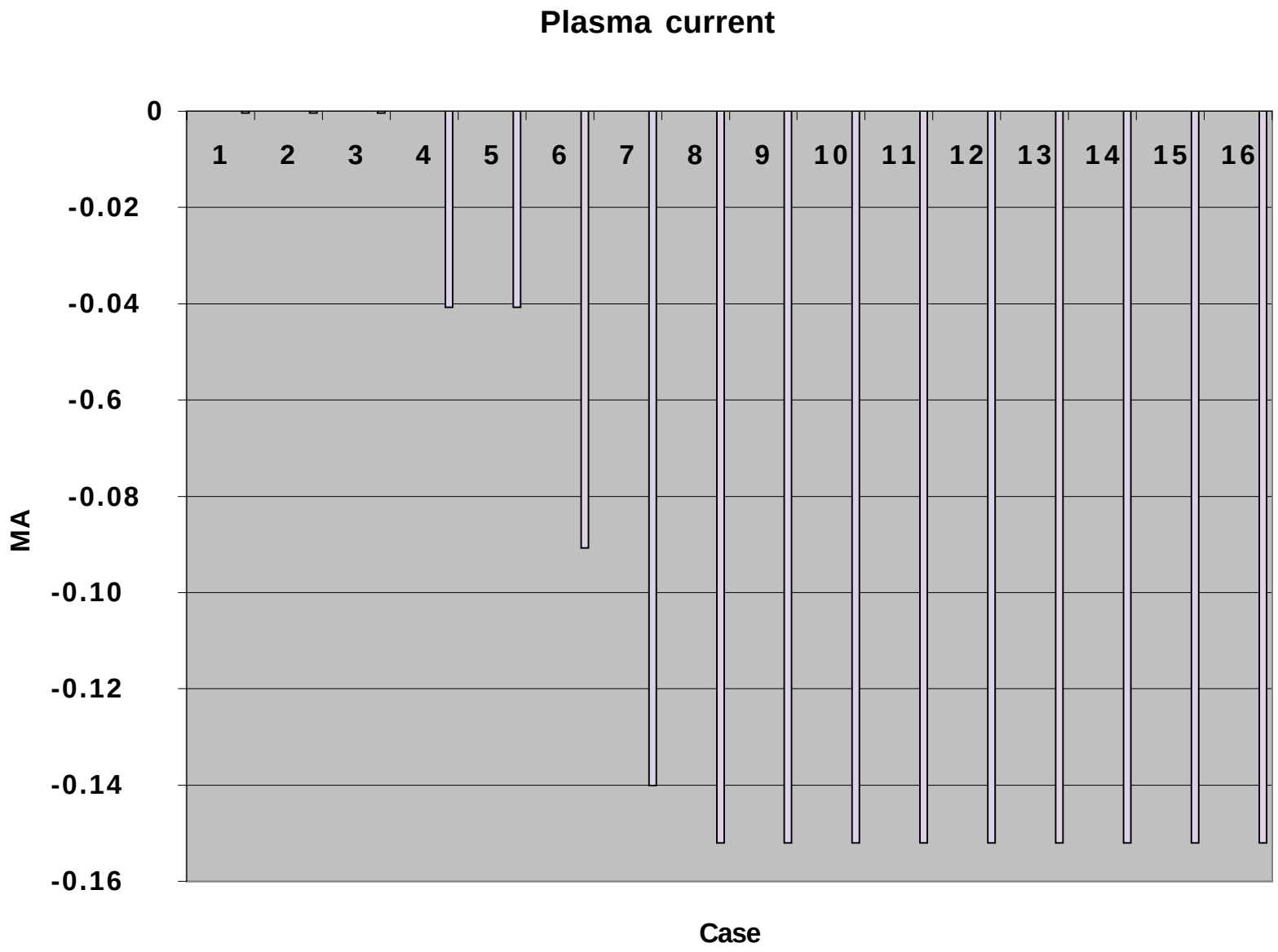


For the modular coil cases the Mercier criterion is usually, arguably positive over most of the plasma.

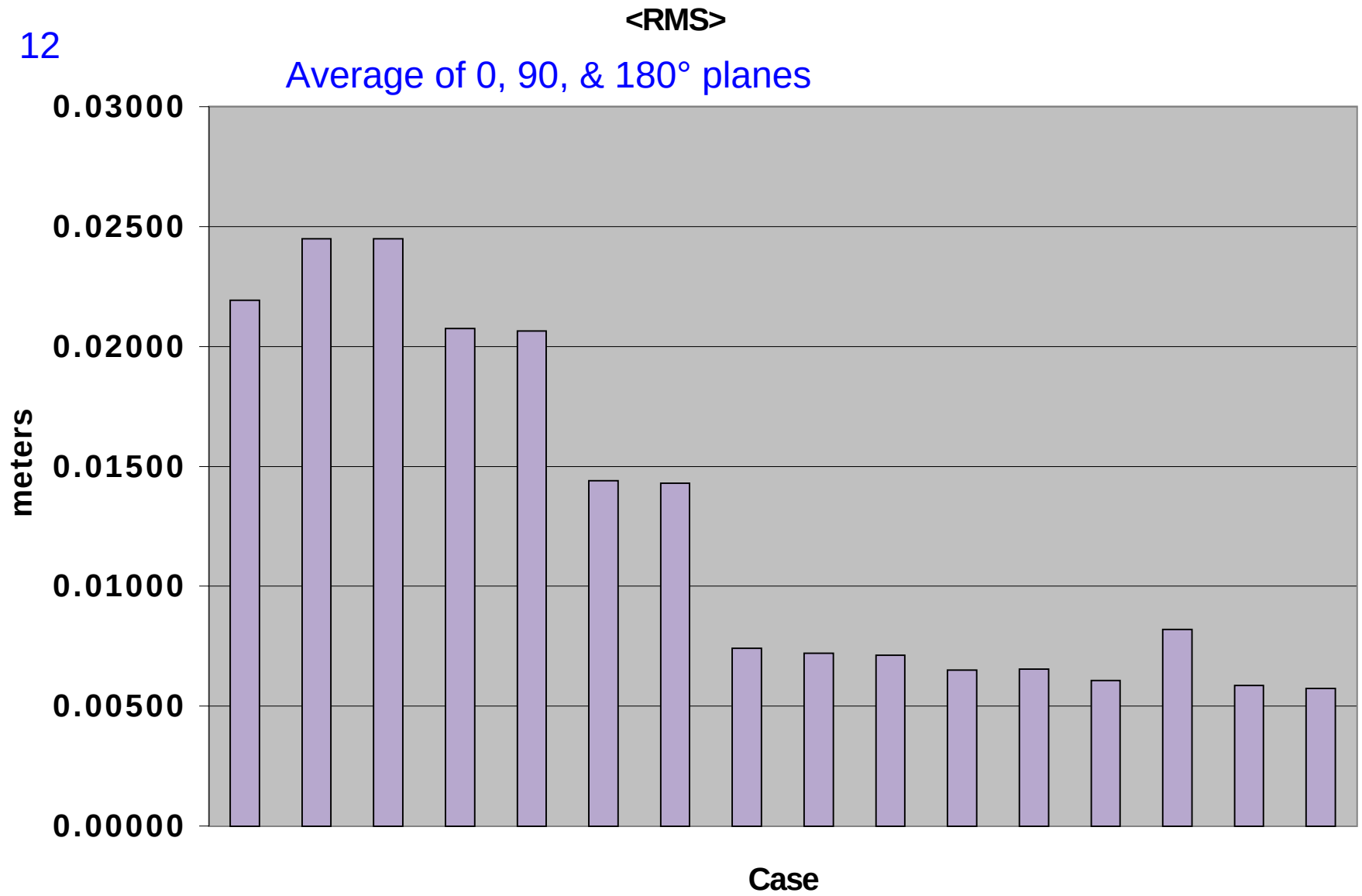


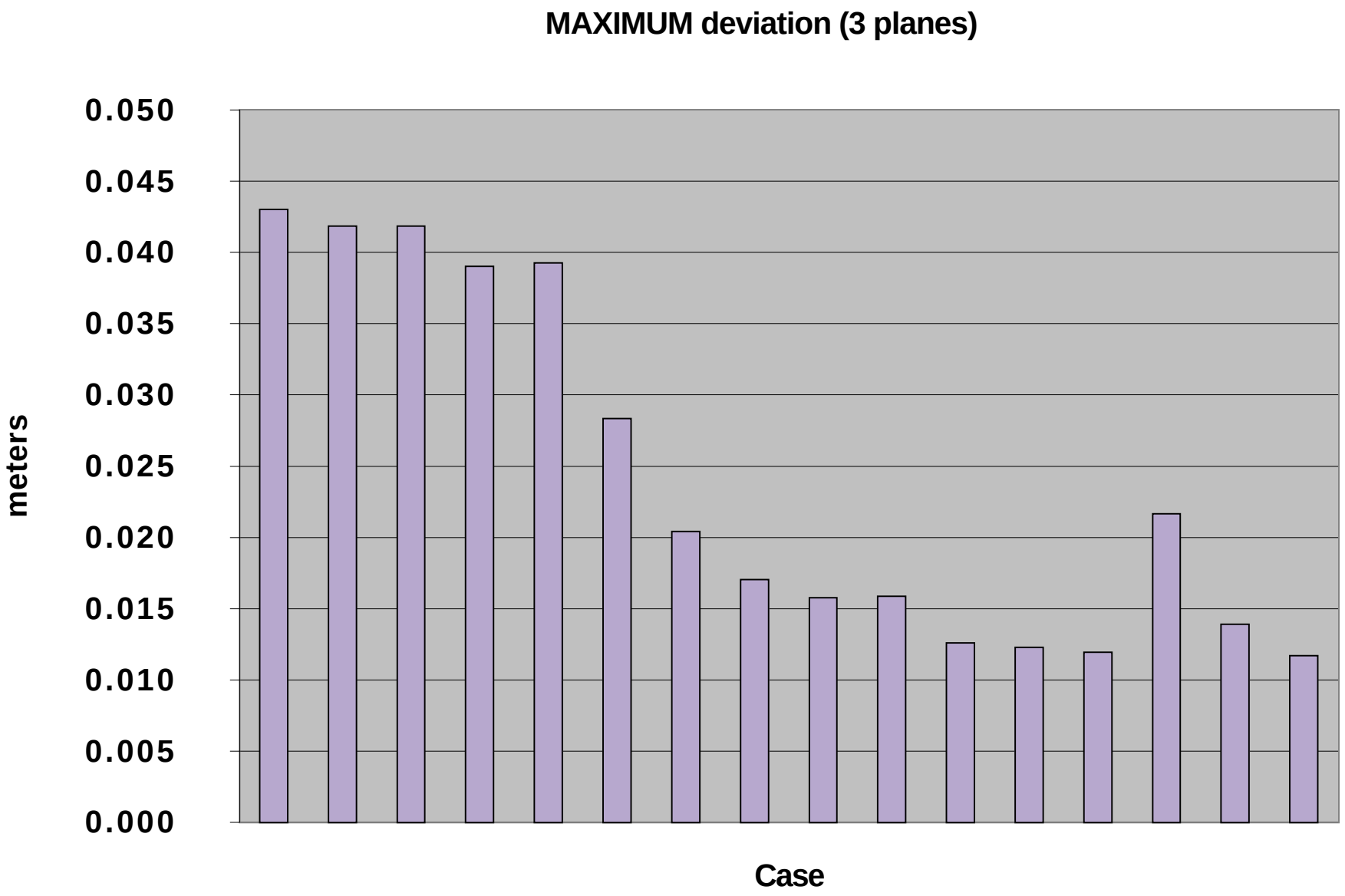
Iota is reasonably similar to the original case, as would be expected where 2/3 of the transform is external.

Modular Coil Set Results

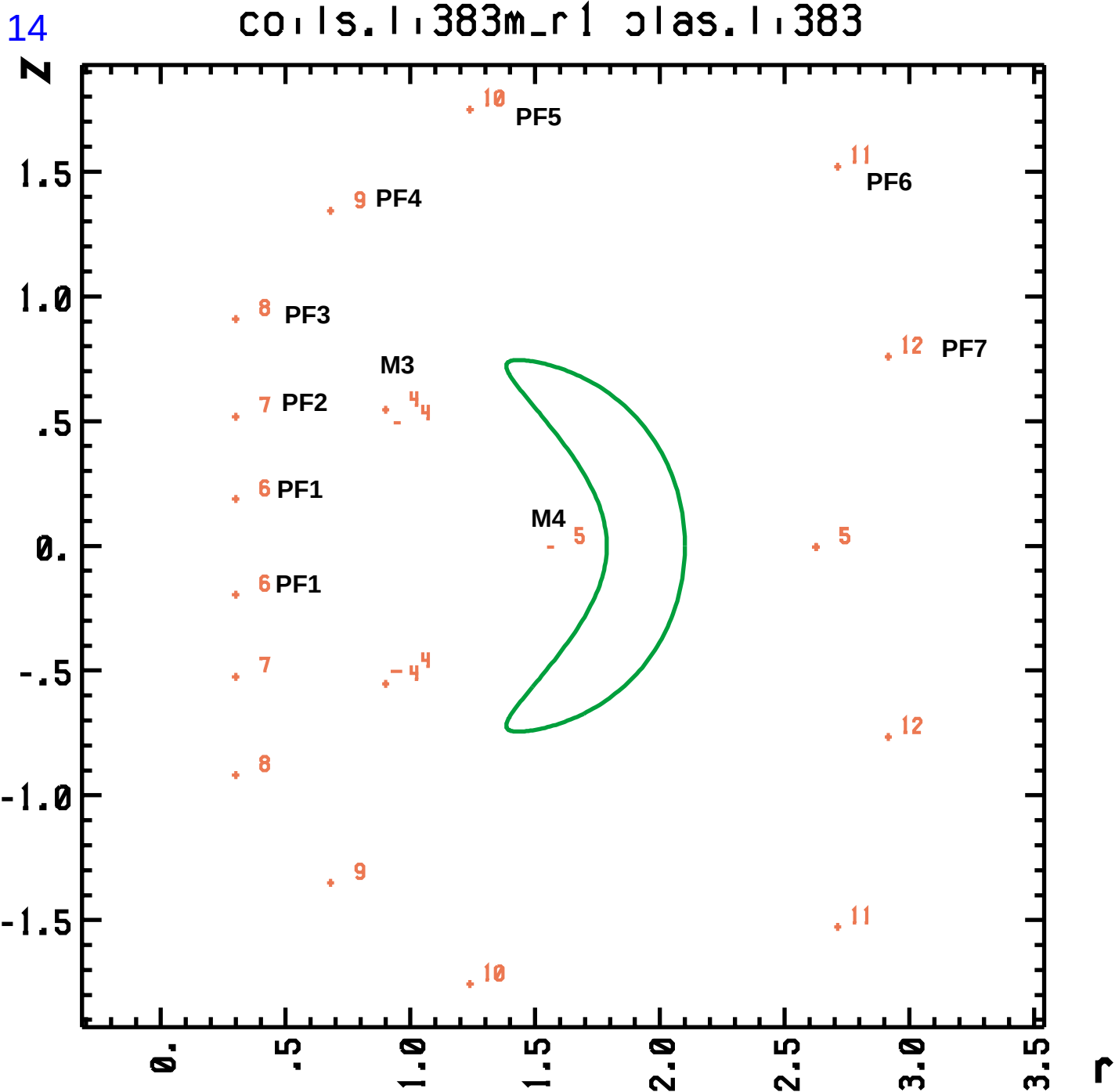


What follows is the coil currents obtained when each of the equilibria with J and p from the TRANSP results is optimized on the criteria listed on Page 1 (the shape).


<RMS>
Average of 0, 90, & 180° planes
0.03000
0.02500
0.02000
0.01500
0.01000
0.00500
0.00000
meters
Case

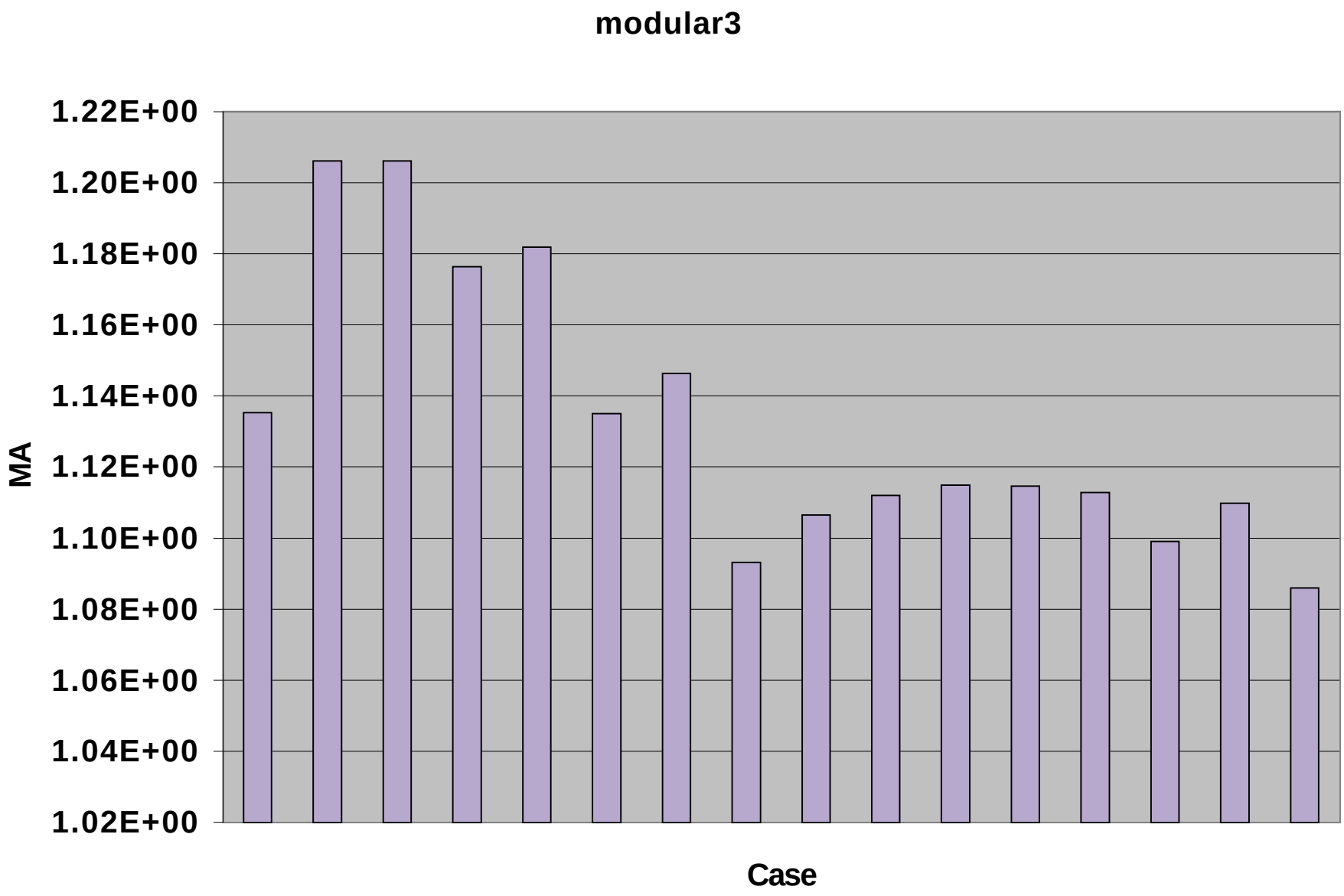

MAXIMUM deviation (3 planes)
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
meters
Case

Max Ł < 5 cm.

