KSTAR Field Error Measurements with an Electron Beam: Experiments of 2009.12.2

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실험운영 팀♪

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무주 리저트

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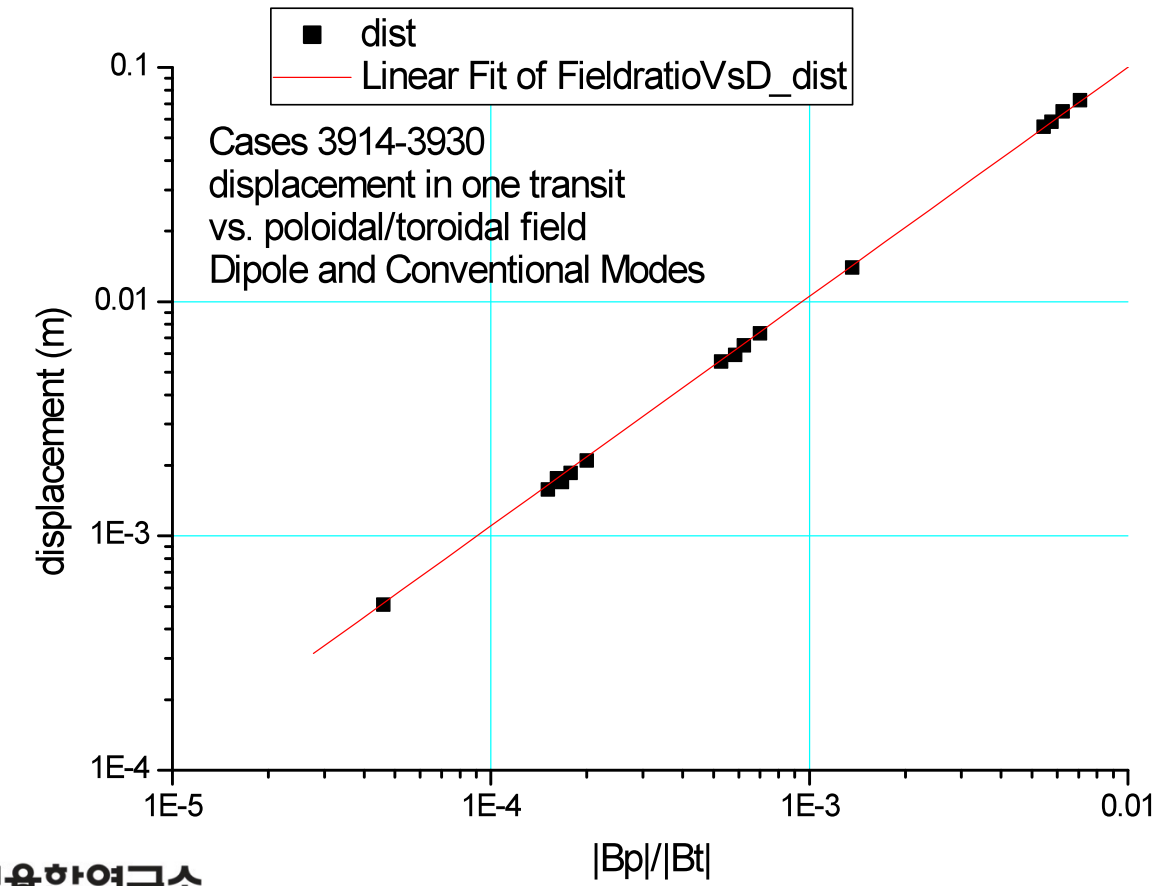
Calculations

Calculations with many poloidal fields showed that the displacement of the beam after one toroidal transit is a function only of the ratio of |Bp|/|Bt|. The slope is ~ 10. Hence a toroidally averaged poloidal field of 30 g in a toroidal field of 3 T will produce a displacement of ~1 cm.



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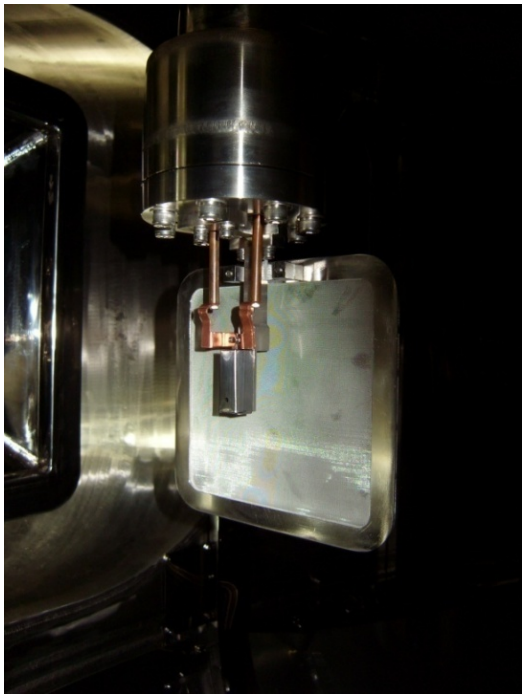

