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Development of Improved Vertical Position Control

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Location
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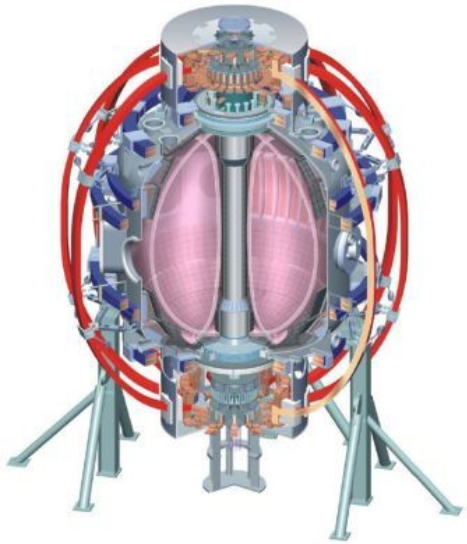

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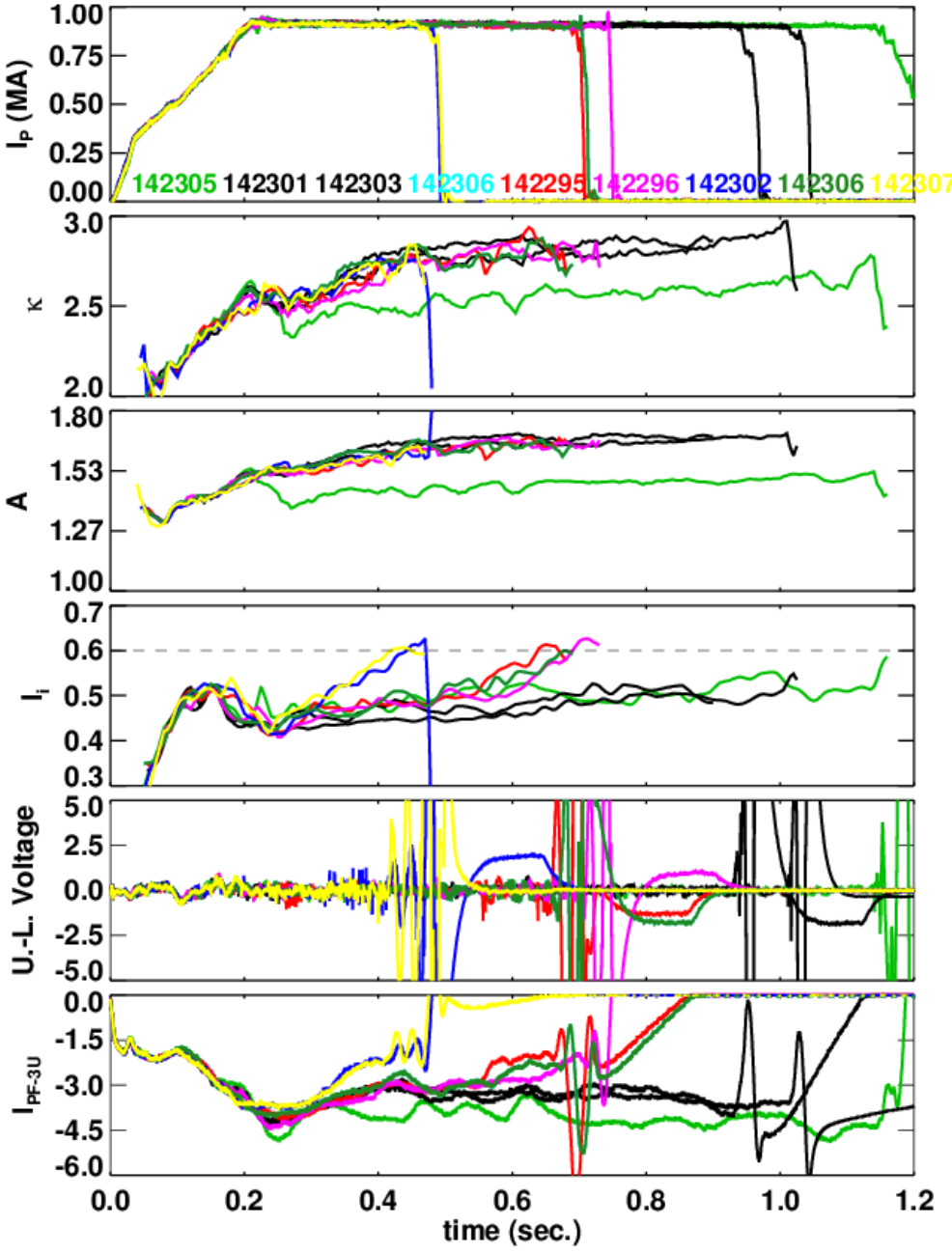
XP in 2010 Showed that Vertical Position Control can be Lost at Higher Aspect Ratio