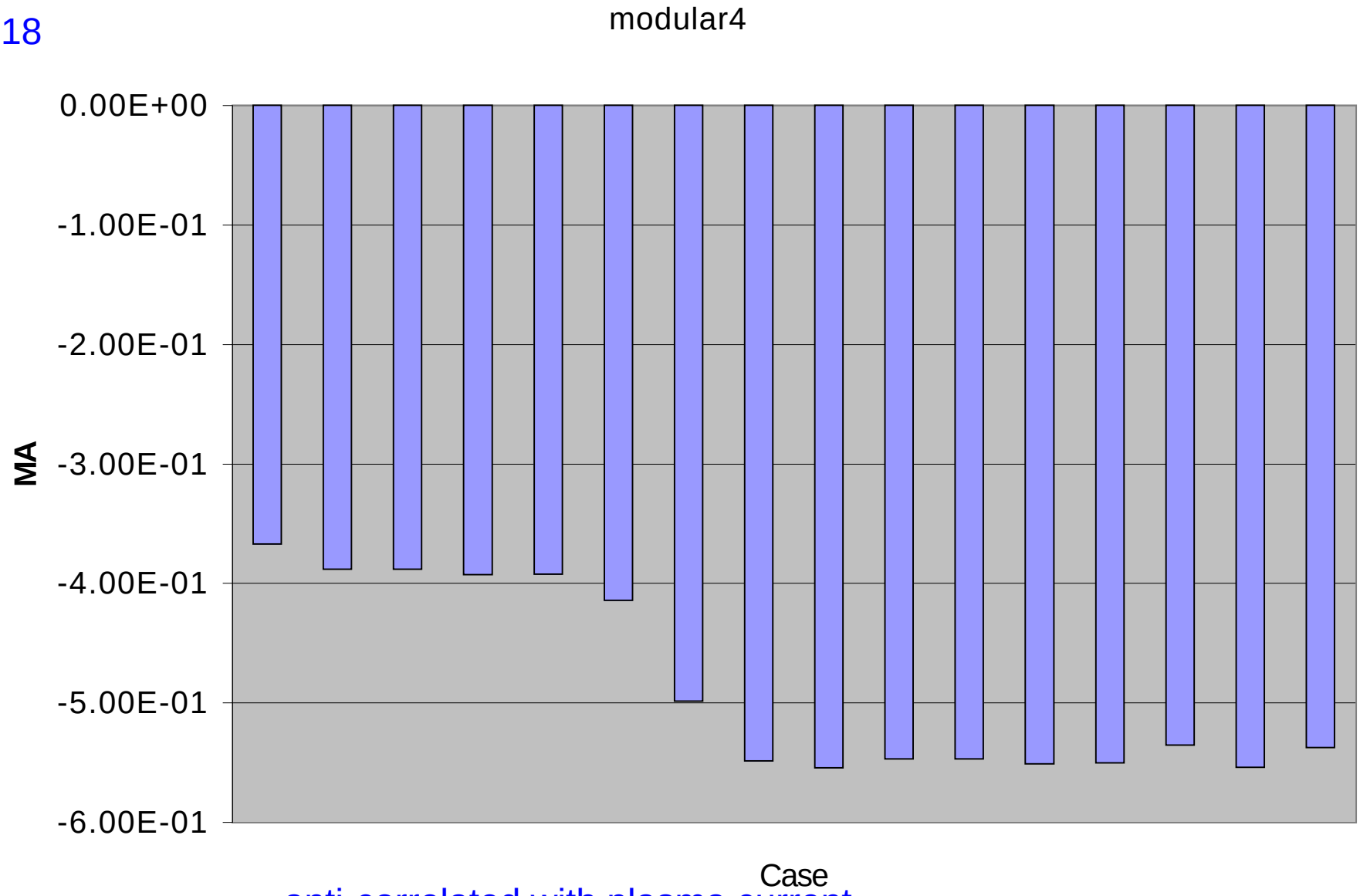

coils.l383m_rl clas.l383
Z
r
PF5
PF6
PF4
PF3
PF7
M3
PF2
PF1
M4
PF1
1.5
1.0
.5
0.
-.5
-1.0
-1.5
0.
.5
1.0
1.5
2.0
2.5
3.0
3.5

modular 1 current increase with plasma current

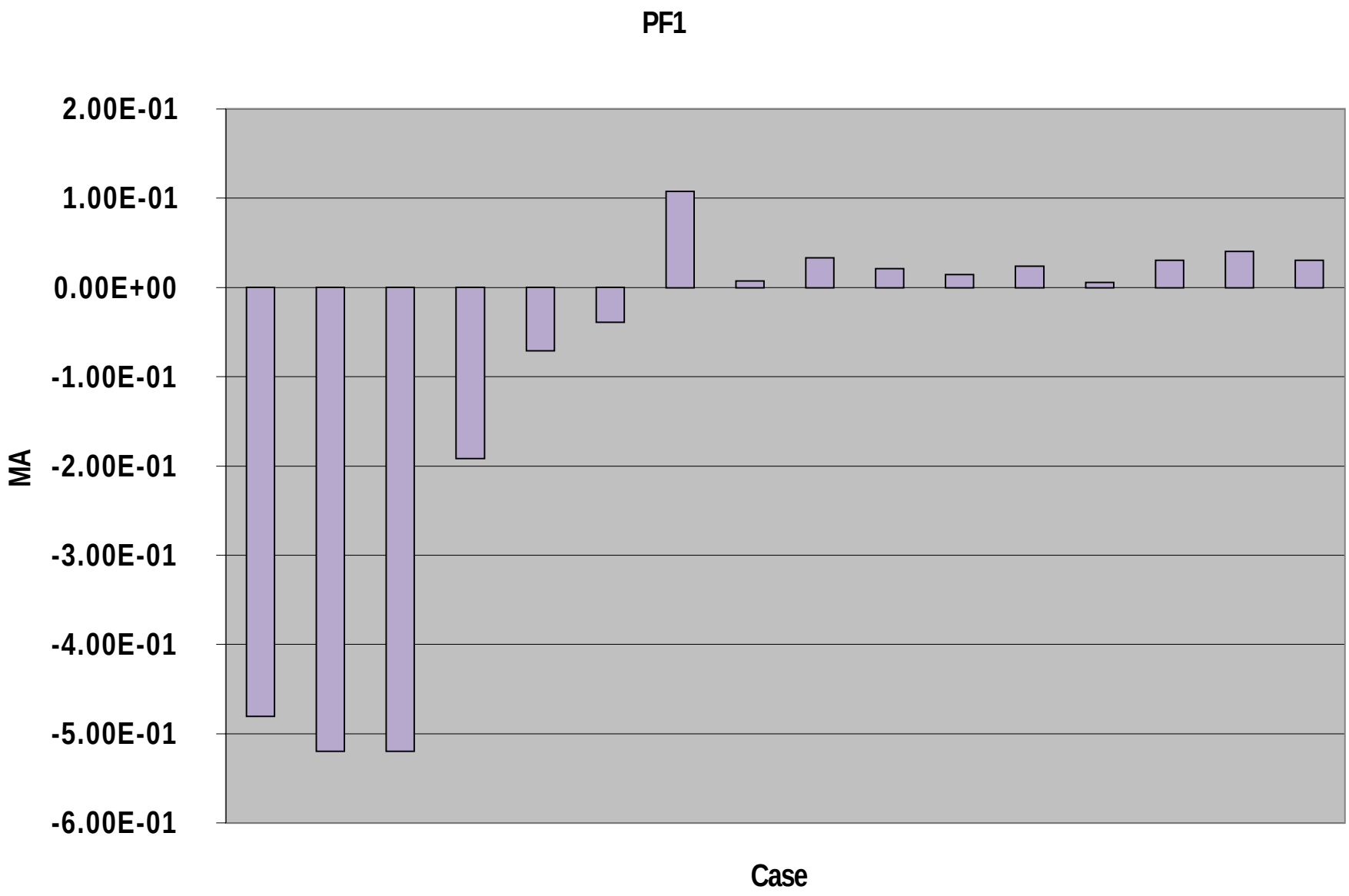
Current not highly correlated with plasma current



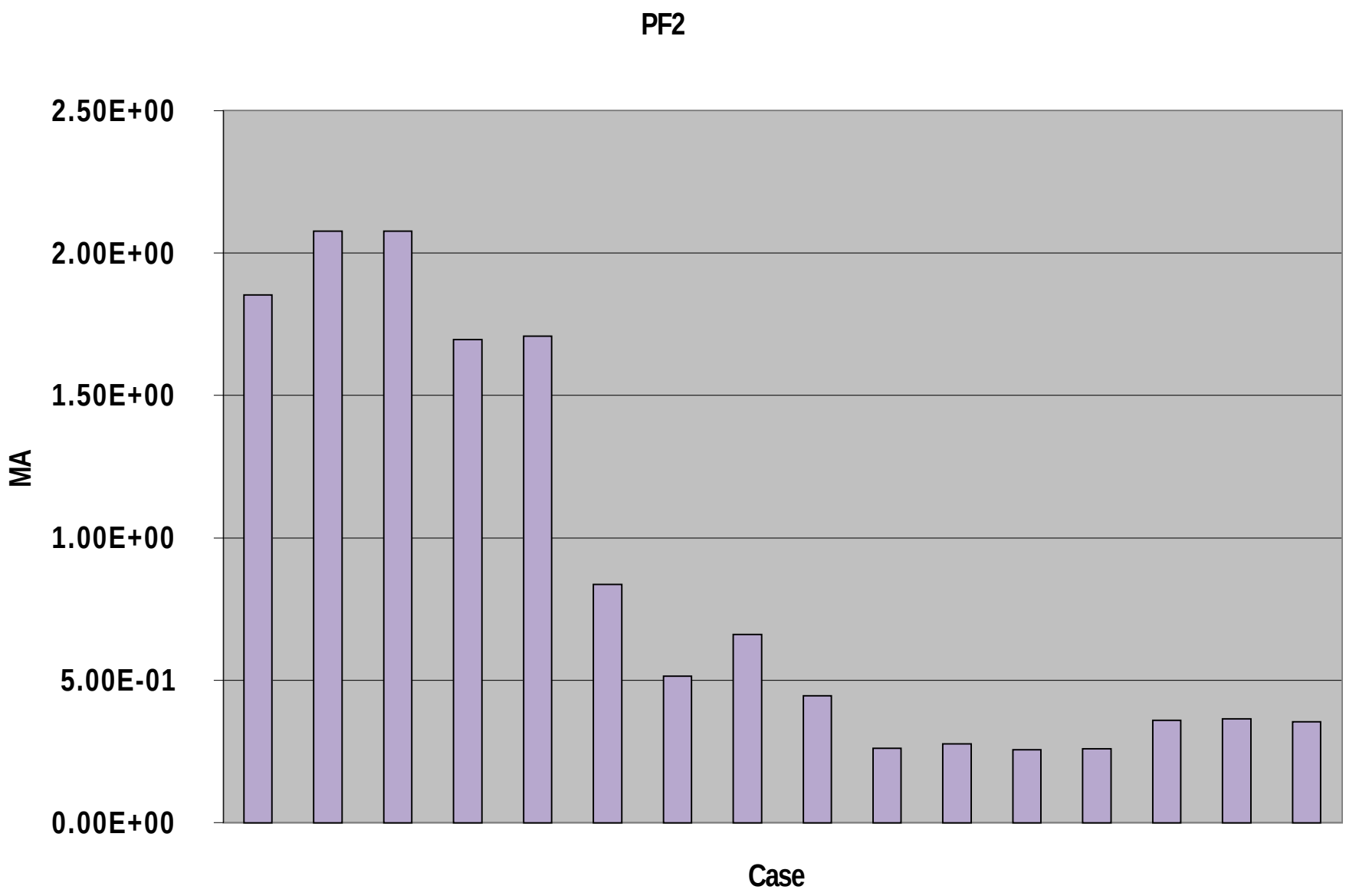
coil current highest at low plasma current



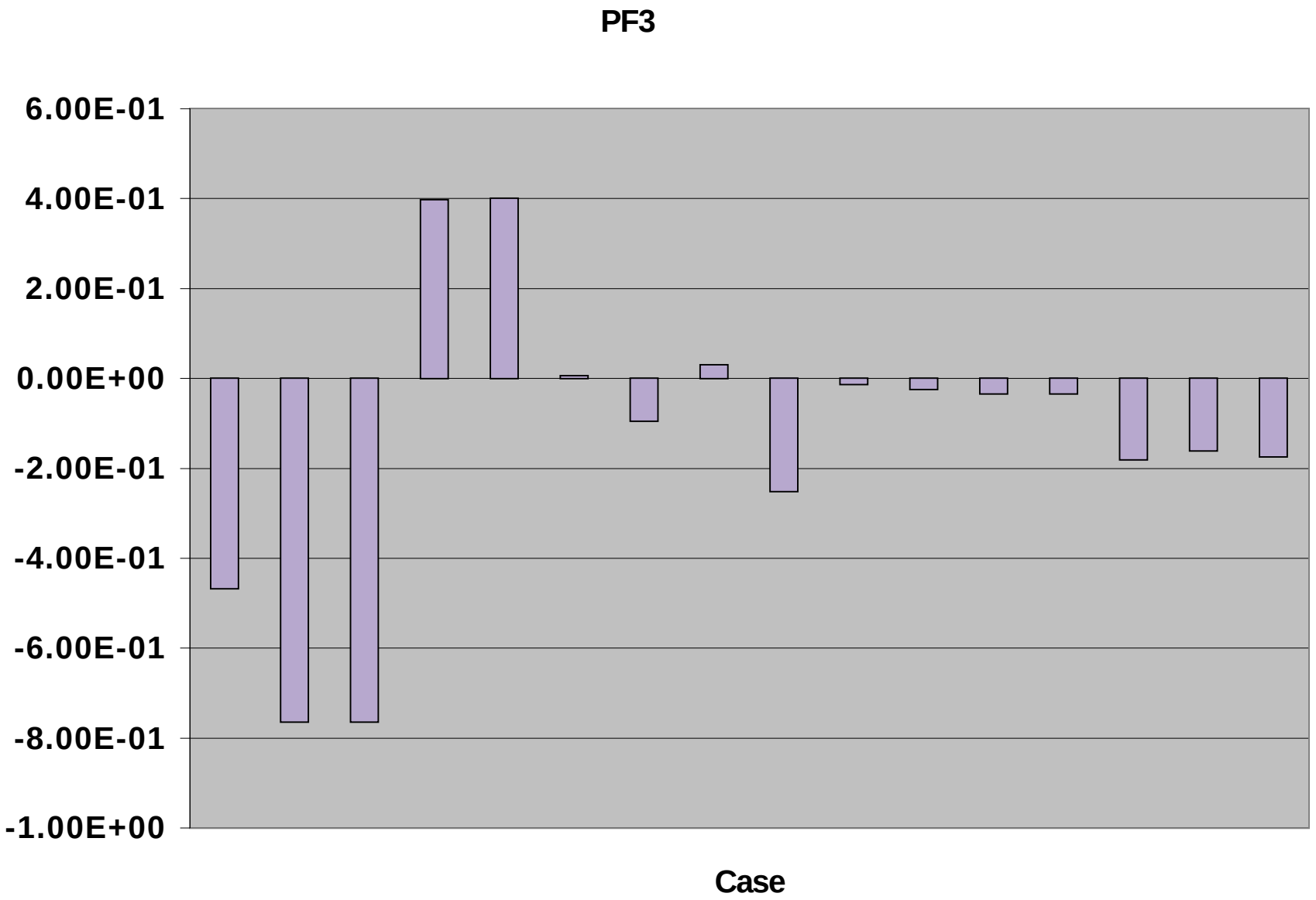
anti-correlated with plasma current



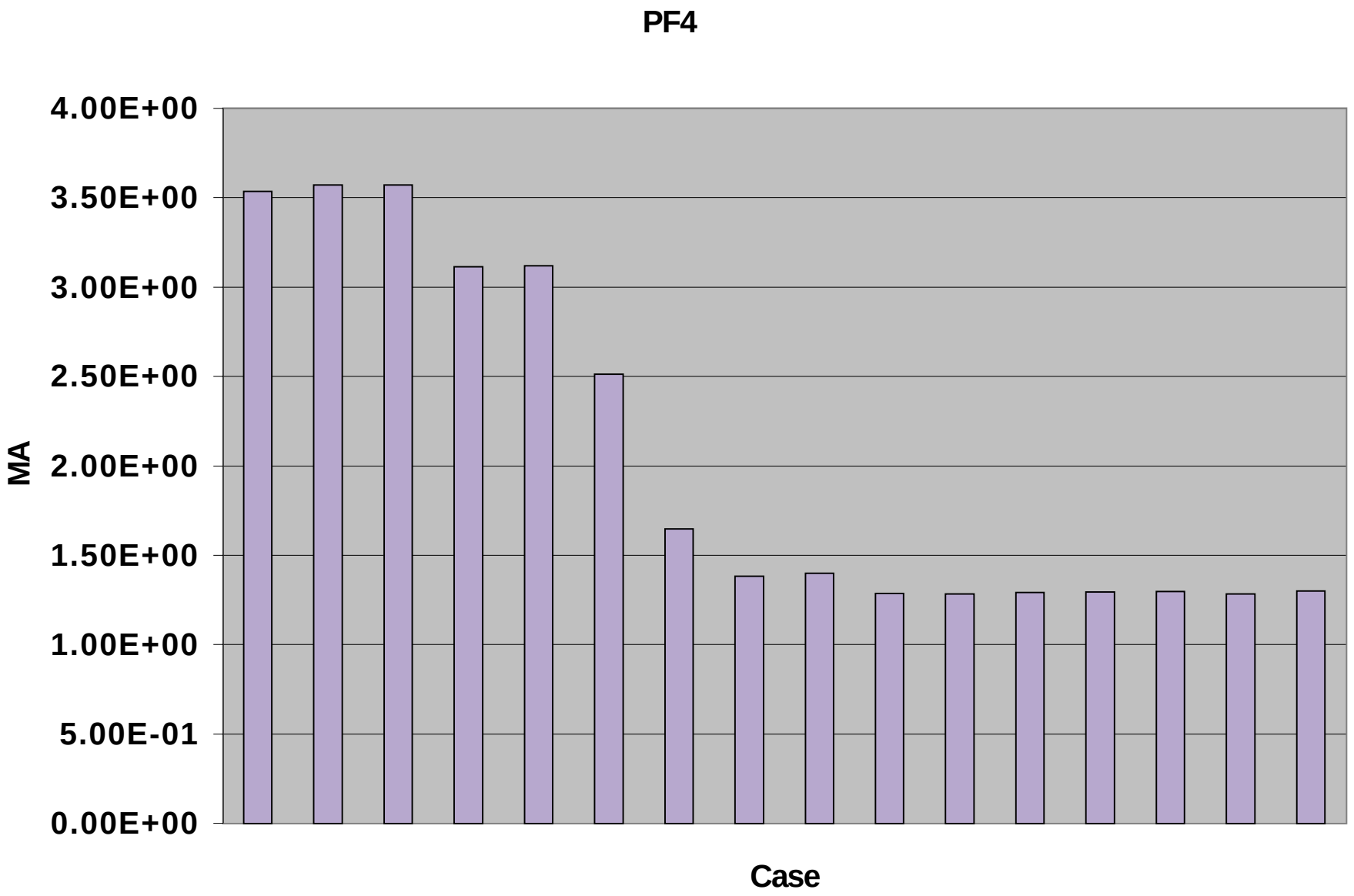
Changes sign - not desireable in PF coils