Photo of e-beam probe and fluorescent screen in sector J

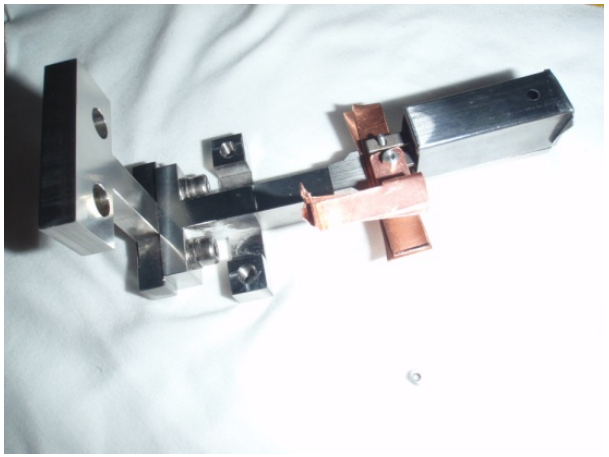

Photo of e-gun

Camera in sector H and
e-beam probe in sector J

e-beam probe
and screen♪

Inspection camera in sector H

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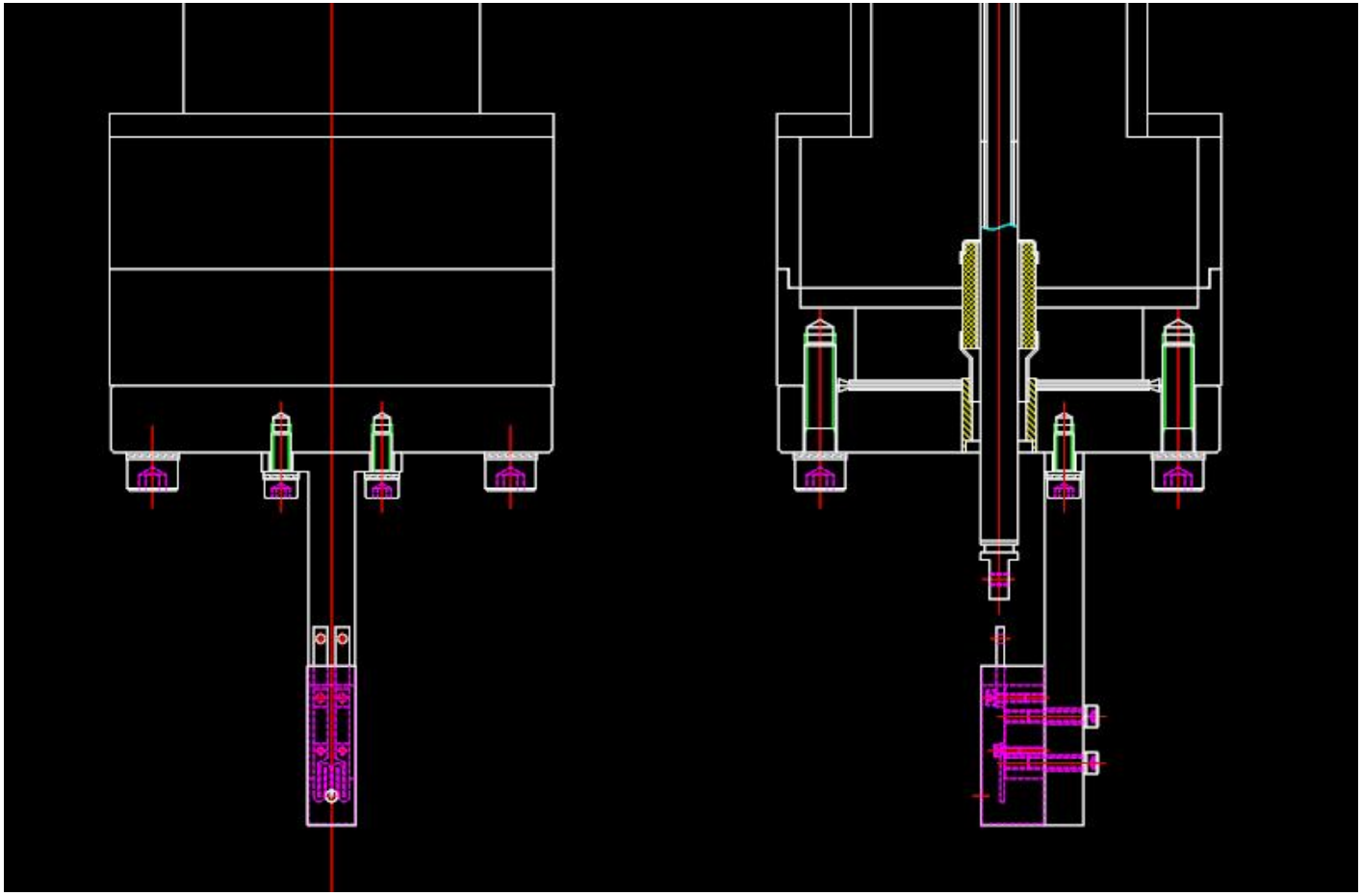
Electron Gun at end of GDC probe in KSTAR♪



LaB_6 filament♪

A screen is mounted on the back of the gun ♪

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Experimental Arrangements

Initial The experiment was performed on 2009.12.2 after the end of the KSTAR 2nd campaign plasma experiments.