- 1 Fiducial (green) and 8 shots at higher aspect ratio.
  - Black cases vertically stable, the colored ones have VDEs.
- *VDE is always triggered when l_i=0.6.*
  - This is not a particularly high value.
  - Would preclude use of the scenario for many XPs.
  - Many upgrade scenarios with central NBCD have l_i>0.6
- *Motivates improvements to the n=0 controller.*



Strategy To Fix Problem

- Improve the detection of small vertical motion.
  - "dZ/dt Observer"
- Re-optimize vertical control gains with improved observer.
- If necessary, use RWM coils for vertical control.

Vertical Position Controller is a PD Controller Using Loop Voltages for dZ/dt Measurement

- Proportional controller is simply the Isoflux shape control algorithm:

$$V_{PF-3,P} = M \times PID(\text{segment error})$$

- Fast derivative controller is based on the up-down loop voltage difference.

$$V_{PF-3,D} = D \times \left(\dot{\psi}_{Upper-Loop} - \dot{\psi}_{Lower-Loop}\right)$$

- The underlying assumption is that the plasma vertical position can be measured by only 2 loops:

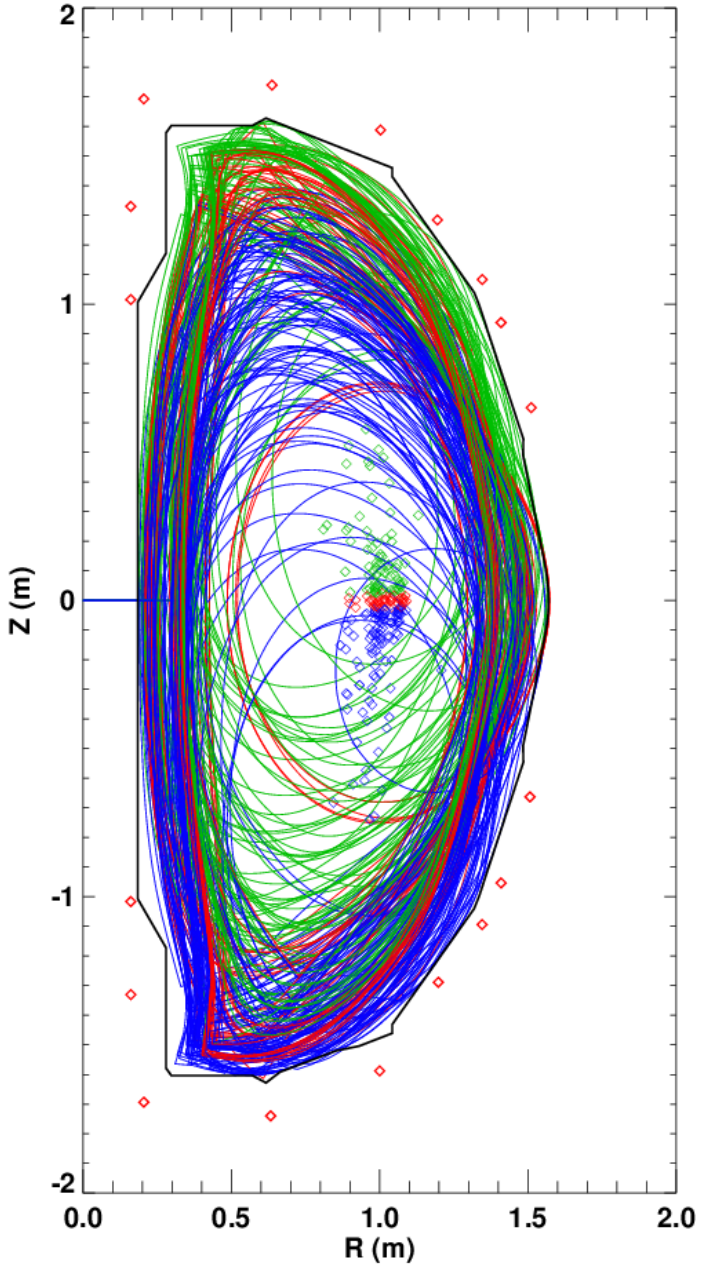
$$I_P Z_P = C \times \left(\psi_{Upper-Loop} - \psi_{Lower-Loop}\right)$$