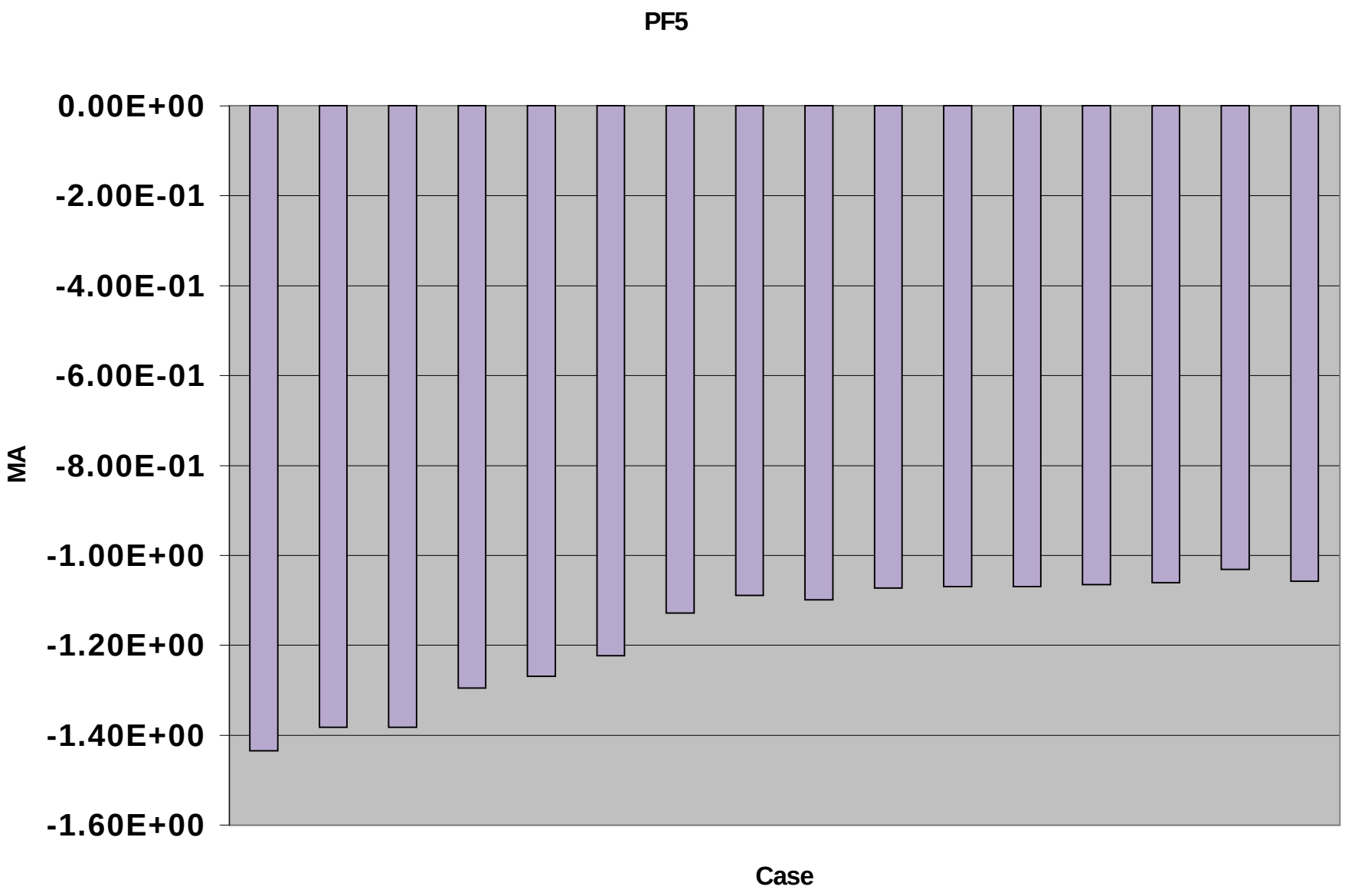
Inverse correlation with plasma current



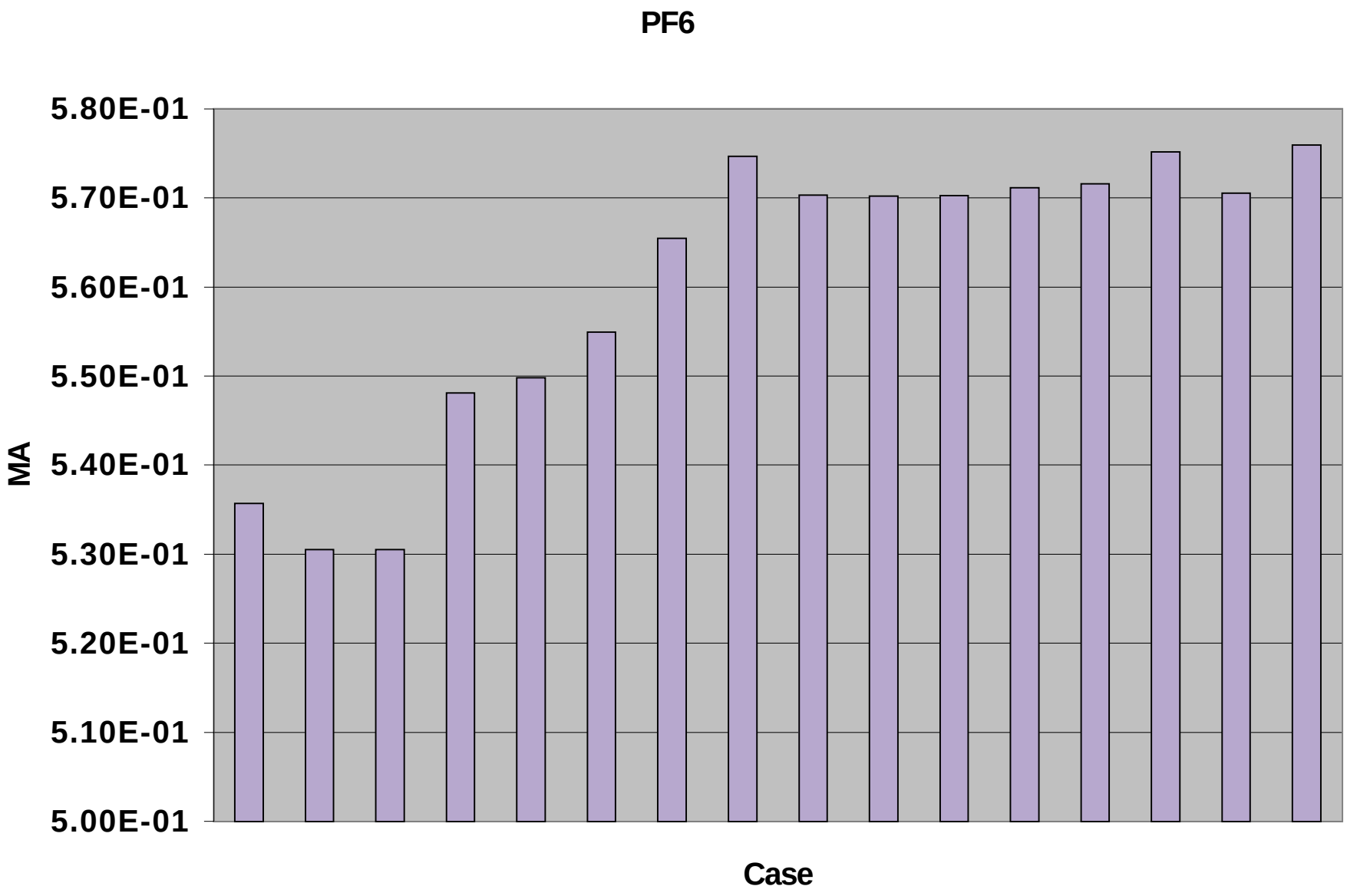
No correlation with plasma current (MA like the others.)

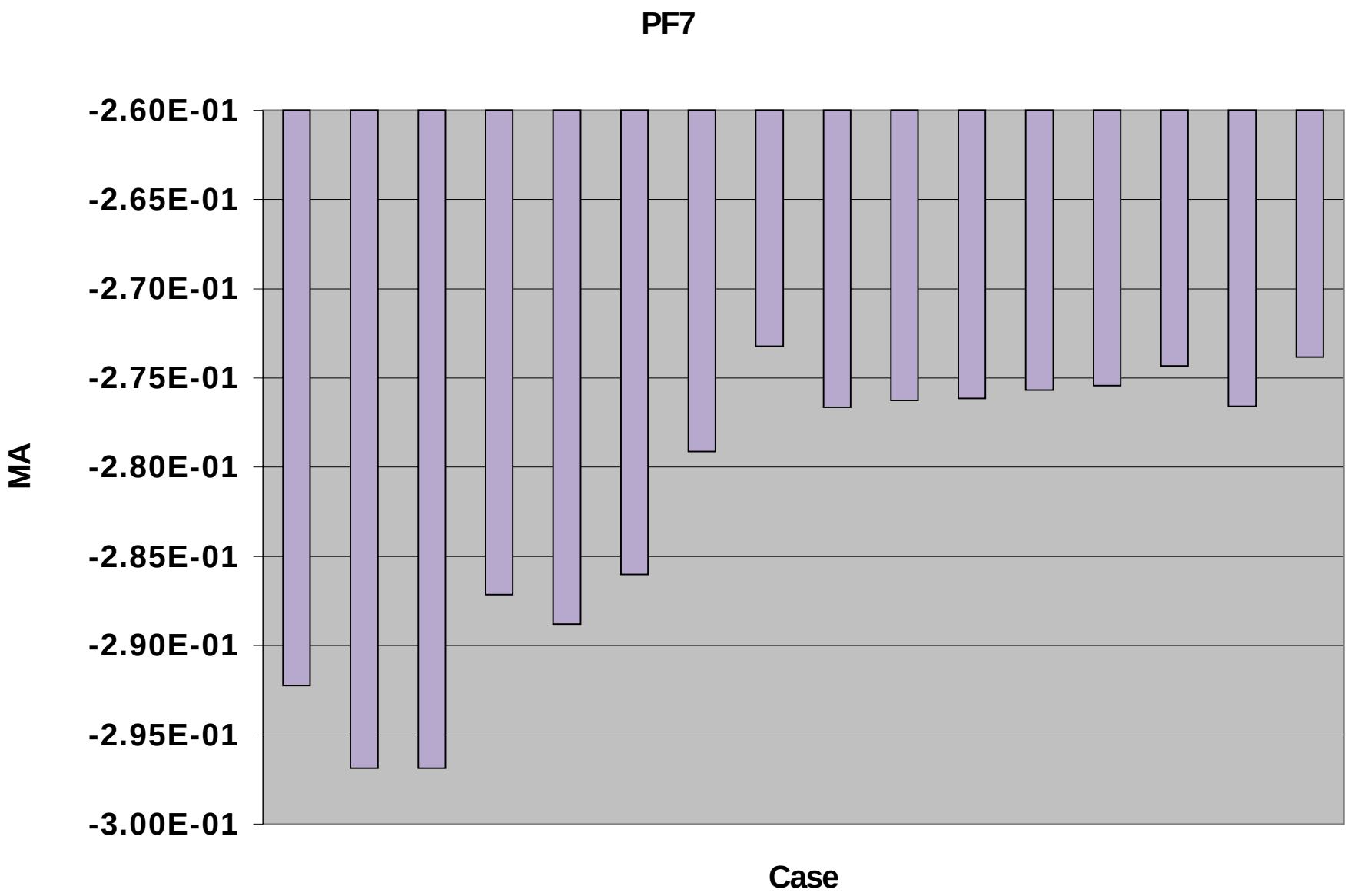


Anti correlation

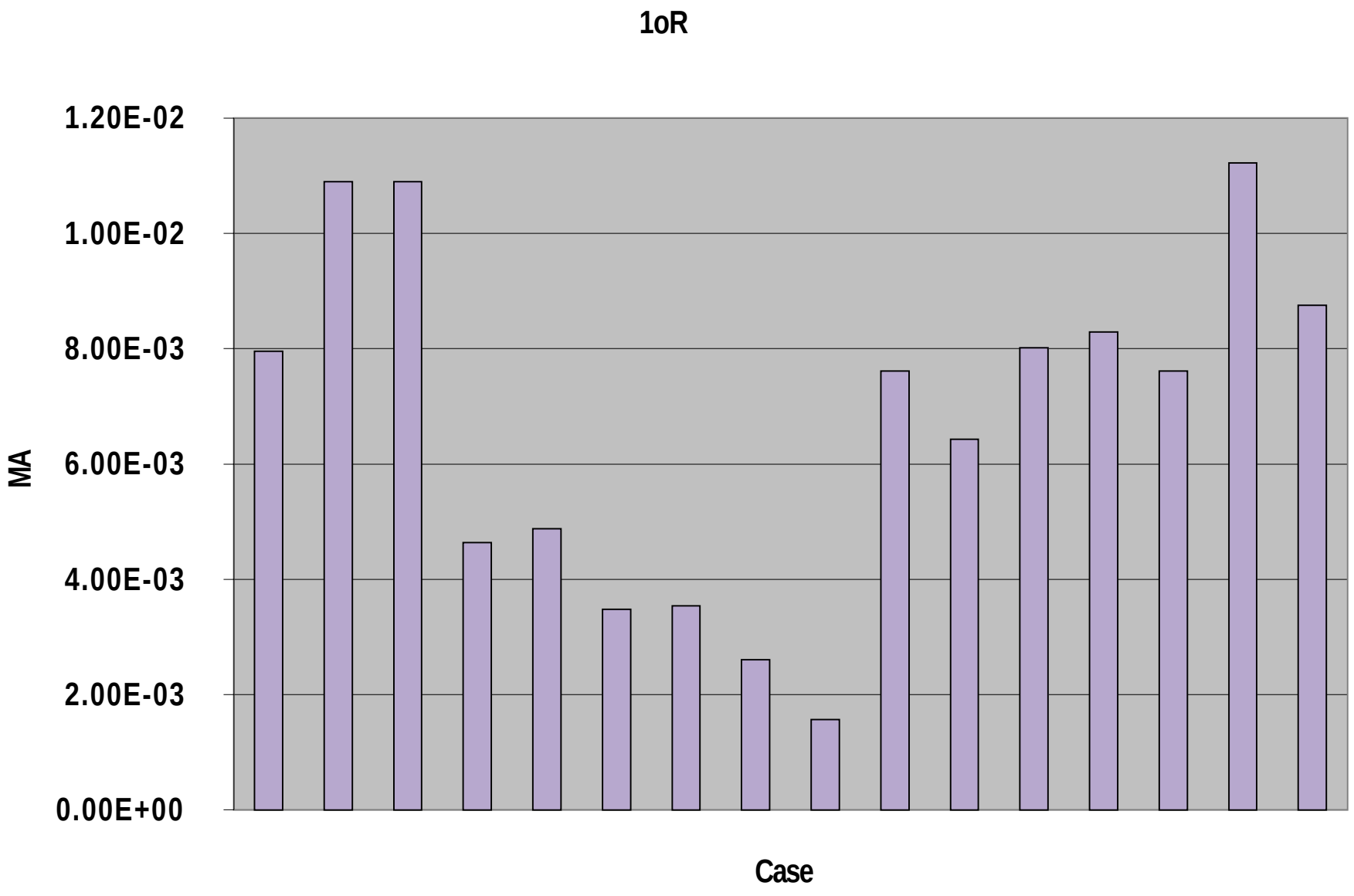


Anti-correlated with plasma current

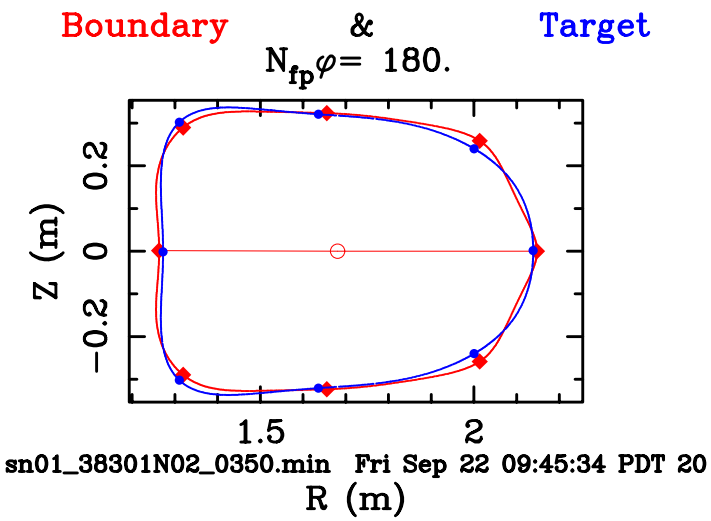

PF6
5.80E-01
5.70E-01
5.60E-01
5.50E-01
5.40E-01
5.30E-01
5.20E-01
5.10E-01
5.00E-01
MA
Case

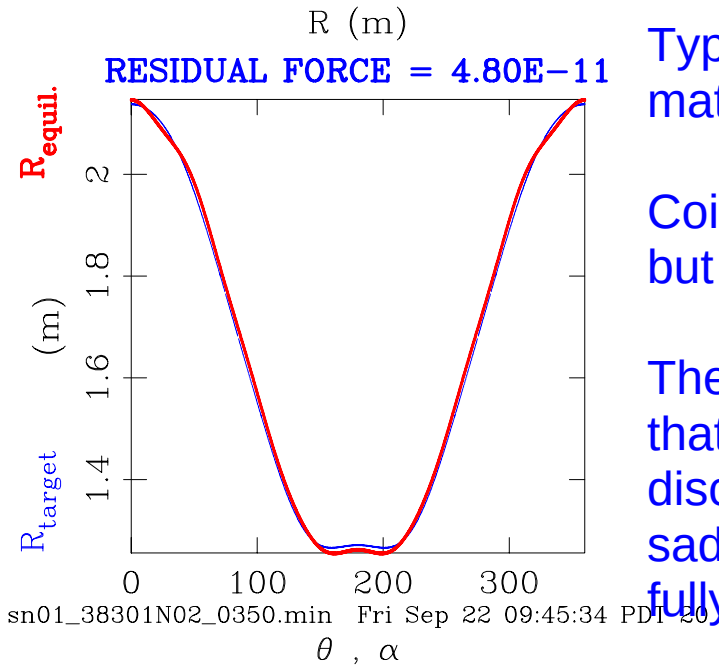


Anti-corrleated with plasma current



TF is varied to attempt to maintain phi_edge and iota_edge

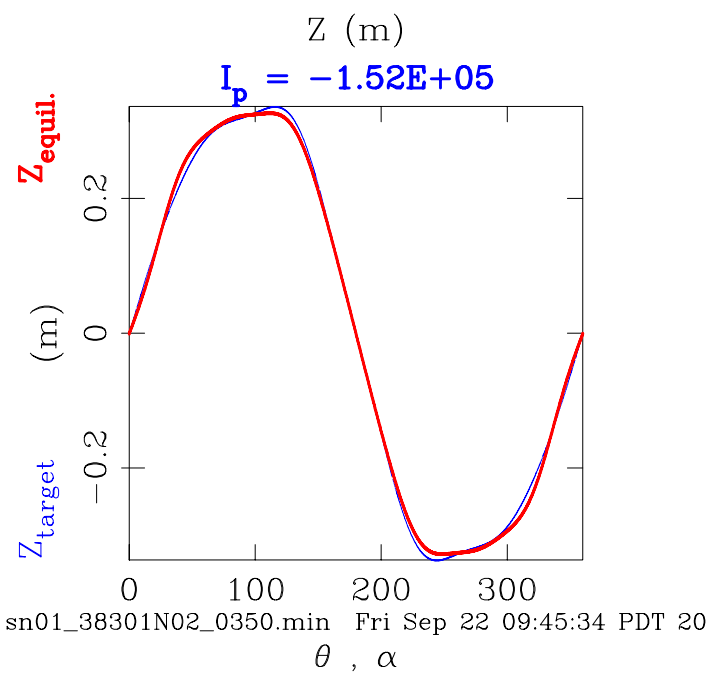


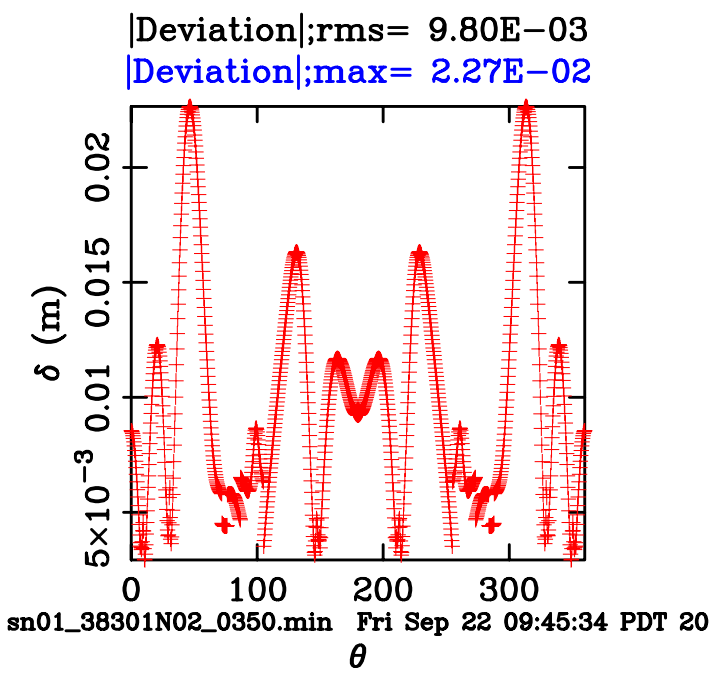


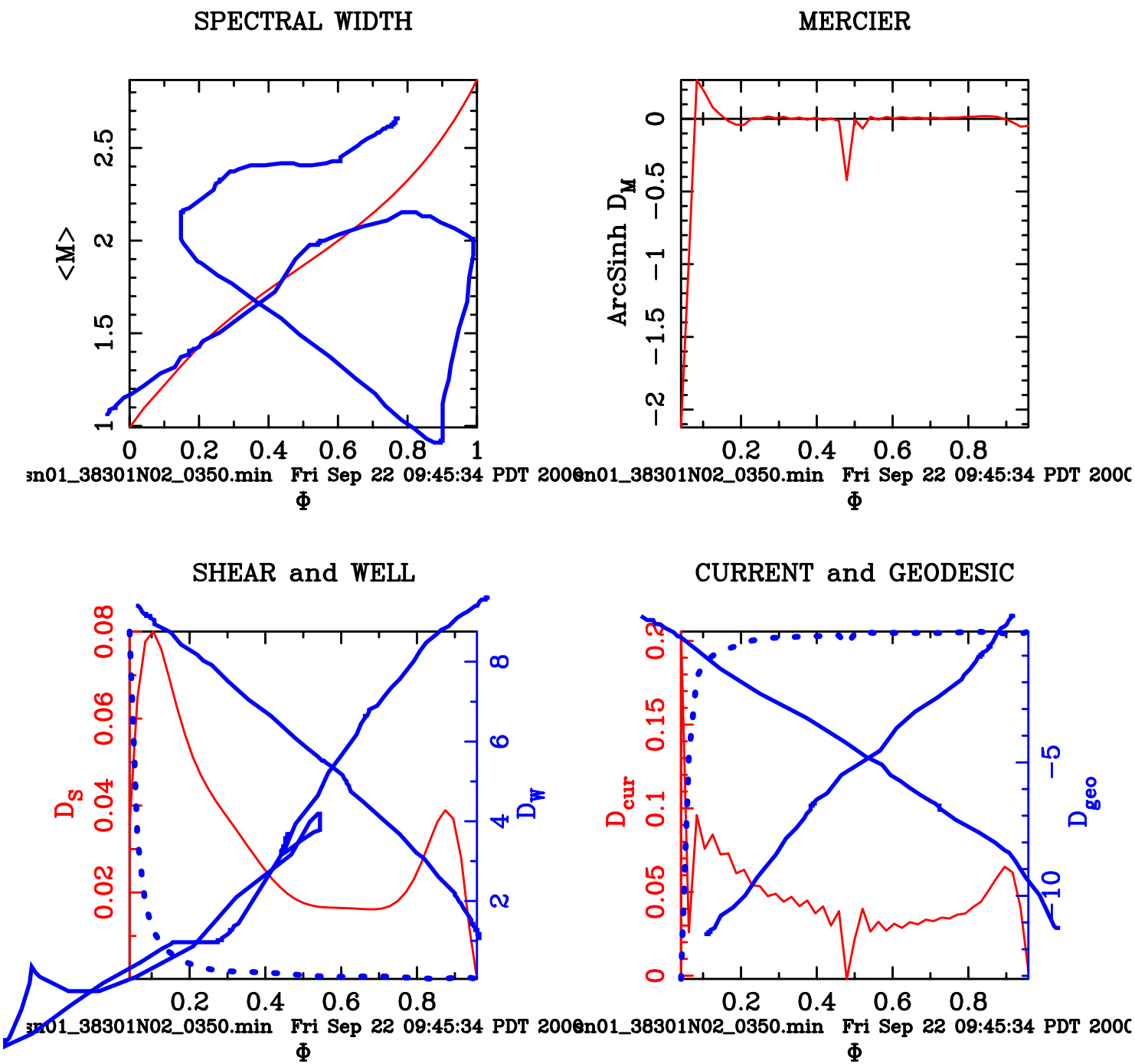
Typical saddle coil results - matching the "a3" shape.