More than 60 shots with various PF coils energized were made and the deflections of the e-beam were measured.

The measurements were made with a camera integration time of 300 ms because of the low light intensity. The fields were held constant during the camera exposure.

Transient measurements could not be made due to the low sensitivity of the camera and the low light levels.

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Plan of Experiment

The beam was positioned on the mid-plane (Z=0.0 m) as well as +0.11 m above the mid-plane and -0.11 m below the mid-plane to check for up-down asymmetries.

Each of the poloidal field (PF) coils was individually energized to cause a deflection of the electron beam in all 3 locations. The coils were energized with positive and negative currents to check for asymmetries and to reset any magnetization to the original value.

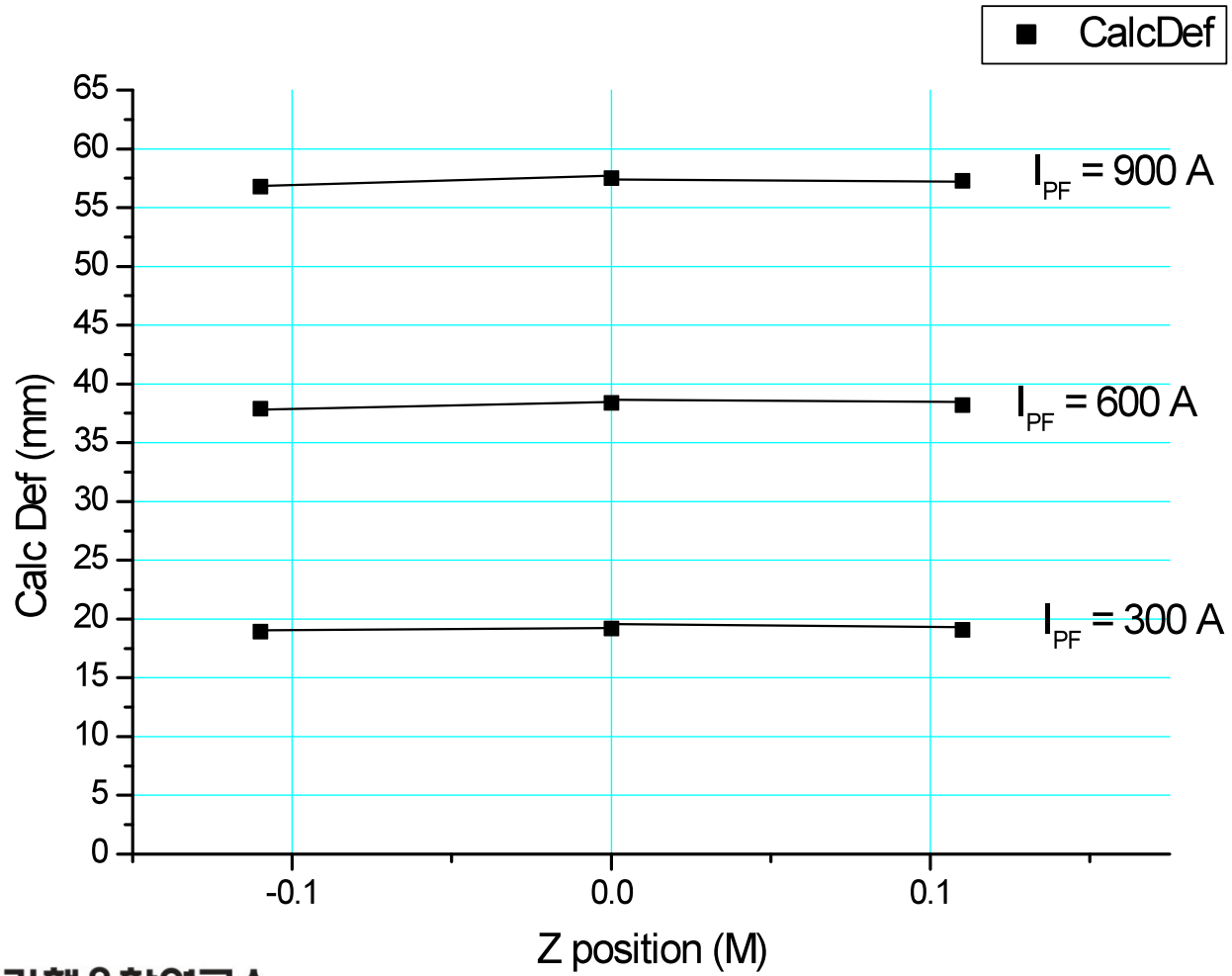
The PF coils were also energized together to make a field null scenario with a null at R = 2.02 m, which was the radial location of the e-beam. A toroidal field (TF) current of 15 kA was used for these measurements.