- Thesis: Using more loops will lead to a better estimation of the plasma position.
  - Eliminate n=1 pickup from random loop orientation problems.
  - More information for shapes that are distorted.

Numerical Tests Have Found That More Loops Are Better (I)

- Constructed ~220 NSTX equilibria.
  - Shift them off the axis, change the divertor coils, change I_P.
- Computed the flux at the various flux loop locations.
- Fit the magnetic axis location to a function:

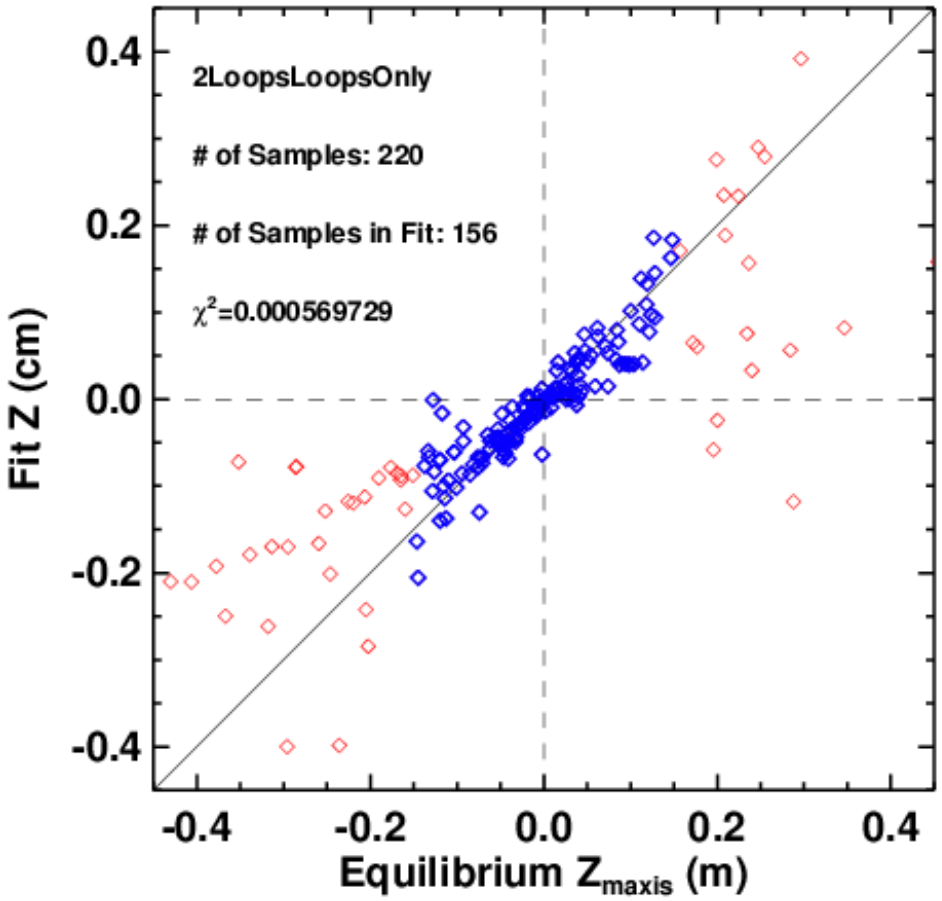
$$I_P Z_P = \sum_{i=1}^{NumLoopPairs} C_i \times \left(\psi_{Upper-Loop,i} - \psi_{Lower-Loop,i} \right)$$