Coil currents are in the pdf file but will not be presented.

There may be a problem in that the early phase of the discharge requires higher saddle coil currents than the fully-developed plasma.

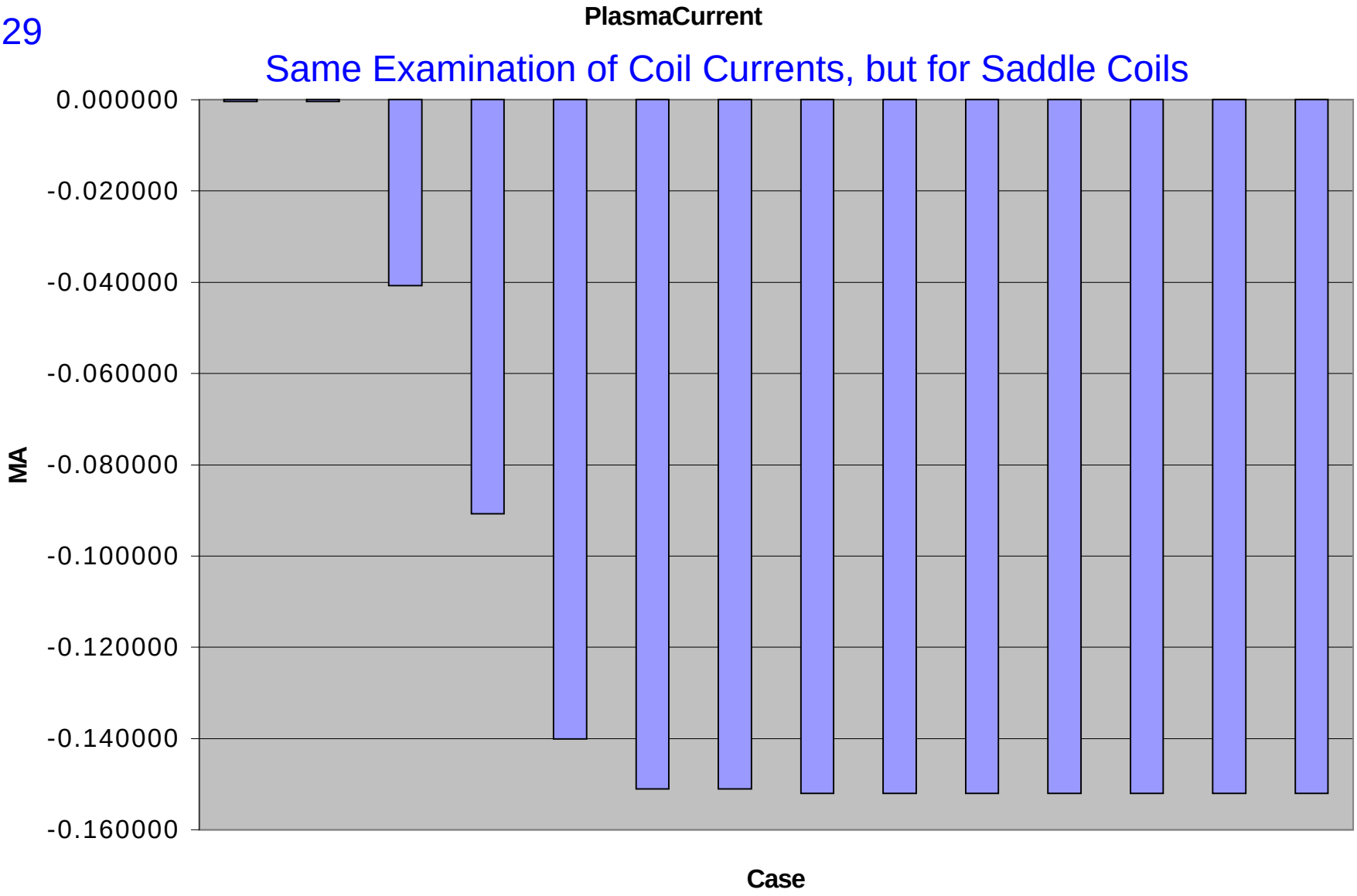


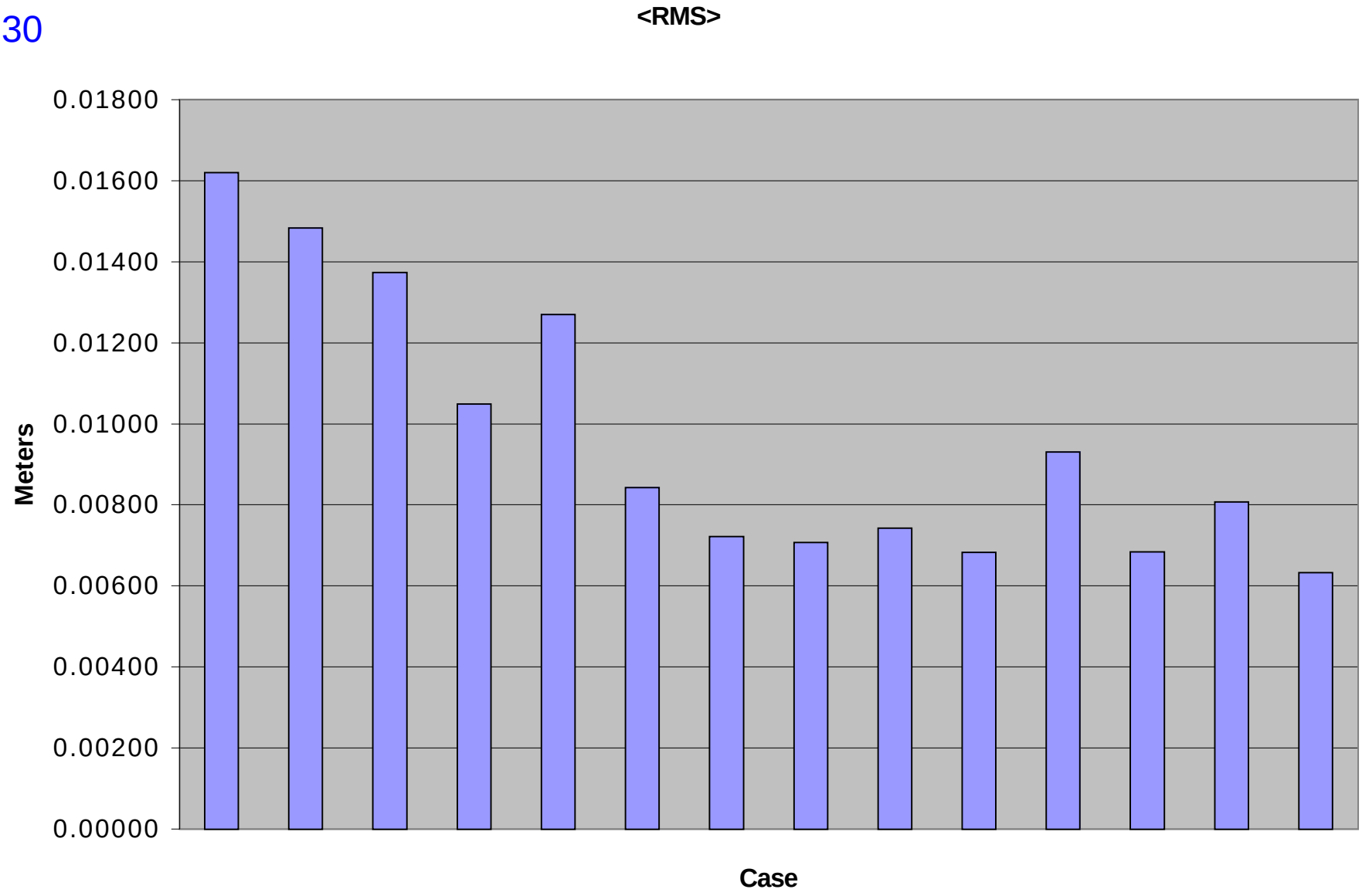


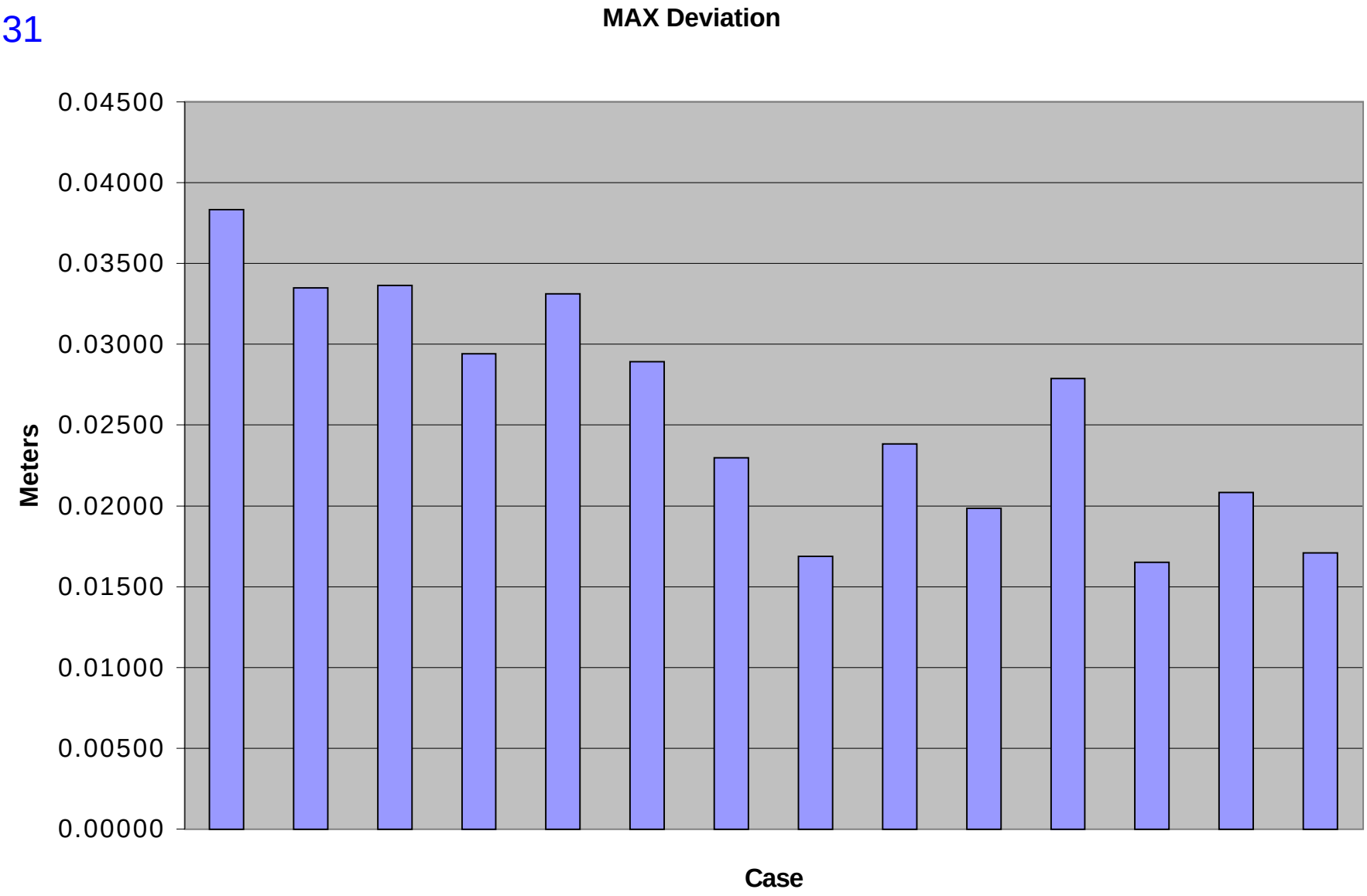


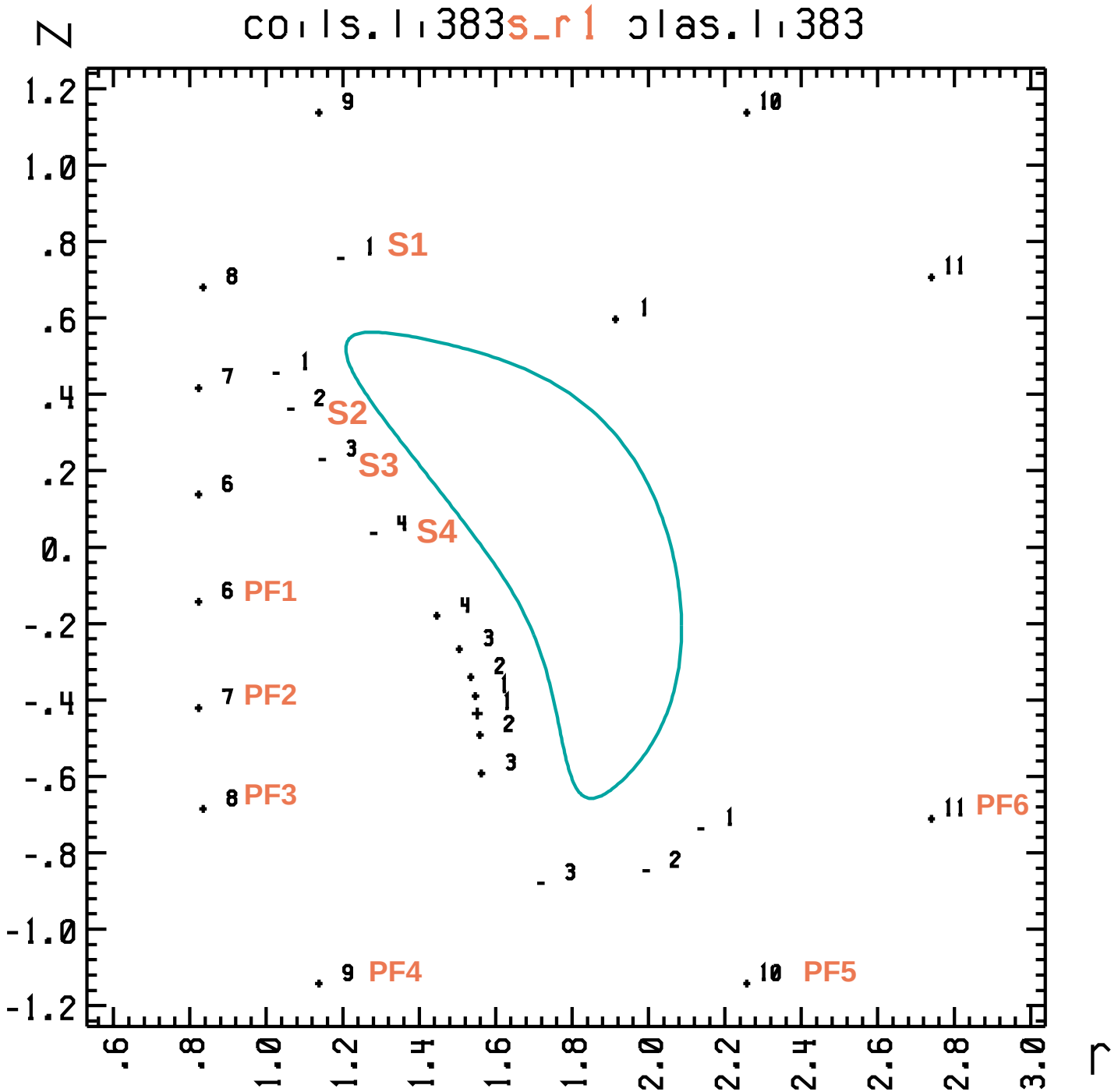
In general, there is a less positive (stabe) Mercier Criterion for the saddle coils than the modular coils.