Photo of e-beam

Photograph of the screen for the gun at -0.11 m and the PF1 coil energized with -300 A and the TF coils energized with 10 kA. Measurements of deflection were made by counting pixels.♪

Results for PF1-1

The calculated deflection for the given coil currents for three e-gun positions : +0.11 m, 0.0 m, and -0.11 m.



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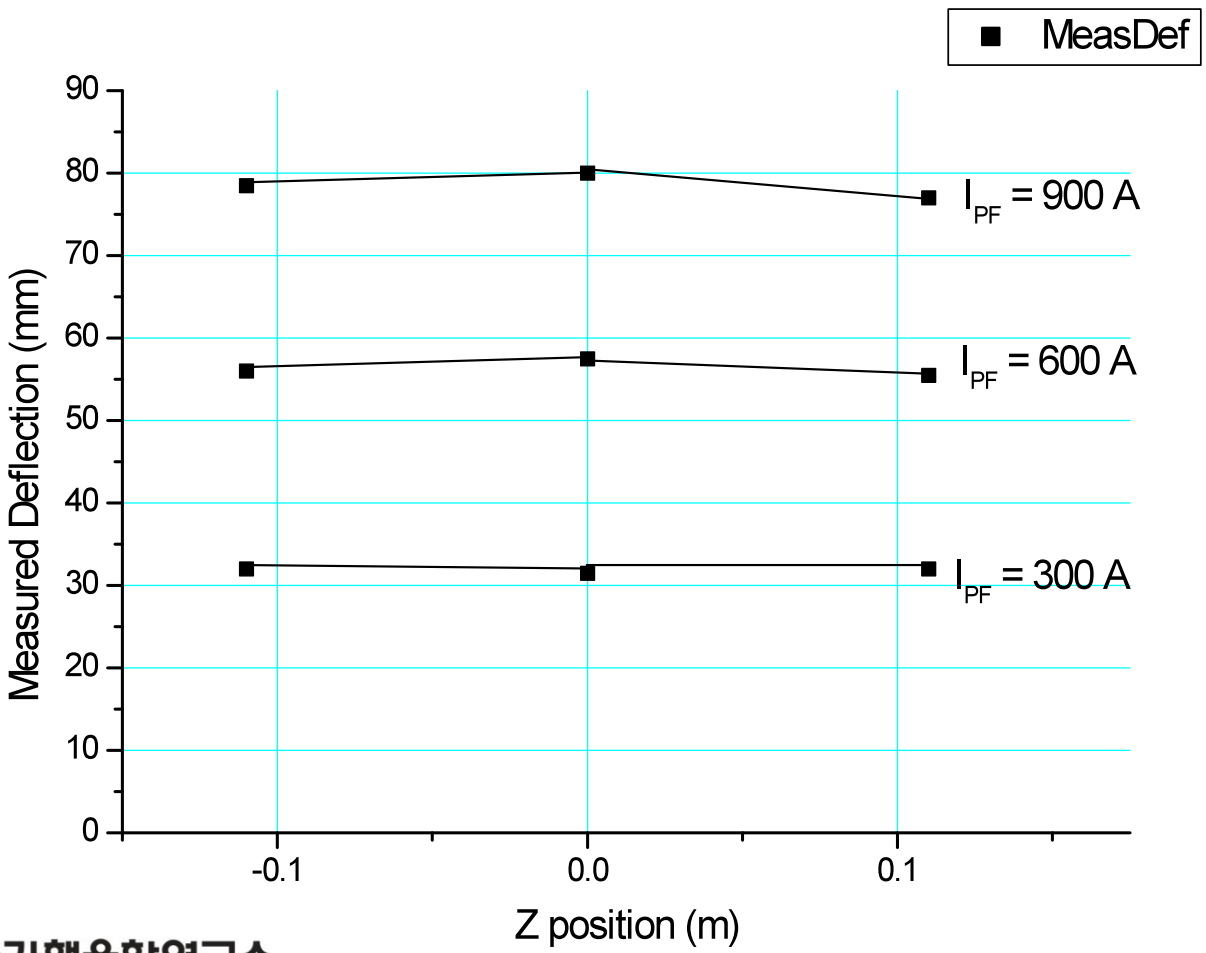
Results for PF1-continued

The measured deflection for the given coil currents.
Note that the deflections are not linear with coil current and display some saturation.