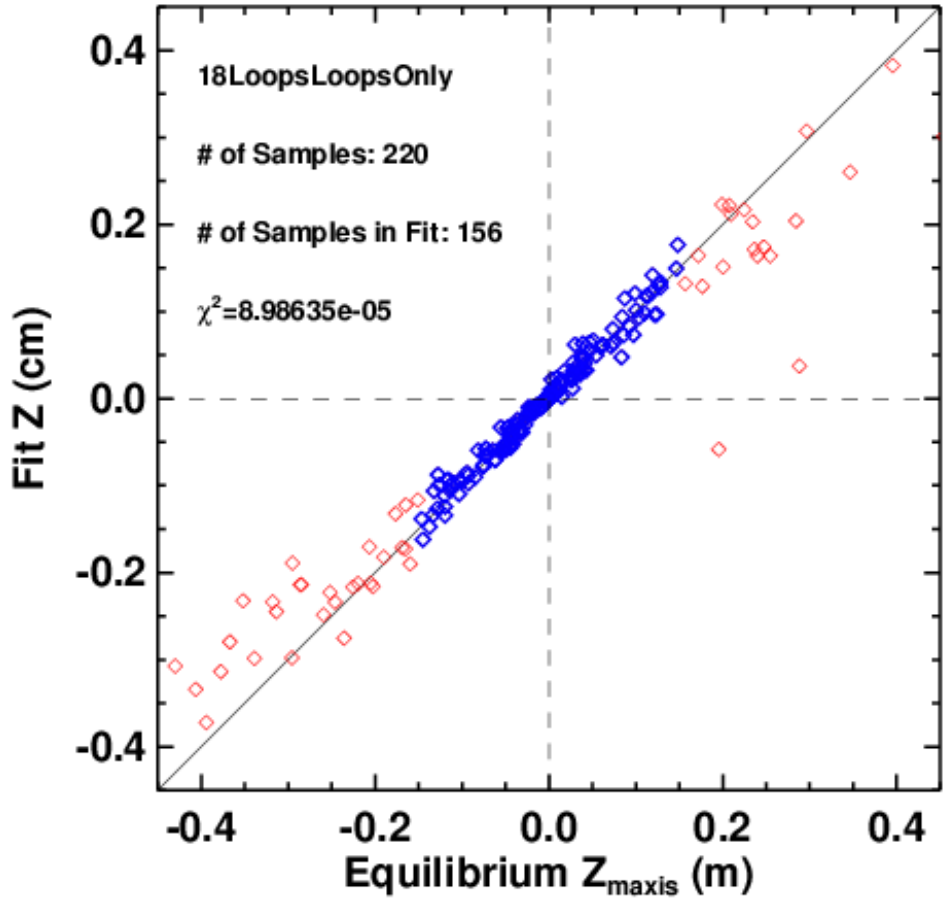
Numerical Tests Have Found That More Loops Are Better (II)

- Use only blue points in the fits ($|Z_{maxis}|$<15 cm)

1 Pair of Loops (On Primary Passive Plates)



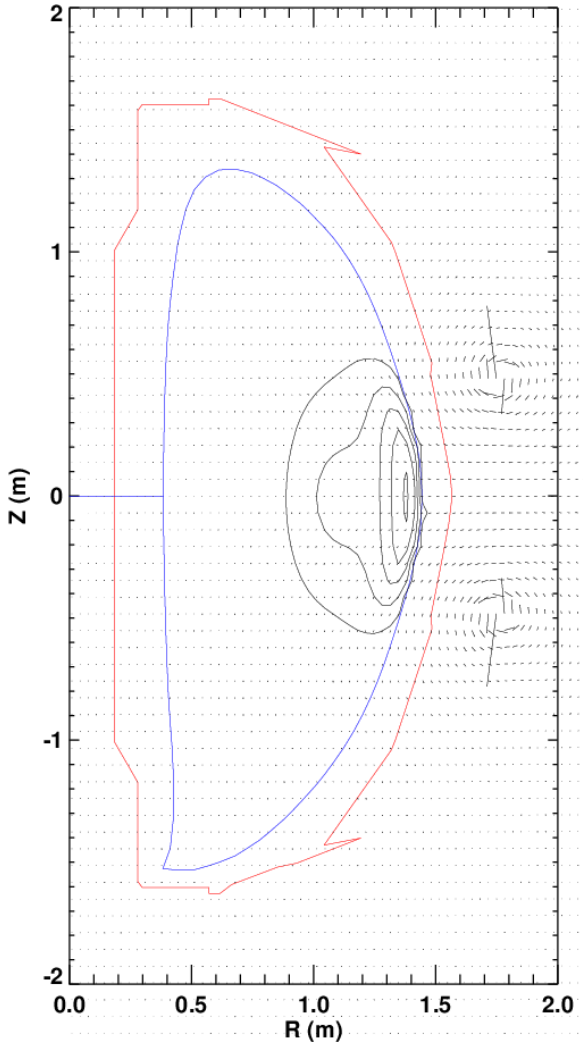
9 Pair of Loops (6 Cat. 4, 3 Cat. 3)