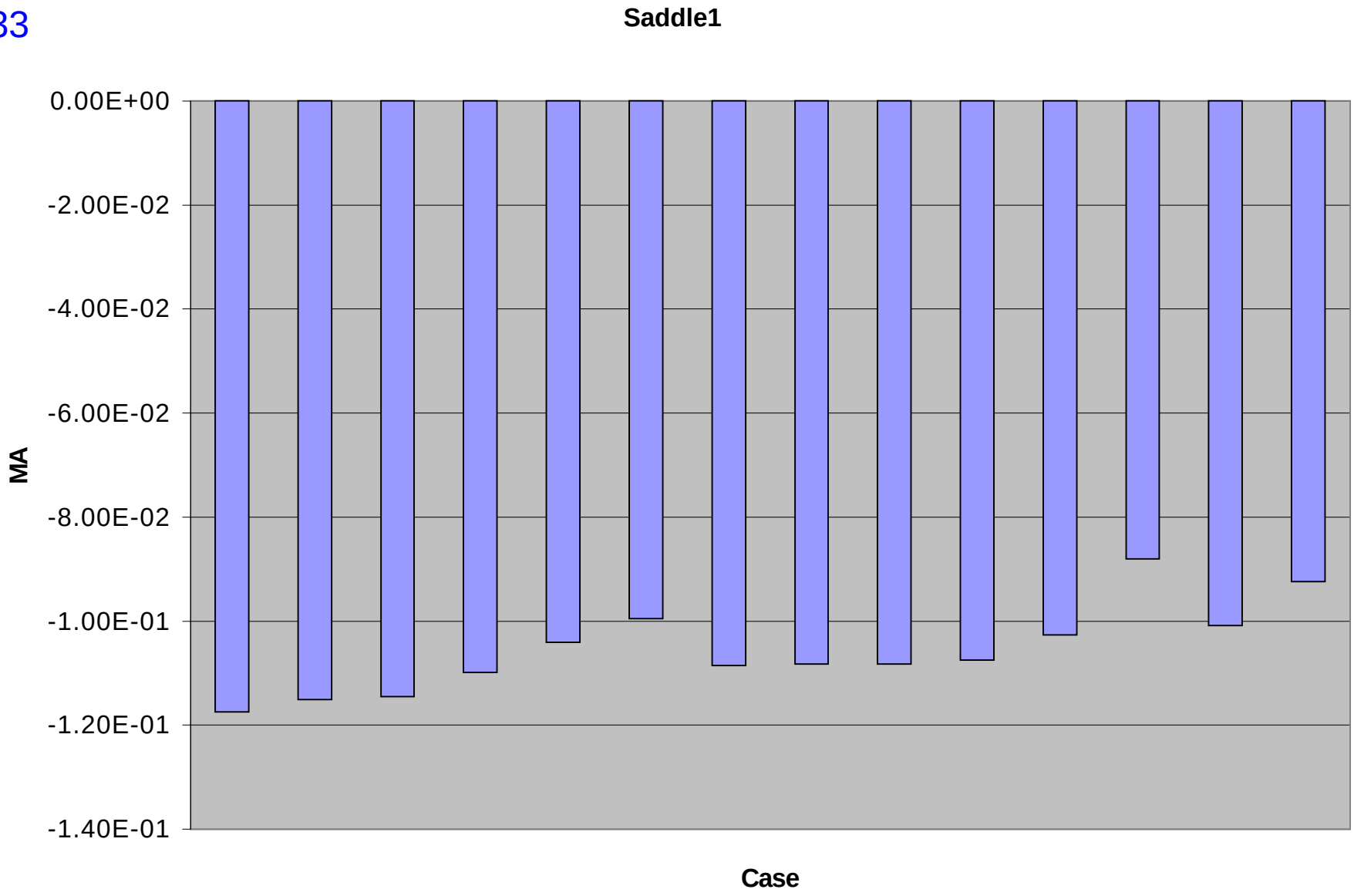
Same Examination of Coil Currents, but for Saddle Coils

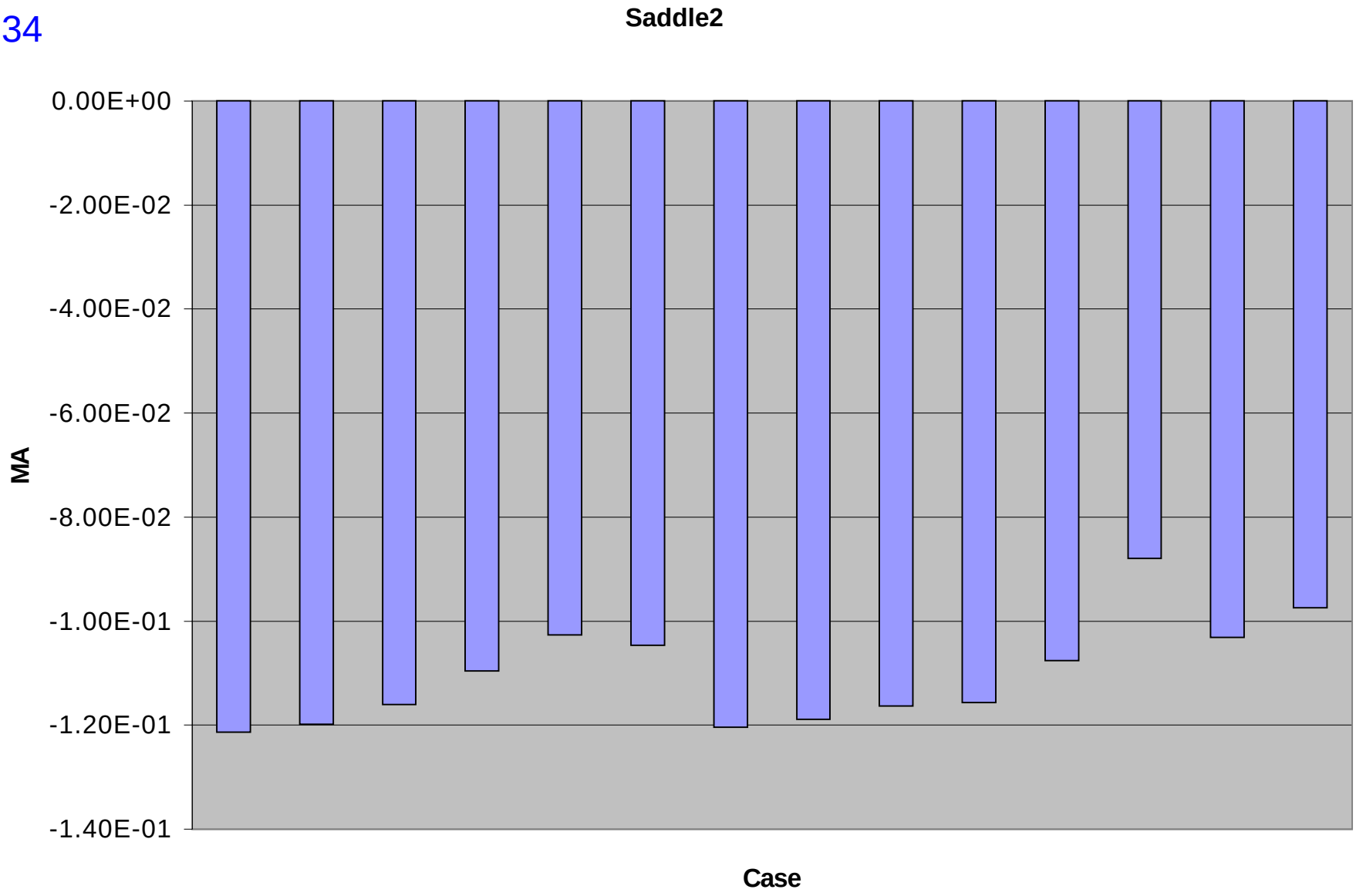


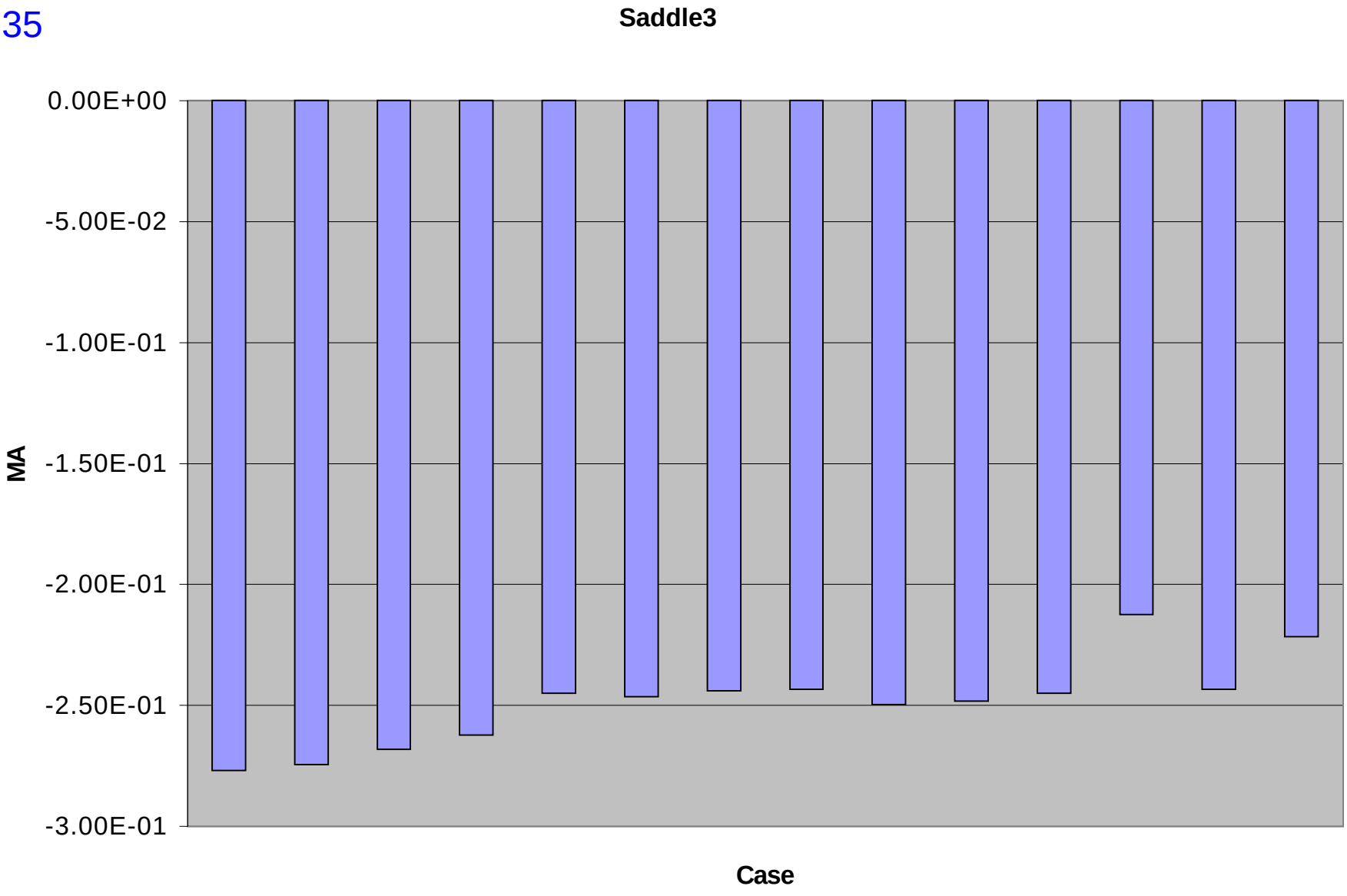

<RMS>
0.01800
0.01600
0.01400
0.01200
0.01000
0.00800
0.00600
0.00400
0.00200
0.00000
Meters
Case

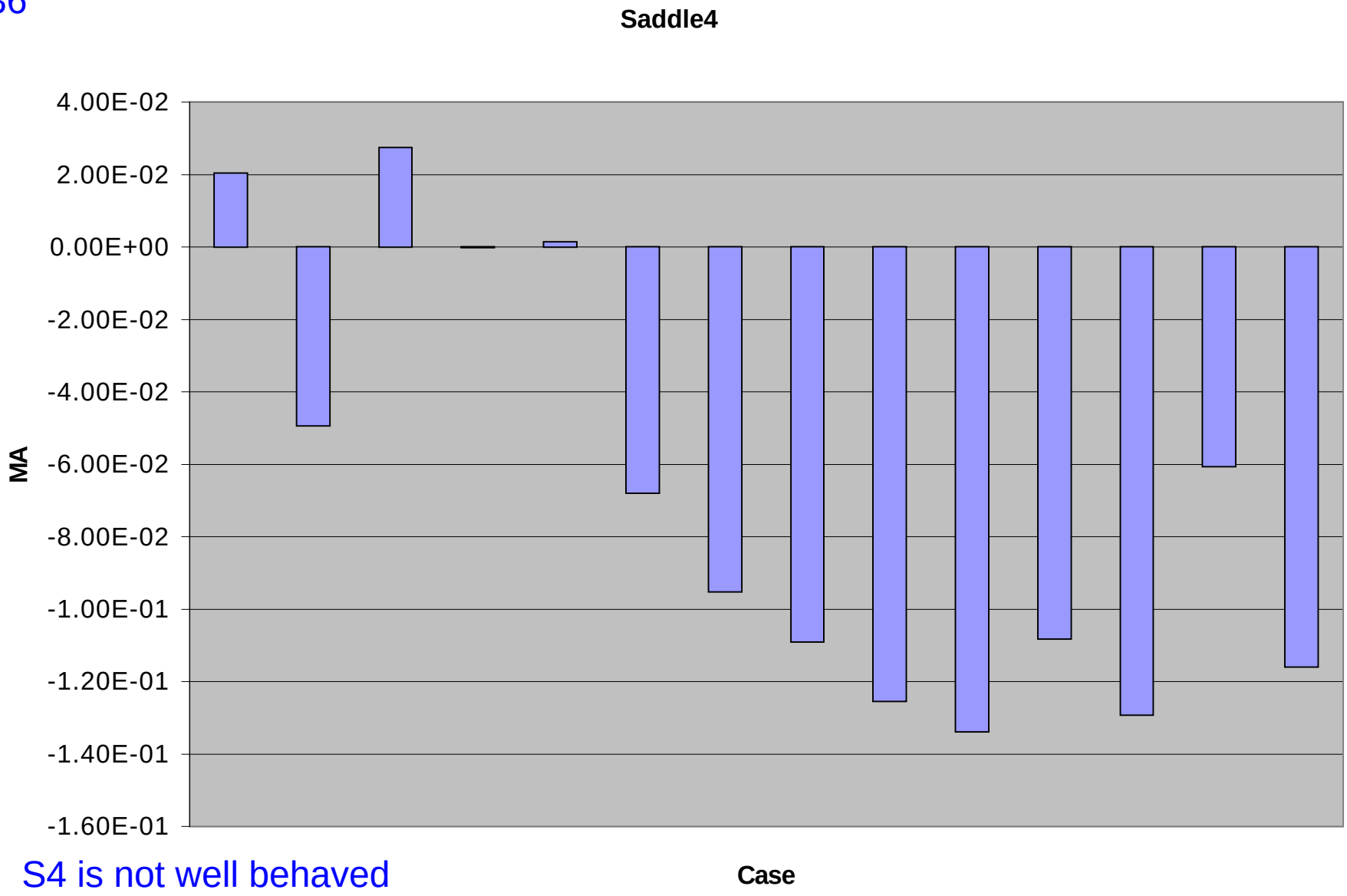

MAX Deviation
0.04500
0.04000
0.03500
0.03000
0.02500
0.02000
0.01500
0.01000
0.00500
0.00000
Meters
Case


coils.l383s_rl clas.l383
Z
r
S1
S2
S3
S4
PF1
PF2
PF3
PF4
PF5
PF6

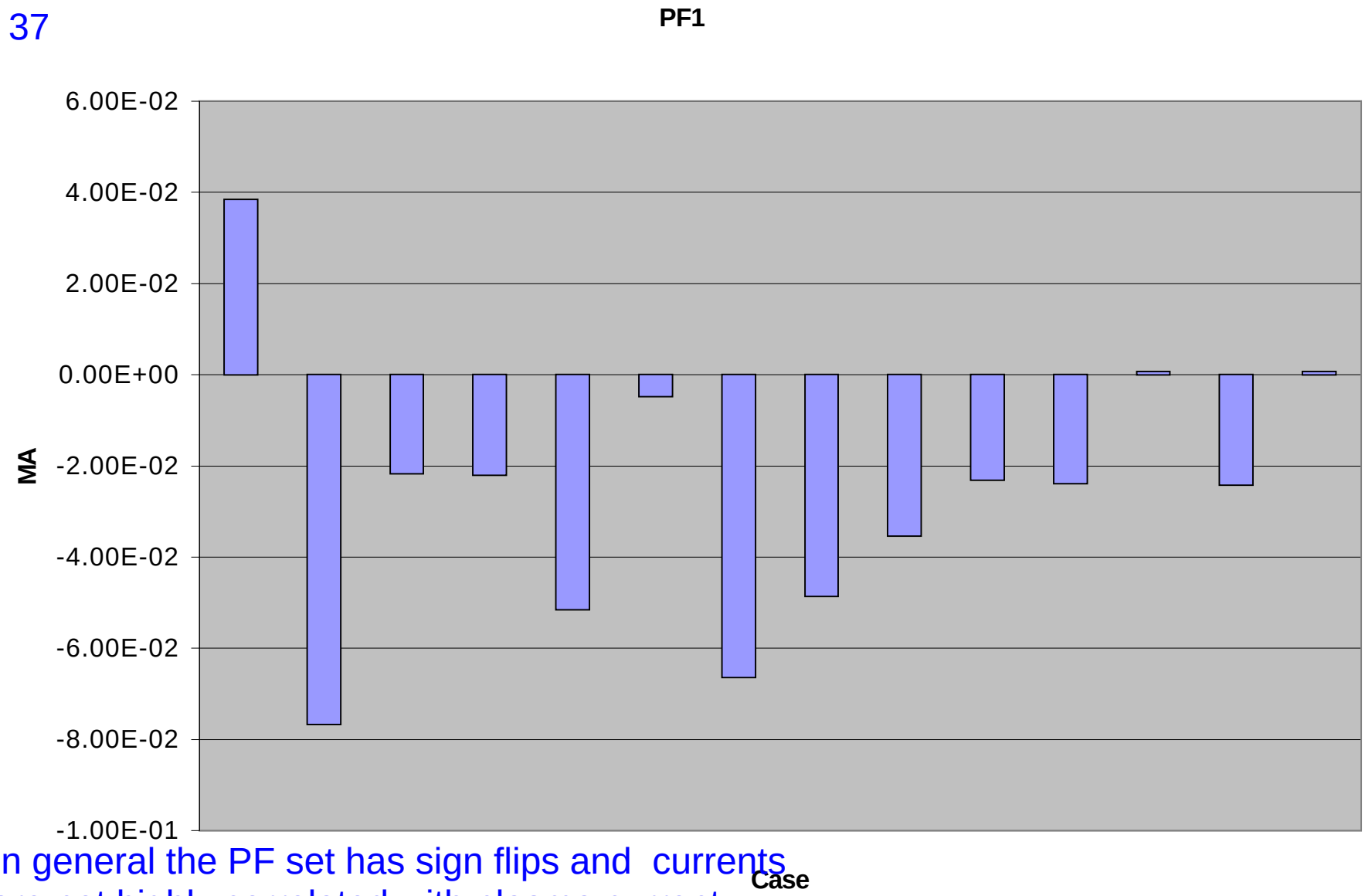

Saddle1
0.00E+00
-2.00E-02
-4.00E-02
-6.00E-02
-8.00E-02
-1.00E-01
-1.20E-01
-1.40E-01
MA
Case


Saddle2
0.00E+00
-2.00E-02
-4.00E-02
-6.00E-02
-8.00E-02
-1.00E-01
-1.20E-01
-1.40E-01
MA
Case

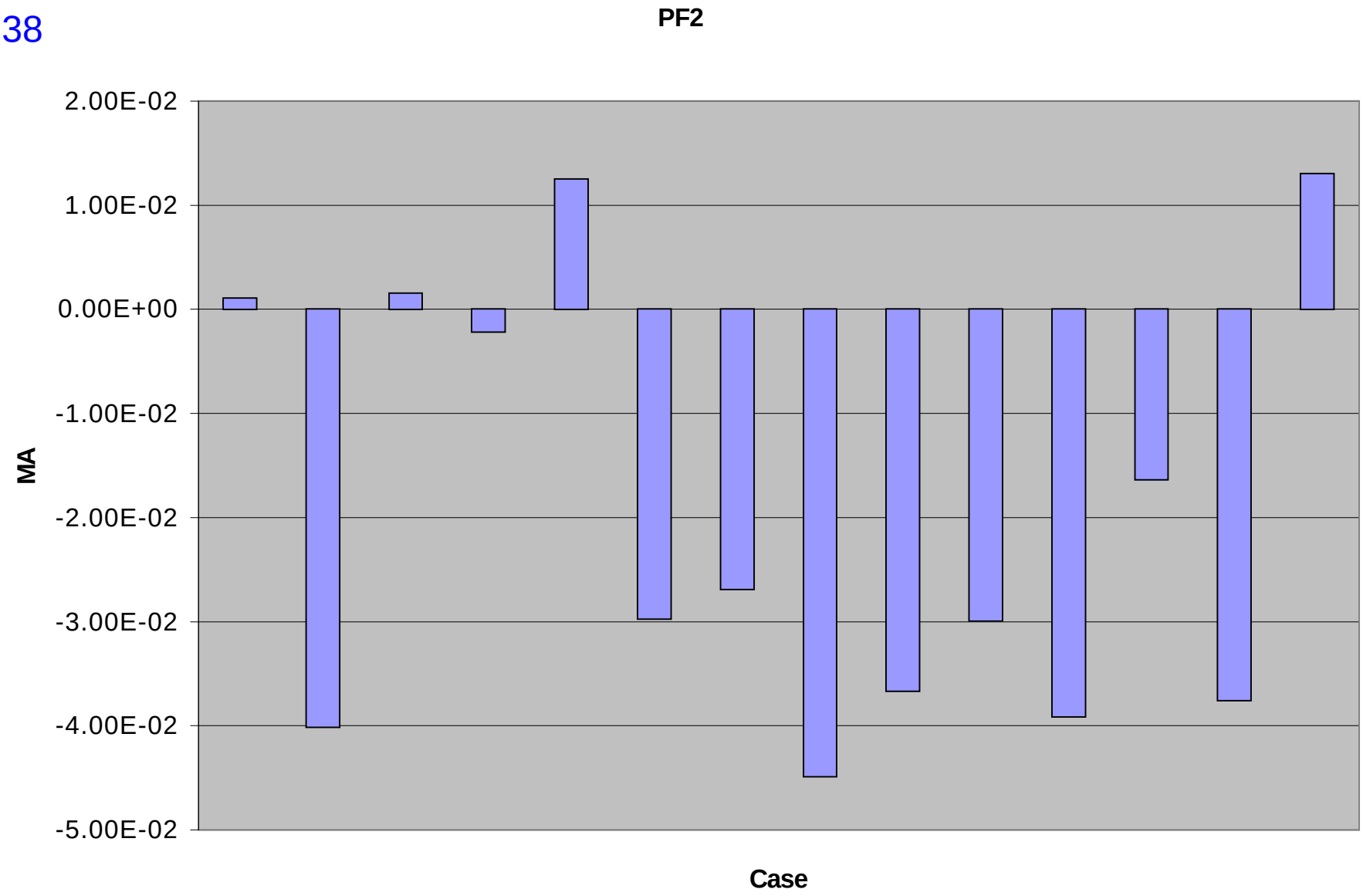

Saddle3
0.00E+00
-5.00E-02
-1.00E-01
-1.50E-01
-2.00E-01
-2.50E-01
-3.00E-01
MA
Case