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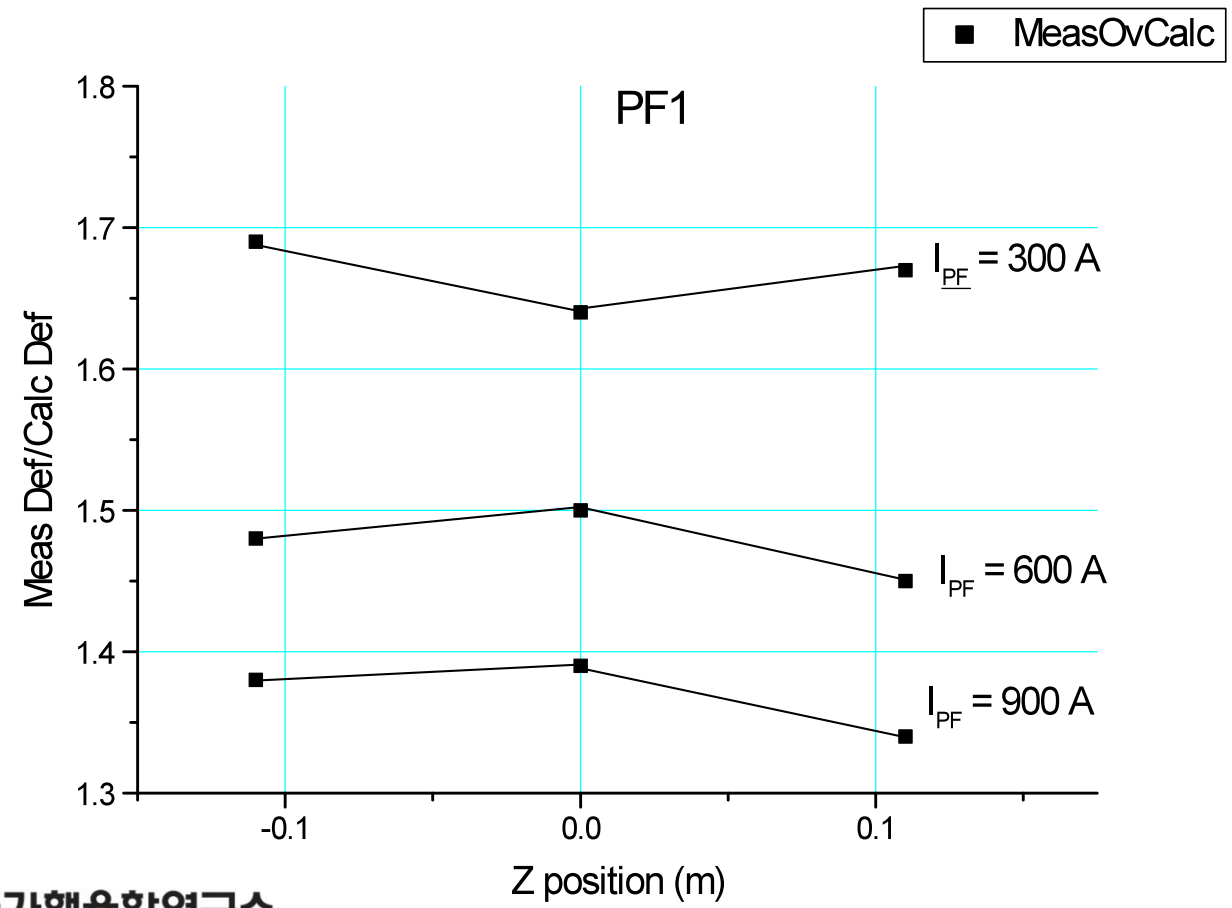
Results for PF1-continued

The ratio of measured to calculated deflections. Note that the higher coil currents lead to a smaller ratio indicating approaching saturation. The error bars are about +/-0.1