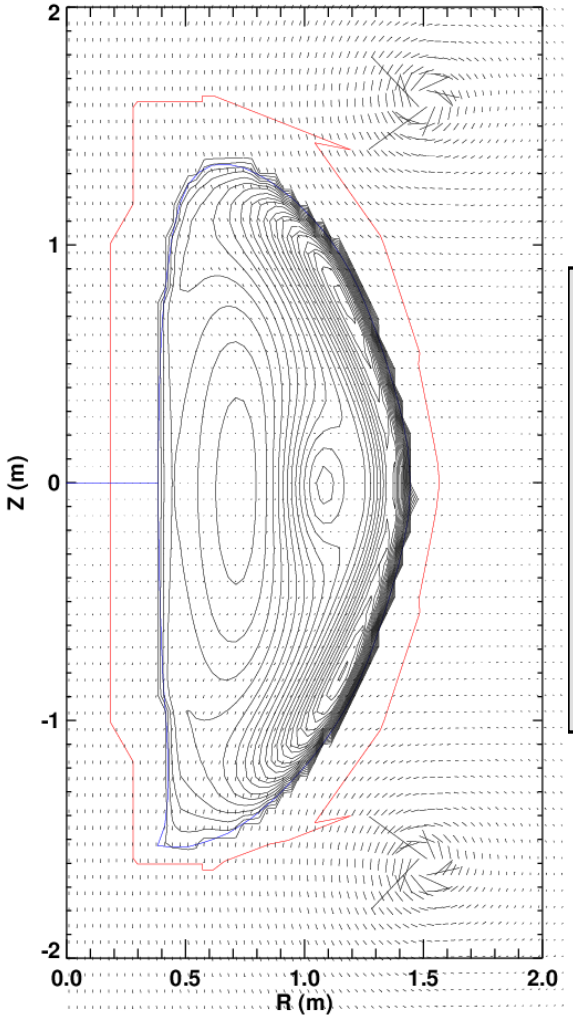
Vertical Position Control May Be Possible With the RWM Coils

Calculate force assuming 1 amp of power supply currents $F_Z = \sum J_\phi B_R$

RWM Coils: F_Z=78



PF-3 Coil: F_Z=1500



RWM Coils make far less force for the same power supply current.

(ratio is not as bad for lower-elongation plasmas)

However….

1) SPA are very fast (to 3 kA in 1-2 msec)

2) RWM coil field may not couple as strongly to the passive plates.

Use this as a last resort if we have insufficient vertical control margin after other things are tried.

Run Plan

- Debugging: Compare PCS calculations to identical off-line versions.
- XMP (?): Test that system is correctly coupled to the PF-3 coils.
- Day 1: Optimize gains with PF-3 as actuator, new dZ/dt observer.
  - Reload vertically unstable target, A~1.75, κ=2.9
  - Use divertor gas injection to drive l_i up ?
- Day 2 (if necessary):
  - Repeat unstable scenario, using RWM coils for n=0 control. Do a derivative gain scan.

What if this does not work?

- Could replace the PD controller with something more sophisticated.
- More voltage capability on PF-3.
- Make PF-2 bi-polar for vertical control.
  - Or always run with a PF-2 positive bias (not-desirable!)

Backup

PCS Status

- dZ/dt Observer
  - Complete specification has been written.
  - Electronics for voltage difference amplifiers have been ordered.
  - Requested they be ready for the ISTP.
  - Have not started coding it in PCS.

- RWM coils for Z_{axis} control.
  - Specification has been written.
    - Will be part of the RWM proportional control algorithm.
  - Relies on the improved dZ/dt observer for the measurement.
  - Have not started on the PCS code yet.