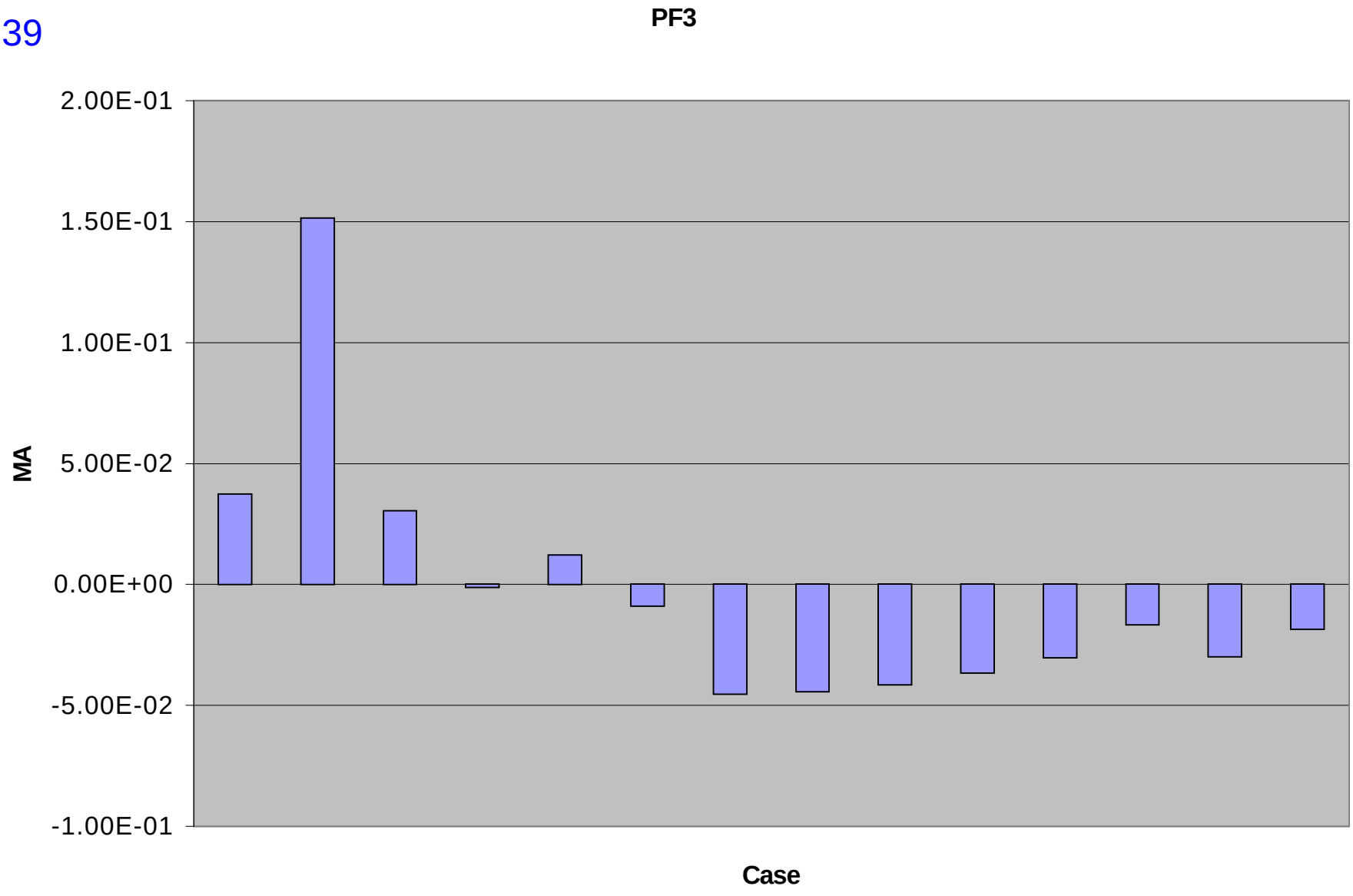


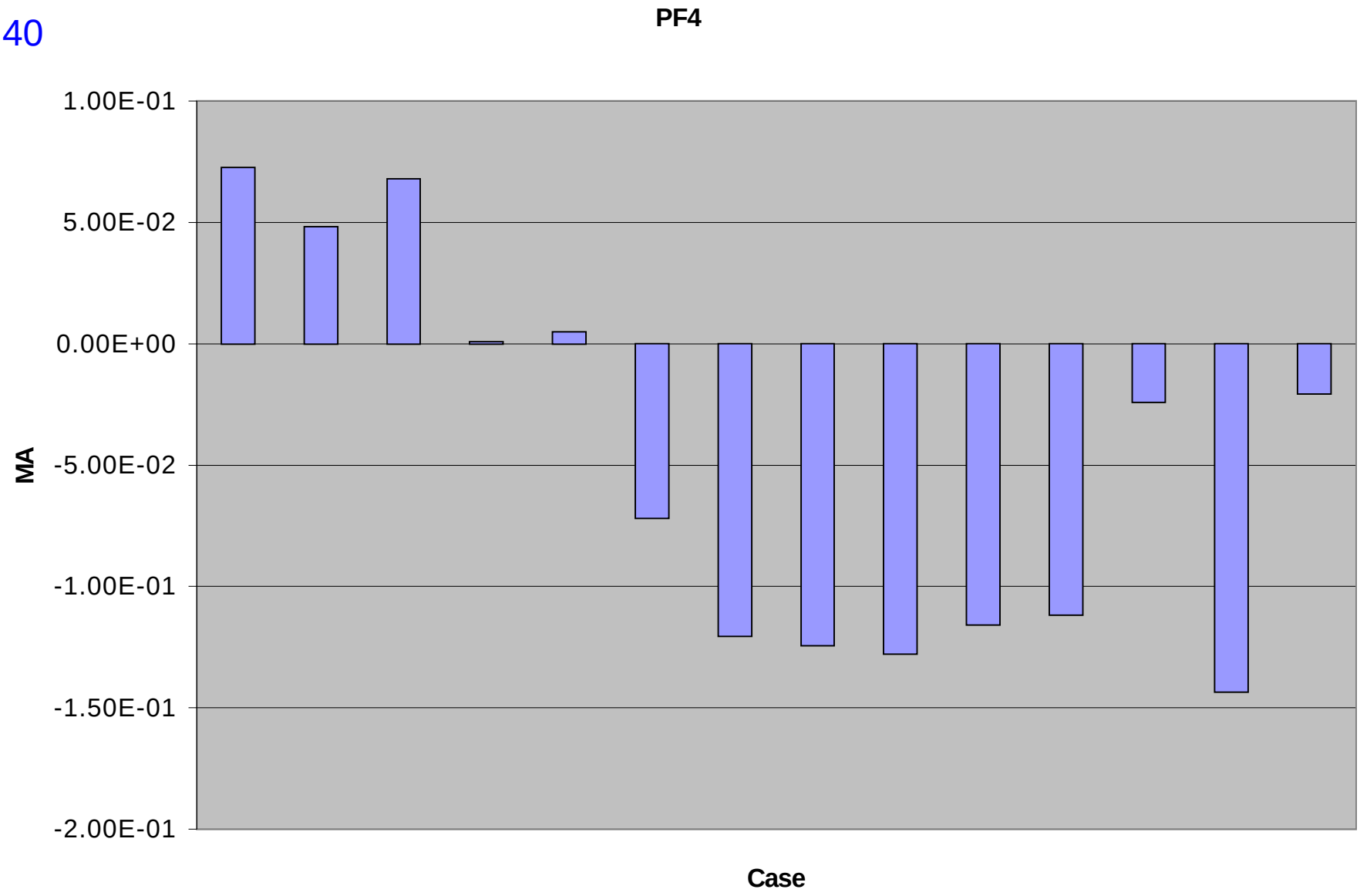
S4 is not well behaved

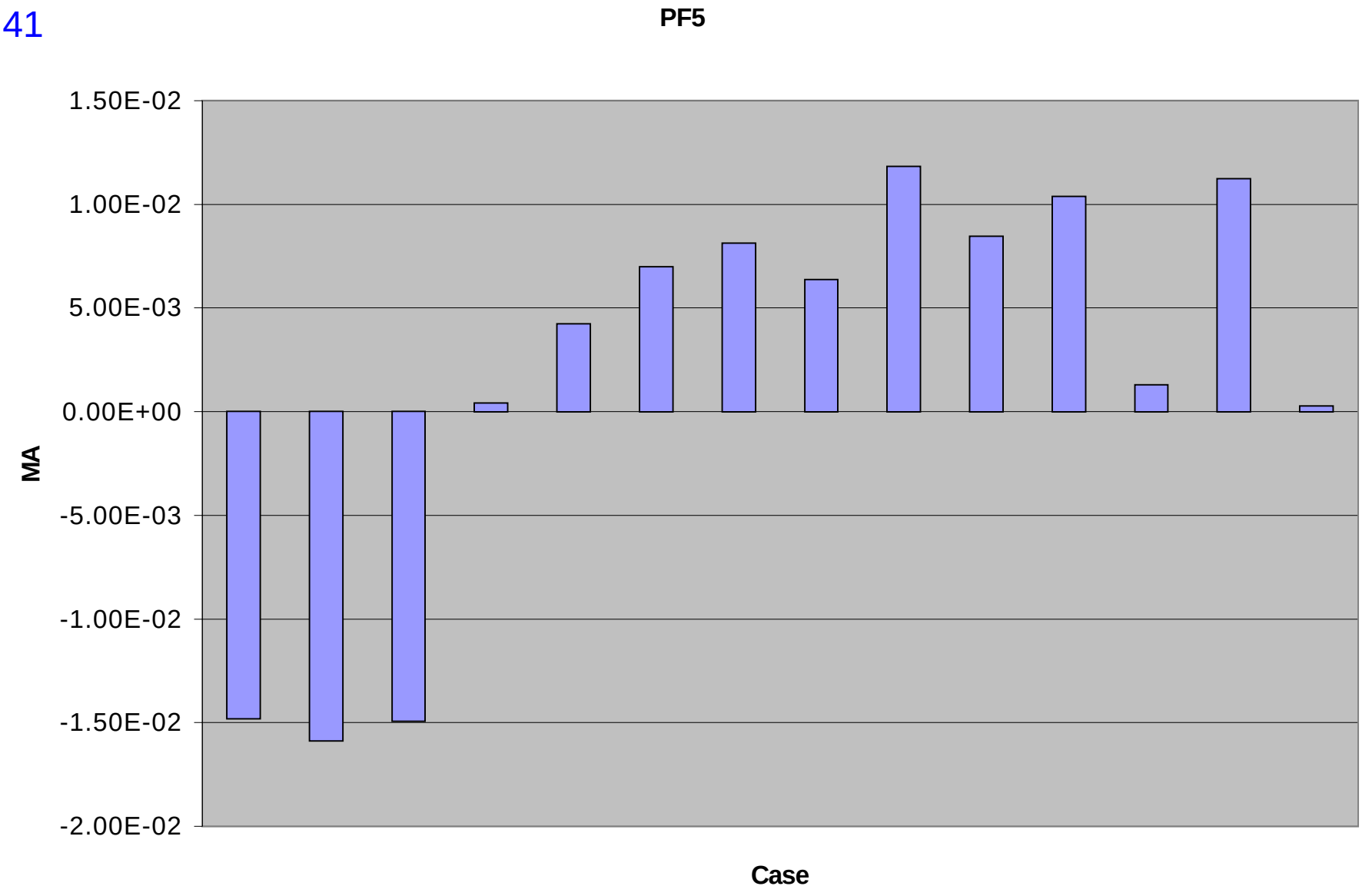


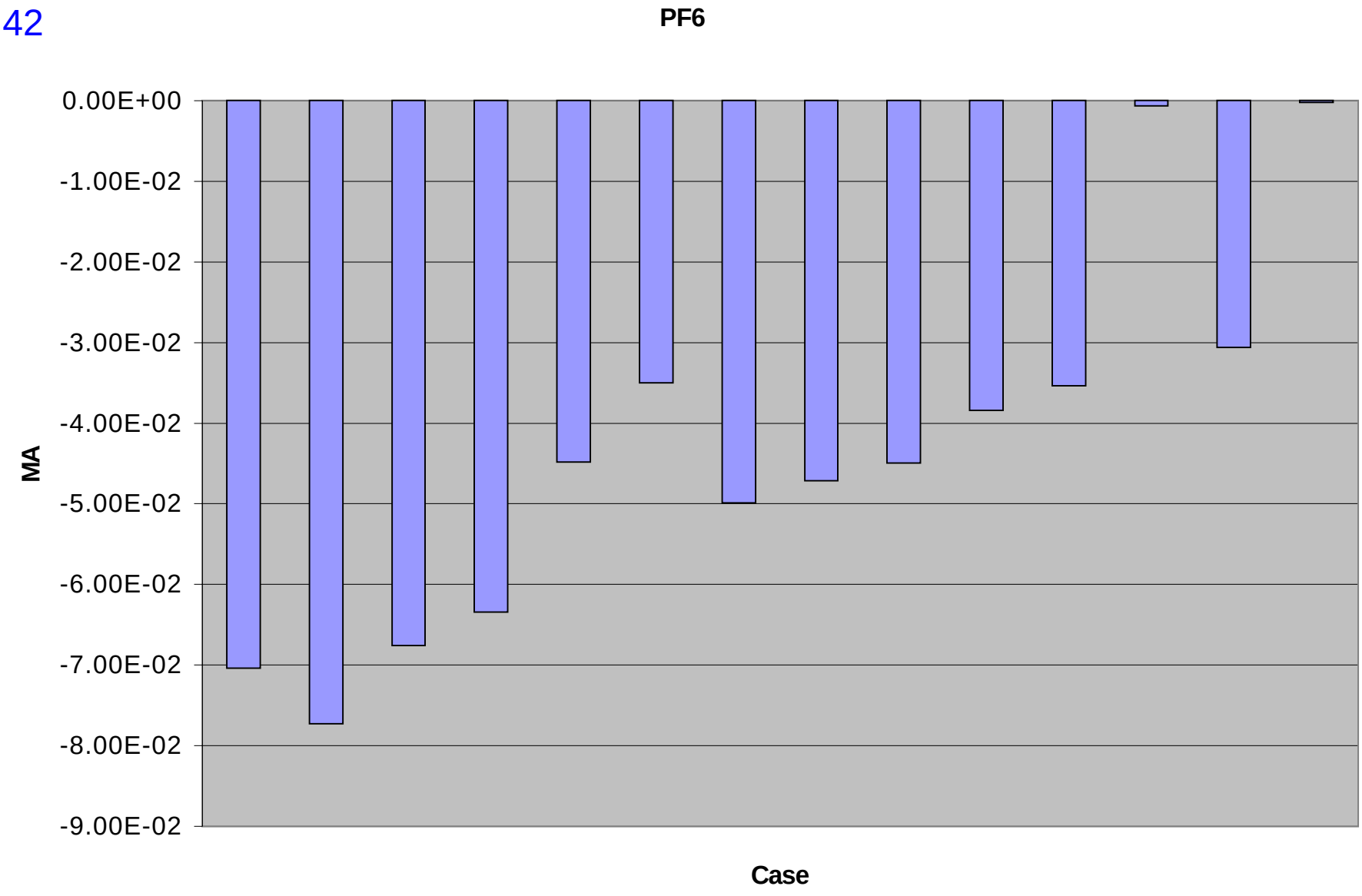
In general the PF set has sign flips and currents are not highly correlated with plasma current

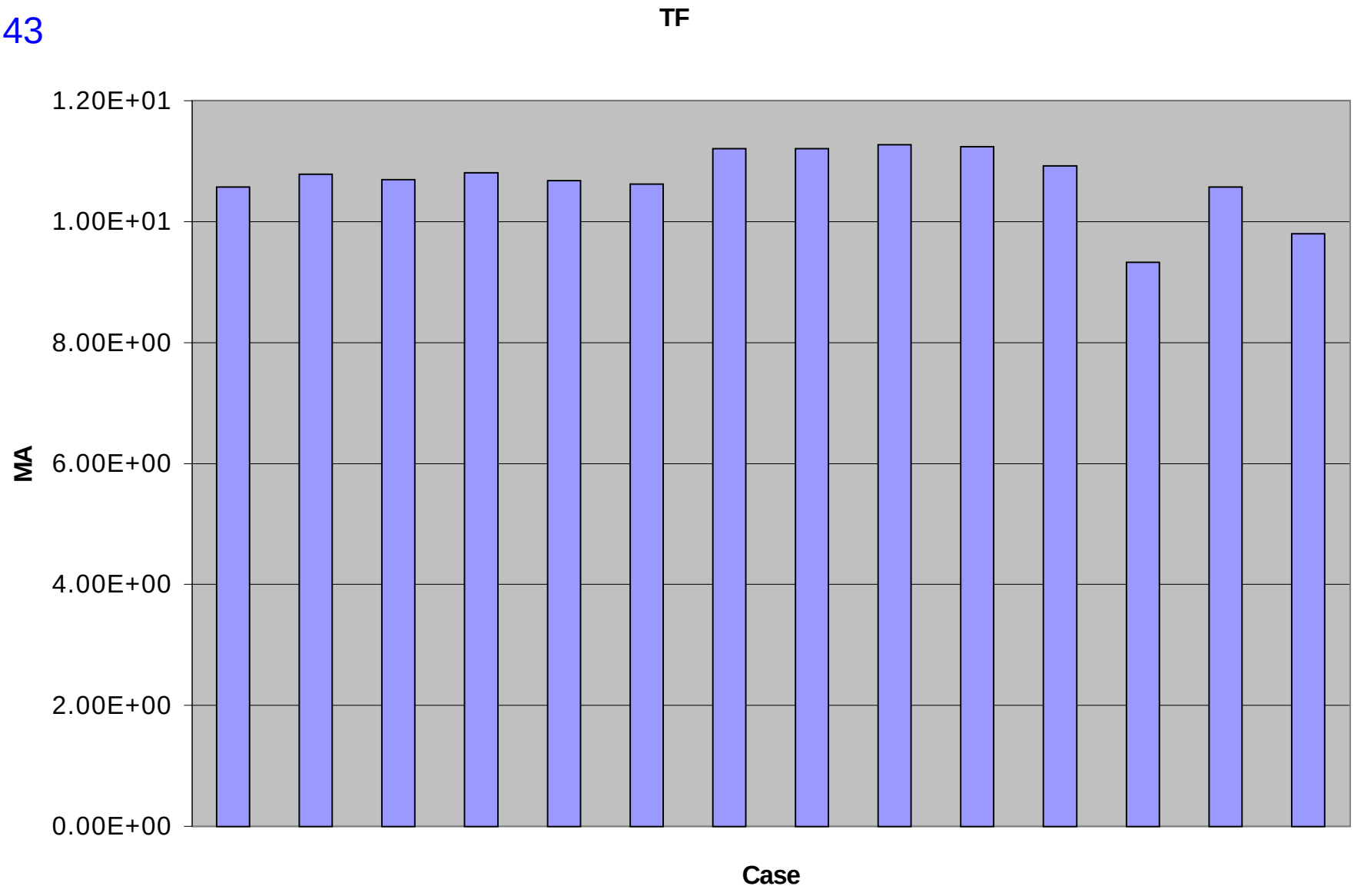

PF2
2.00E-02
1.00E-02
0.00E+00
-1.00E-02
-2.00E-02
-3.00E-02
-4.00E-02
-5.00E-02
MA
Case


PF3
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
-5.00E-02
-1.00E-01
MA
Case


PF4
1.00E-01
5.00E-02
0.00E+00
-5.00E-02
-1.00E-01
-1.50E-01
-2.00E-01
MA
Case


PF5
1.50E-02
1.00E-02
5.00E-03
0.00E+00
-5.00E-03
-1.00E-02
-1.50E-02
-2.00E-02
MA
Case


PF6
0.00E+00
-1.00E-02
-2.00E-02
-3.00E-02
-4.00E-02
-5.00E-02
-6.00E-02
-7.00E-02
-8.00E-02
-9.00E-02
MA
Case


TF
1.20E+01
1.00E+01
8.00E+00
6.00E+00
4.00E+00
2.00E+00
0.00E+00
MA
Case

Are the coil sets adequate to the task?