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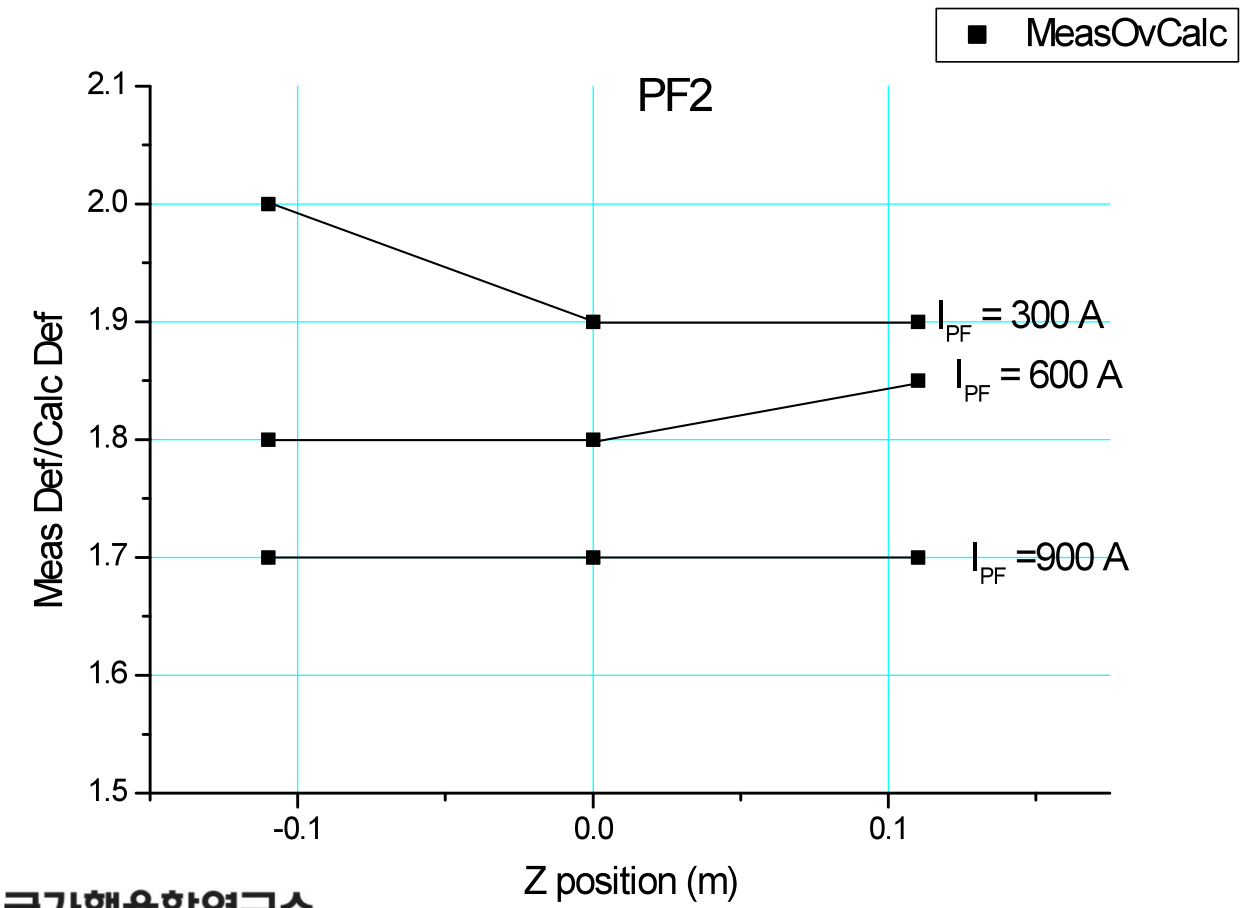
Results for PF2

The ratio of measured to calculated deflections. Note that the higher coil currents lead to a smaller ratio indicating approaching saturation. The error bars are about +/- 0.1



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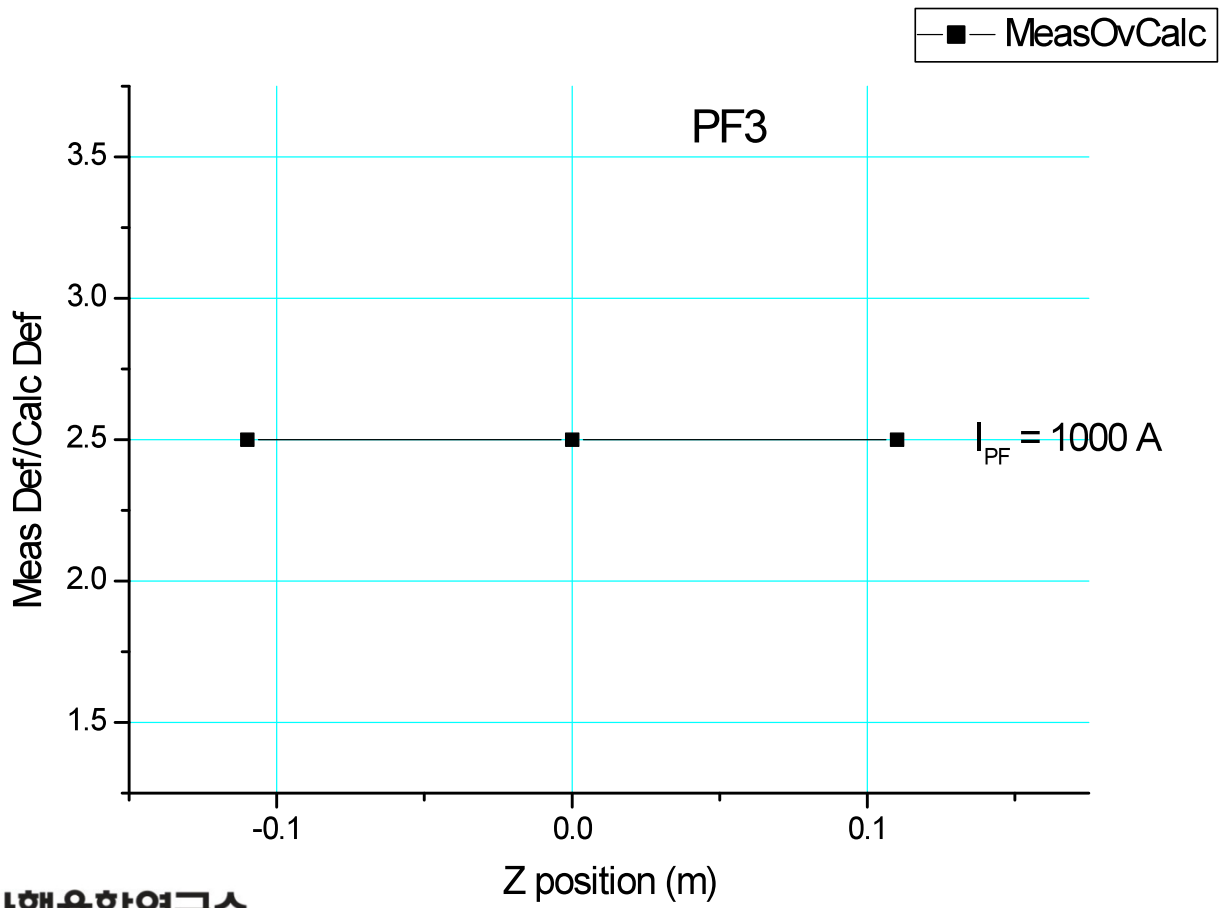
Results for PF3