Case	χ^2_A	χ^2_β	χ^2_ι	χ^2_{DM}	χ^2_{kink}	χ^2_{Bmn}	χ^2_{Curv}	$\chi^2_{Balloon}$
li383_328	2.29	1.22	3.24	1.25	0	26.	0.344E-04	0.127E+04
li383_a31_new	7.46	1.72	3.47	5.63	0	30.1	0.312E-04	2.810E+04
li383_a31m	20.2	1.97	62.0	6.45	0.463	856.	0.211E-04	4.580E+04
li383_a31s	78.9	0.943	12.0	8.33	0.102	122.0	0.403E-04	4.960E+04
li383m_a4.z00	12.5	1.74	3.03	8.10	0.591E-02	92.1	0.264E-04	0.00
li383s_a3.z00	0.78	1.70	6.44	7.53	0.895E-01	97.9	0.253E-04	0.00
<Weight>	100	444.4	4.76	0.135	3333	4211	200	1000

* ballooning unstable only on a few surfaces near s=0.85

1. li383_328 – The original optimization from Long-Poe. Fixed Boundary

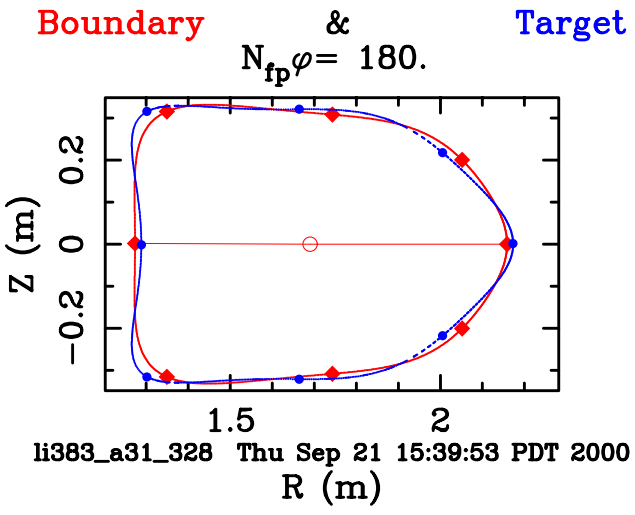
2. li383_a31_new - A new oprtimization by Long-Poe. The same targets as li383_328 but using the “a3” shape as a starting point. Fixed Boundary

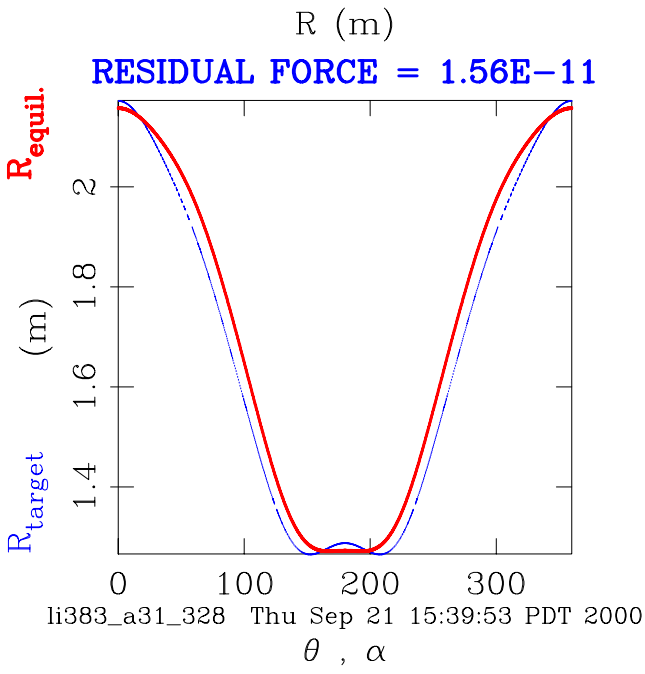
3. li383_a31m - A new shape free boundary optimization to try obtaining the “a31_new” shape with the r1 modular coils.

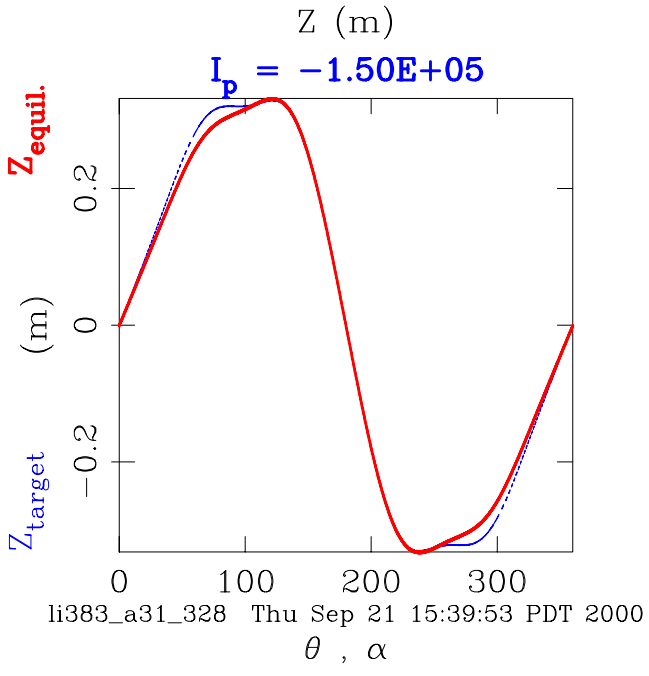
4. li383_a31s - A new shape free boundary optimization to try obtaining the “a31_new” shape with the r1 saddle coils.

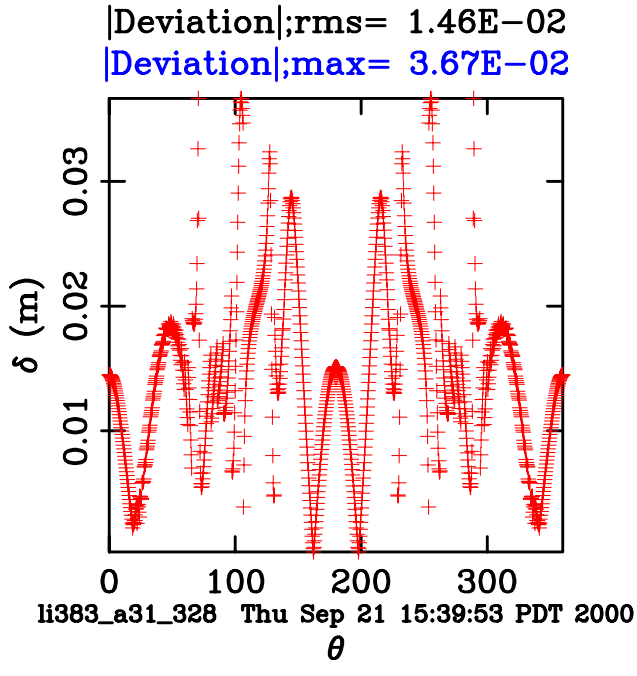
5. li383m_a4.z00 - A free boundary optimization by Zarnstorff using the modular coils.

6. li383s_a3.z00 - A free boundary optimization by Zarnstorff using the modular coils.

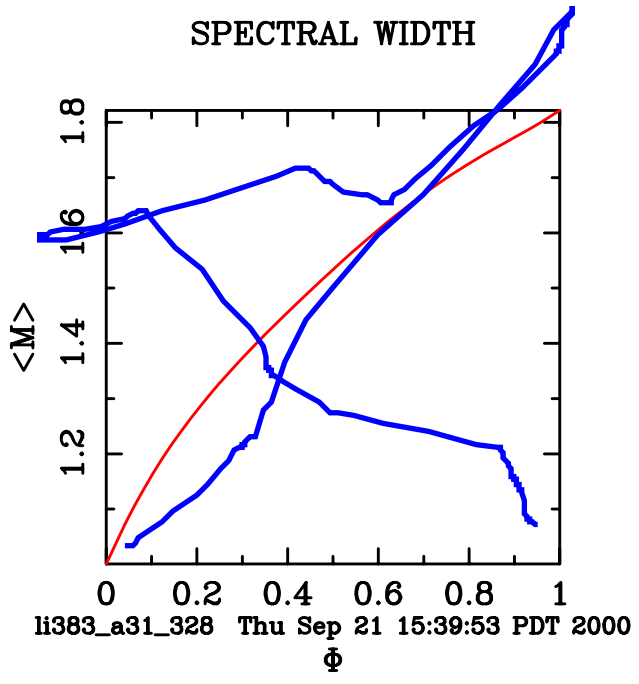


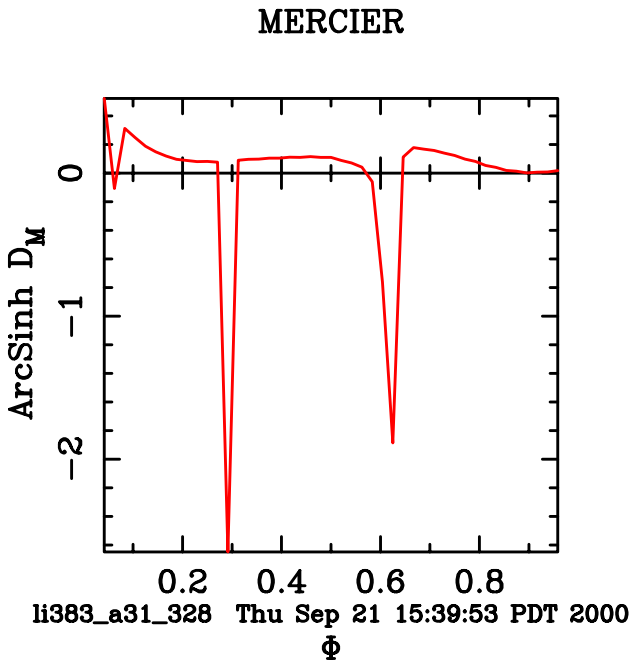


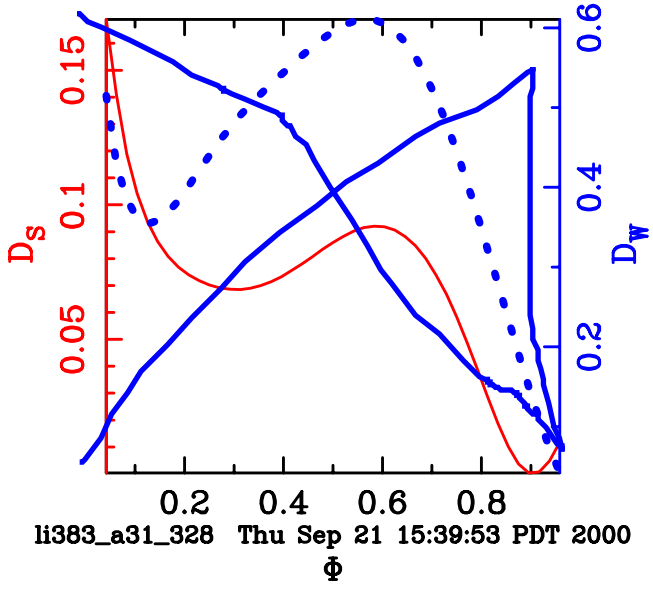


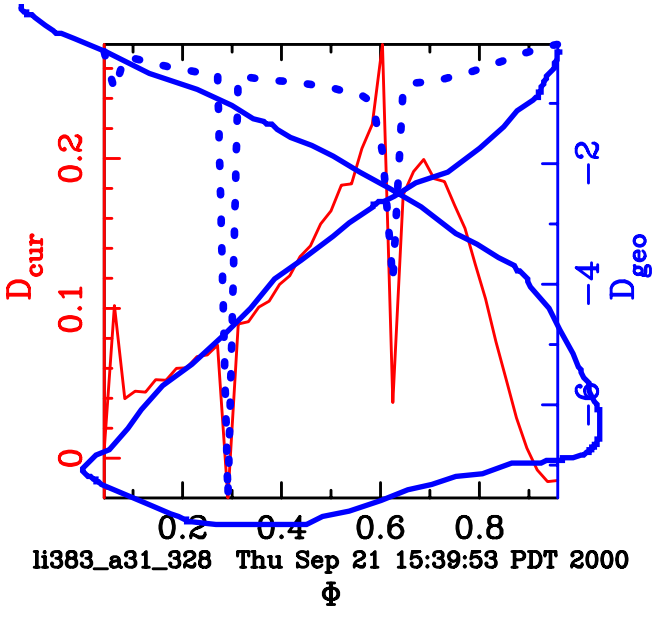


Compare "a31_new" shape to "328" shape
a31_new shape reproduces physics targets
of 328 quite well.

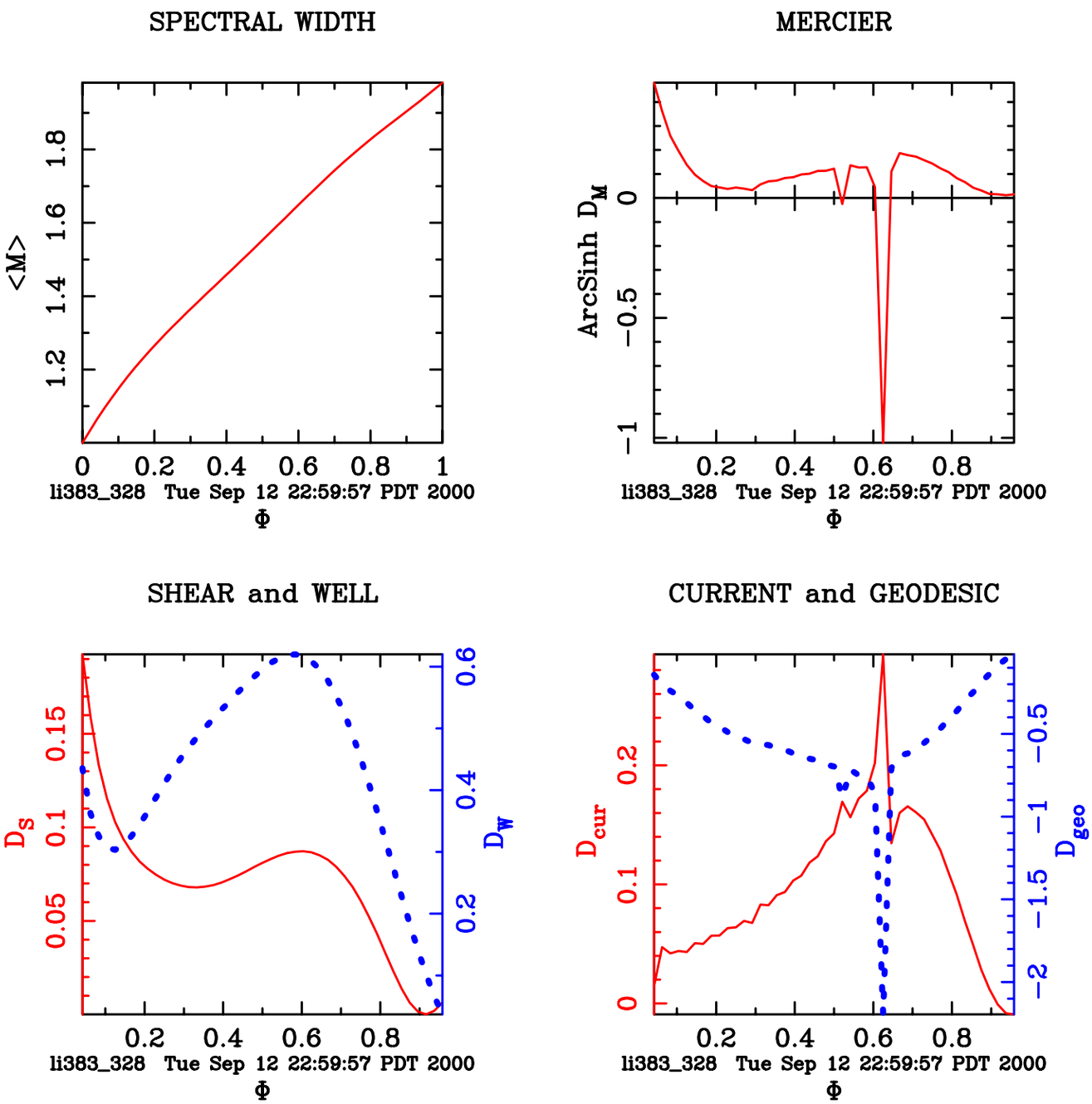




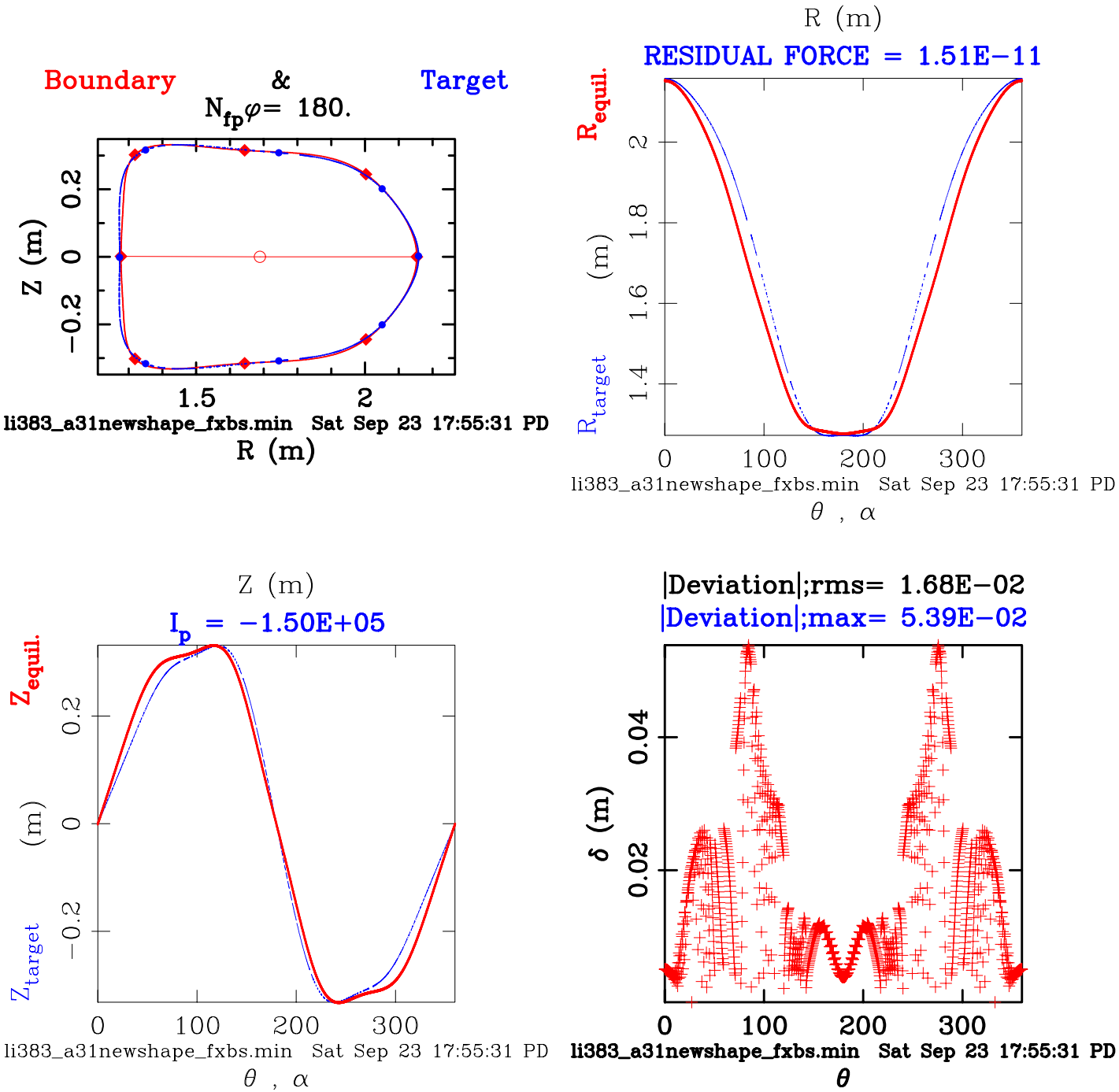




Pretty much recovers Mercier characteristics of original

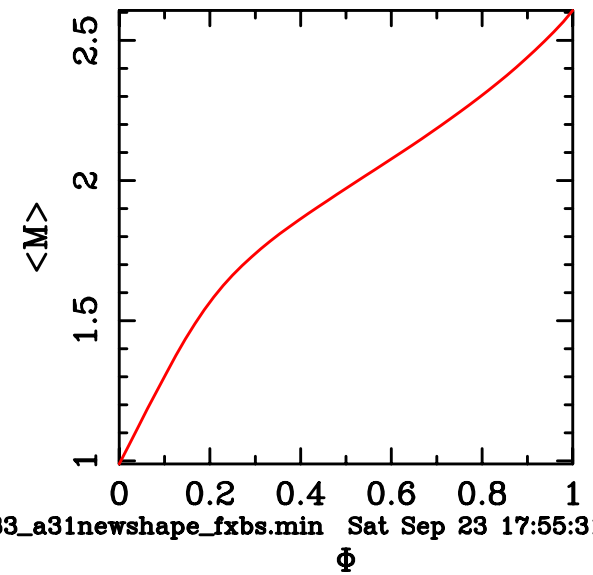


Original li383_328



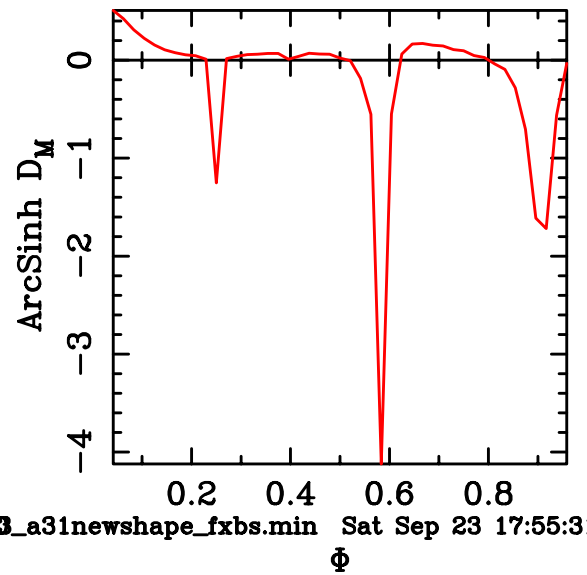
This seems to me awfully good to be not good enough.