The ratio of measured to calculated deflections. Only one coil current was used and the ratio is about 2.5.



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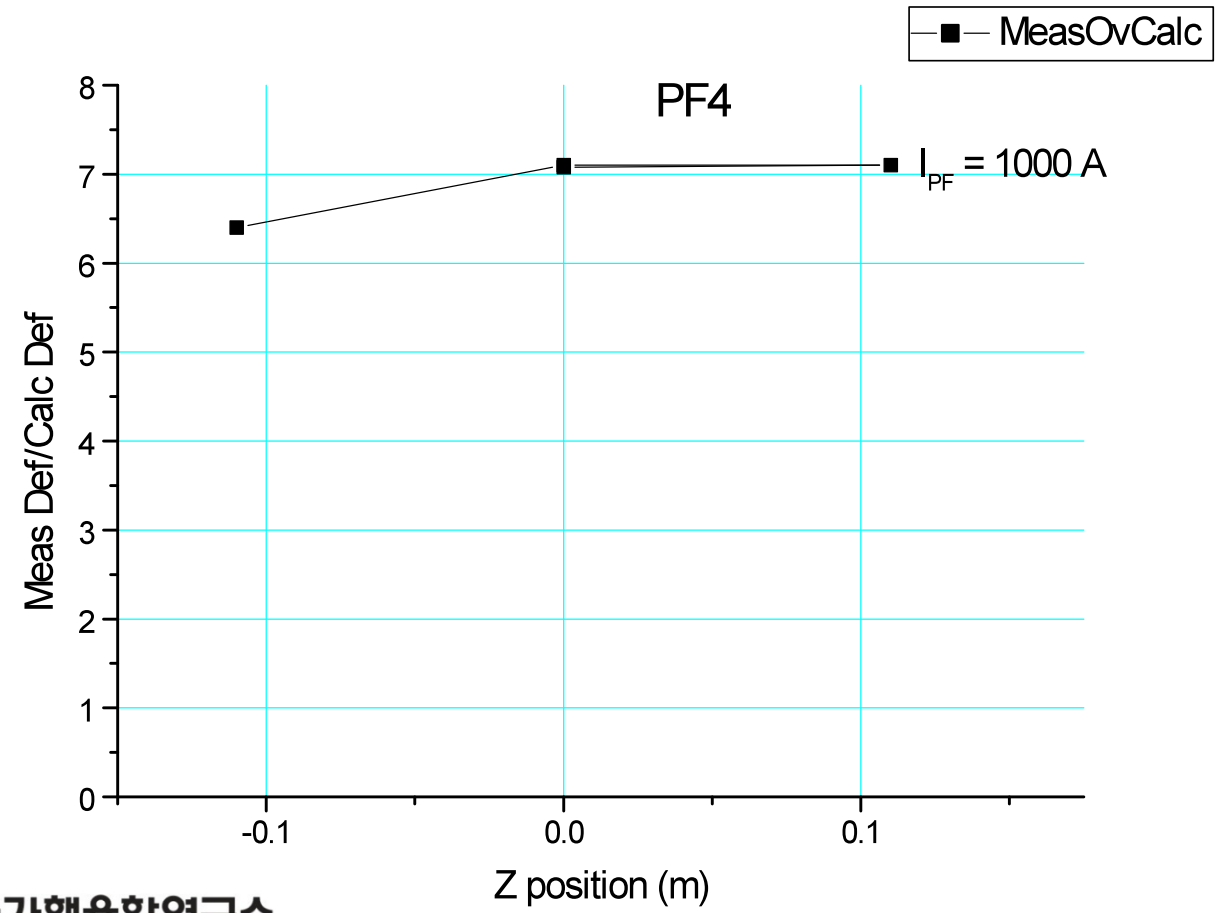
Results for PF4