SPECTRAL WIDTH



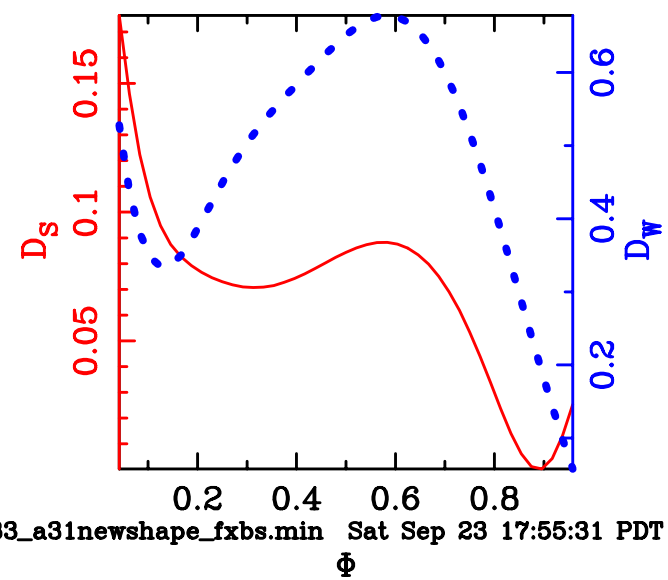
83_a31newshape_fxbs.min Sat Sep 23 17:55:31 PDT 2003

MERCIER



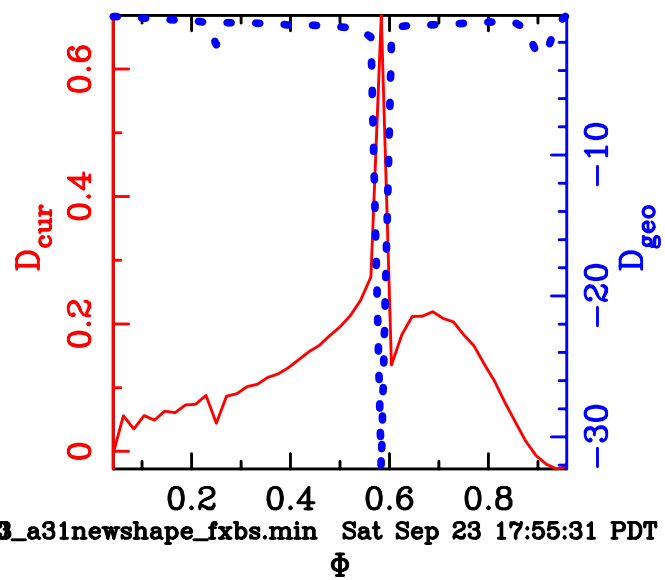
83_a31newshape_fxbs.min Sat Sep 23 17:55:31 PDT 2003

SHEAR and WELL

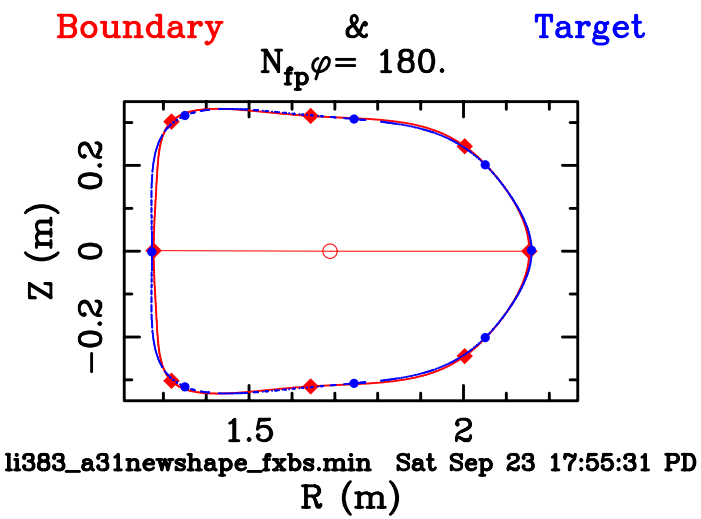


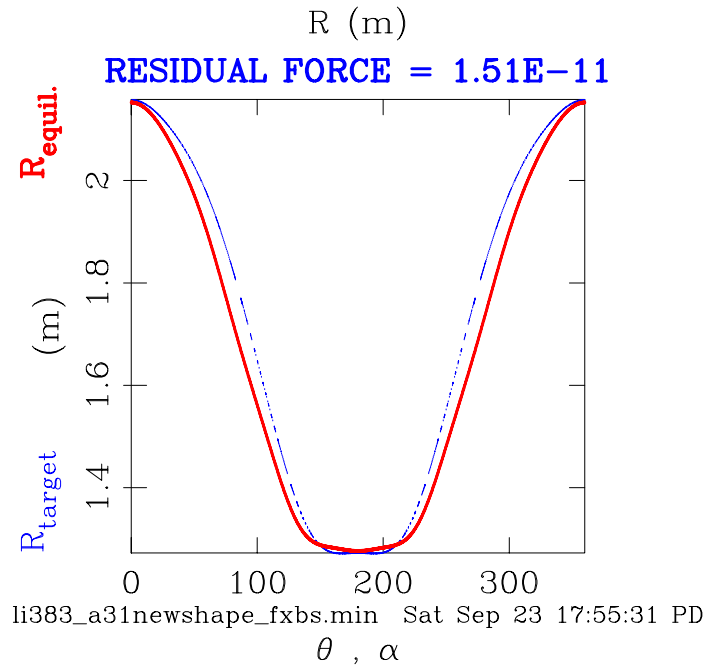
83_a31newshape_fxbs.min Sat Sep 23 17:55:31 PDT 2003

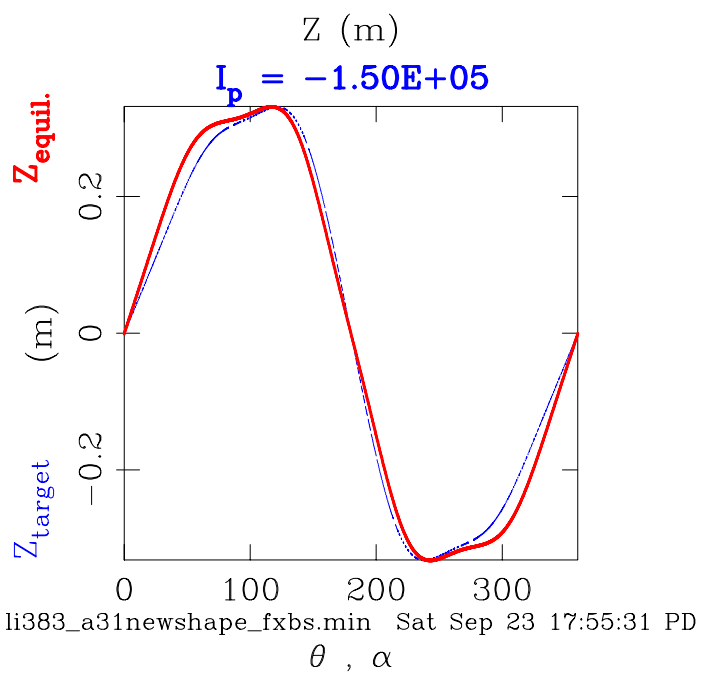
CURRENT and GEODESIC

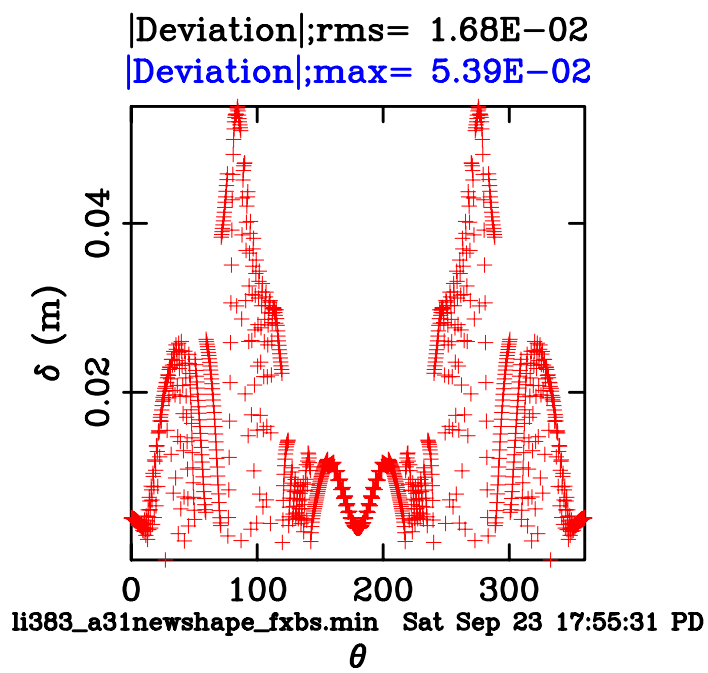


83_a31newshape_fxbs.min Sat Sep 23 17:55:31 PDT 2003

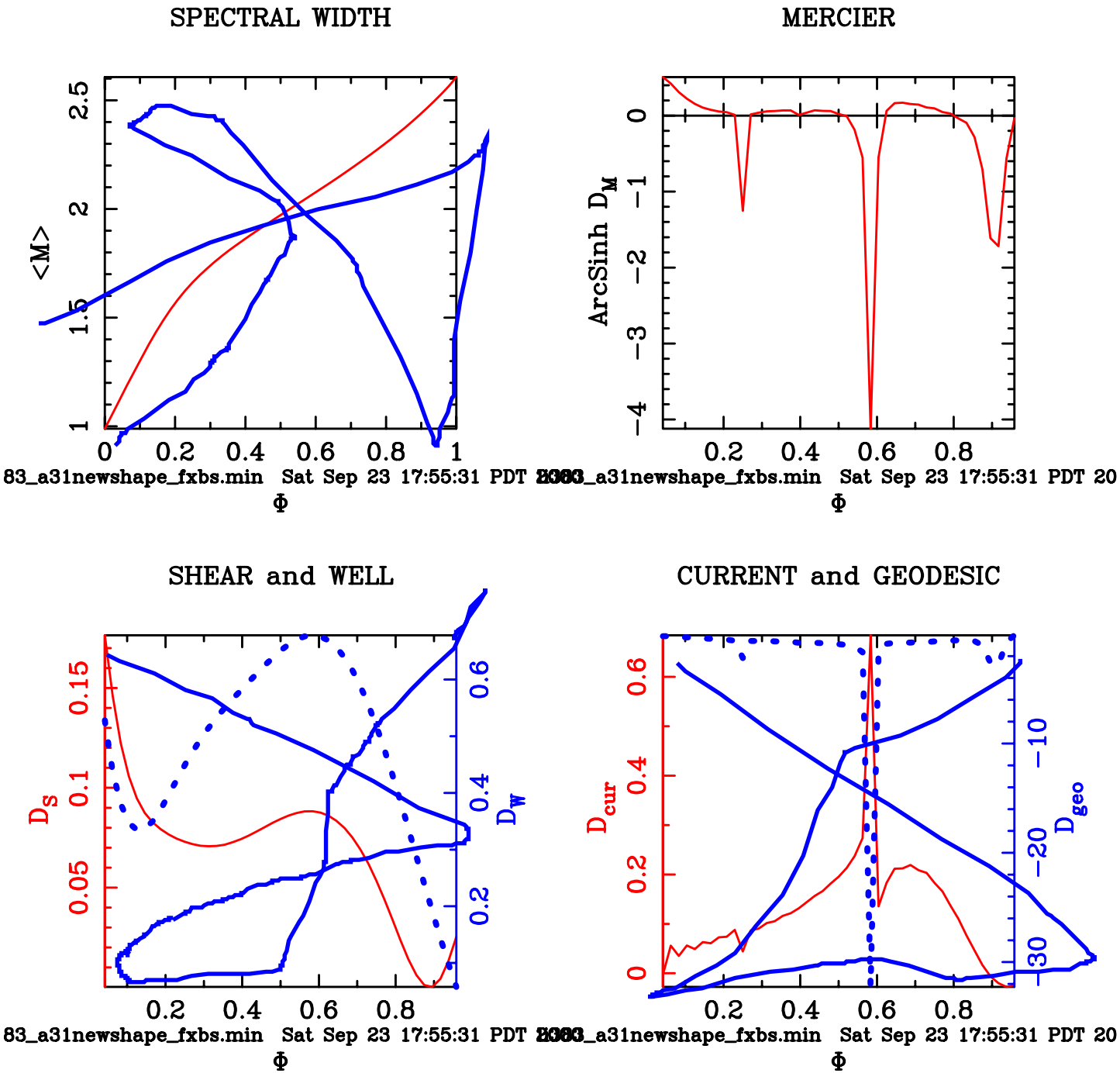








A new free-boundary optimization on shape to try reproducing the "a31_new" shape" with saddle coils. Again very good, but not good enough.



Again a transition to free boundary, trying to obtain the "a31_new" shape indicates an edge stability problem, as is verified by the kink stability calculation.

Conclusions

1. **The stability seems quite sensitive to very small shape changes. The flip side of this is that very small changes in the current profile are potentially stabilizing. These changes will likely require smaller p' in the outer region.**

   - **This would likely result in lower β**

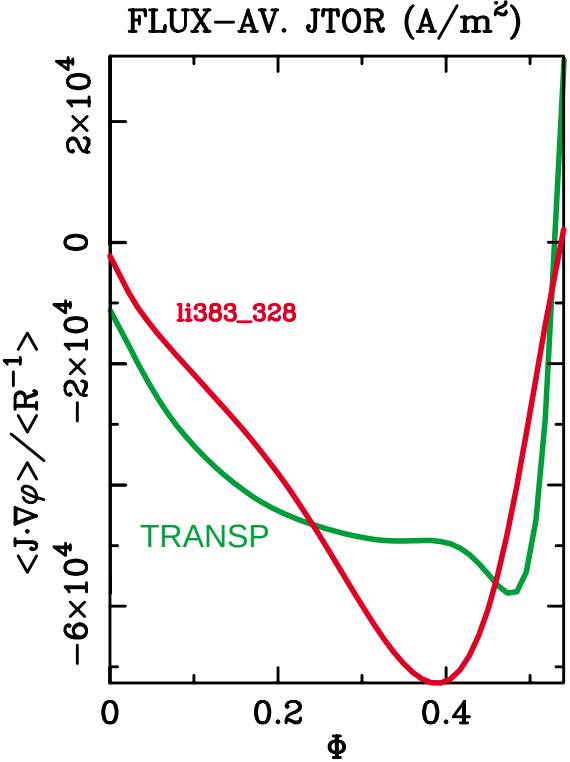
2. **A sampling of the TRANSP simulations shows them to be kink stable ($\gamma < 10^{-4}$) but they only reach β of 3.2%, not the 4.5% of li383_328.**

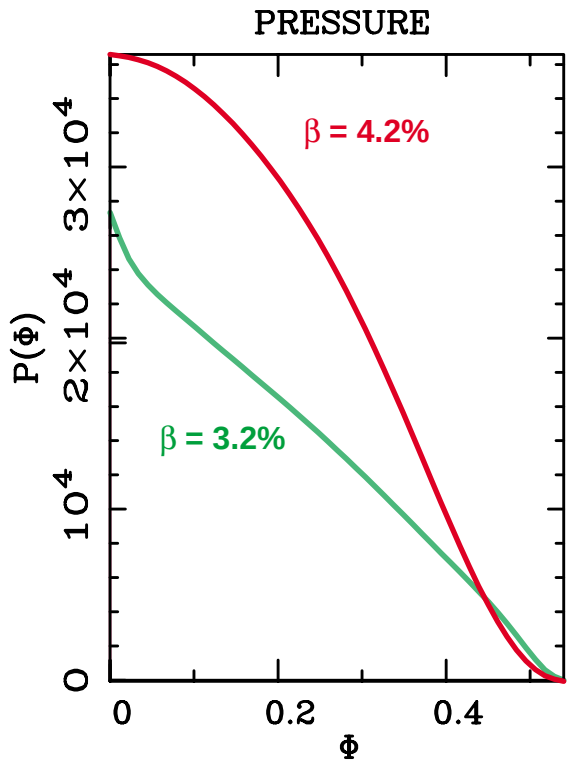
3. **If the window for attractive physics is this sensitive to shape, plasma control will be formidable. Some analysis of this should be done prior to finalizing the coil set. None of the tools for doing this are yet developed. There are also implications for diagnostics and grounding if very precise control is required.**

4. **Determining a combination of coil currents which are better behaved and "good enough" seems to me quite a difficult proposition if the procedure is optimization. It would take a very long time, at best.**

5. **The "r1 " coil sets produce a shape in the 180 degree plane with mopre octopole (squareness) than the original. This, at least correlates with less favorable kink stability. A clue that this might be so is seen in the Mercier Criterion.**

6. **I wrote a different shape optimization which allowed weighting emphasis in particular regions of φ and θ. Since the desired shape still could not be produced, gives me confidence that these coil sets do not have the capability to do so.**





Case (Time)	Plasma Current	Modular Coils		Saddle Coils	
38301N02_00019	-3.368388E+02	External Kink :=	0.182E-09	External Kink :=	0.325E-12
38301N02_00065	-9.045413E+04	External Kink :=	0.00	External Kink :=	0.350E-06
38301N02_00090	-1.400561E+05	External Kink :=	0.126E-07	External Kink :=	0.325E-12
38301N02_00120	-1.501871E+05	External Kink :=	0.145E-08	External Kink :=	0.391E-07
38301N02_00225	-1.506125E+05	External Kink :=	0.660E-08	External Kink :=	0.263E-06
38301N02_00350	-1.508160E+05	External Kink :=	0.660E-08	External Kink :=	0.856E-06

Kink Stability an artifact of the edge current reversal?