The ratio of measured to calculated deflections. Only one coil current was used and the ratio is about 7. The error bars are about +/- 1



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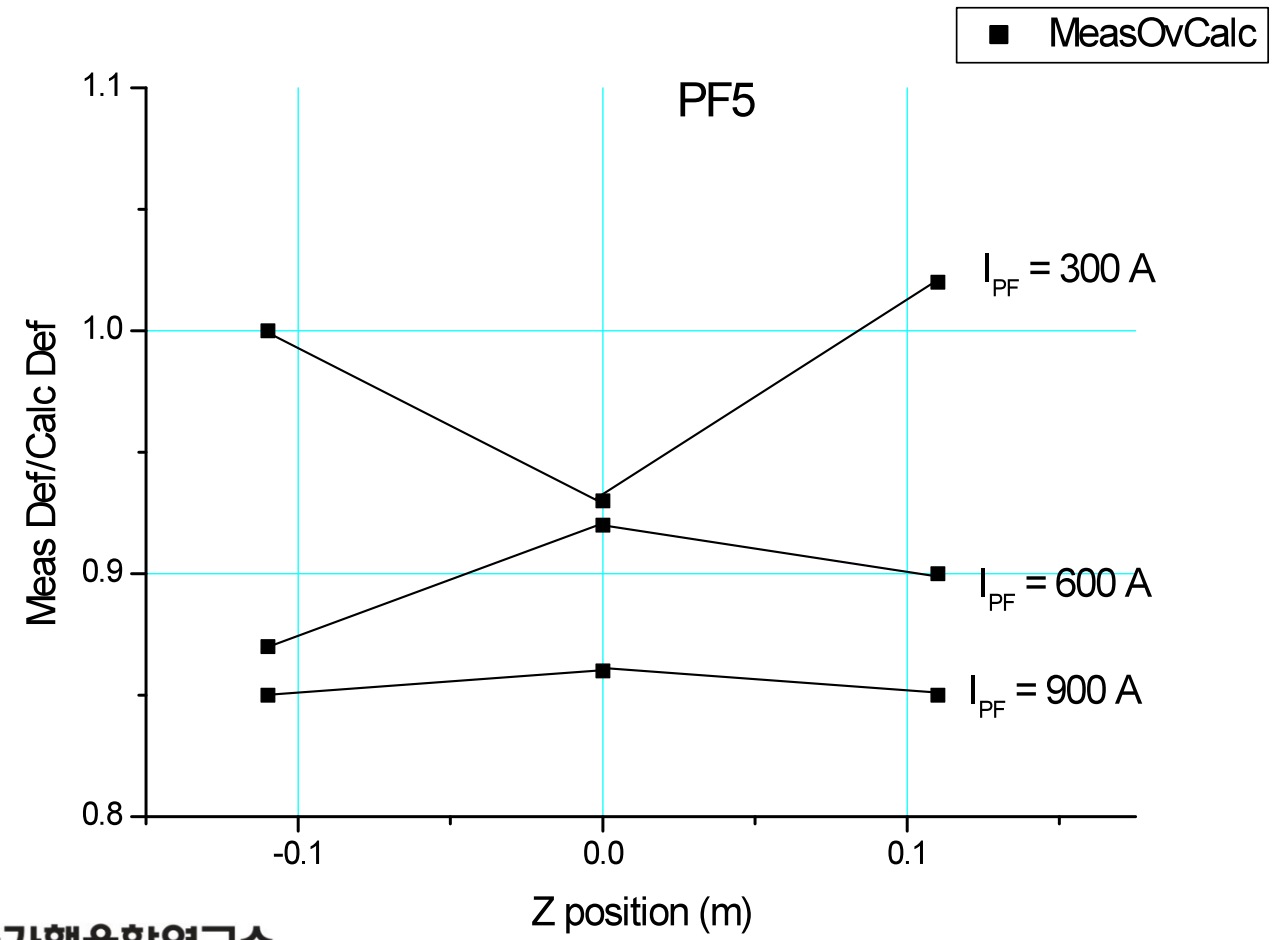
Results for PF5

The ratio of measured to calculated deflections. Three coil currents were used and the ratios are about 1 for the lower currents and less than 1 for the higher currents. The error bars are about +/- 0.1



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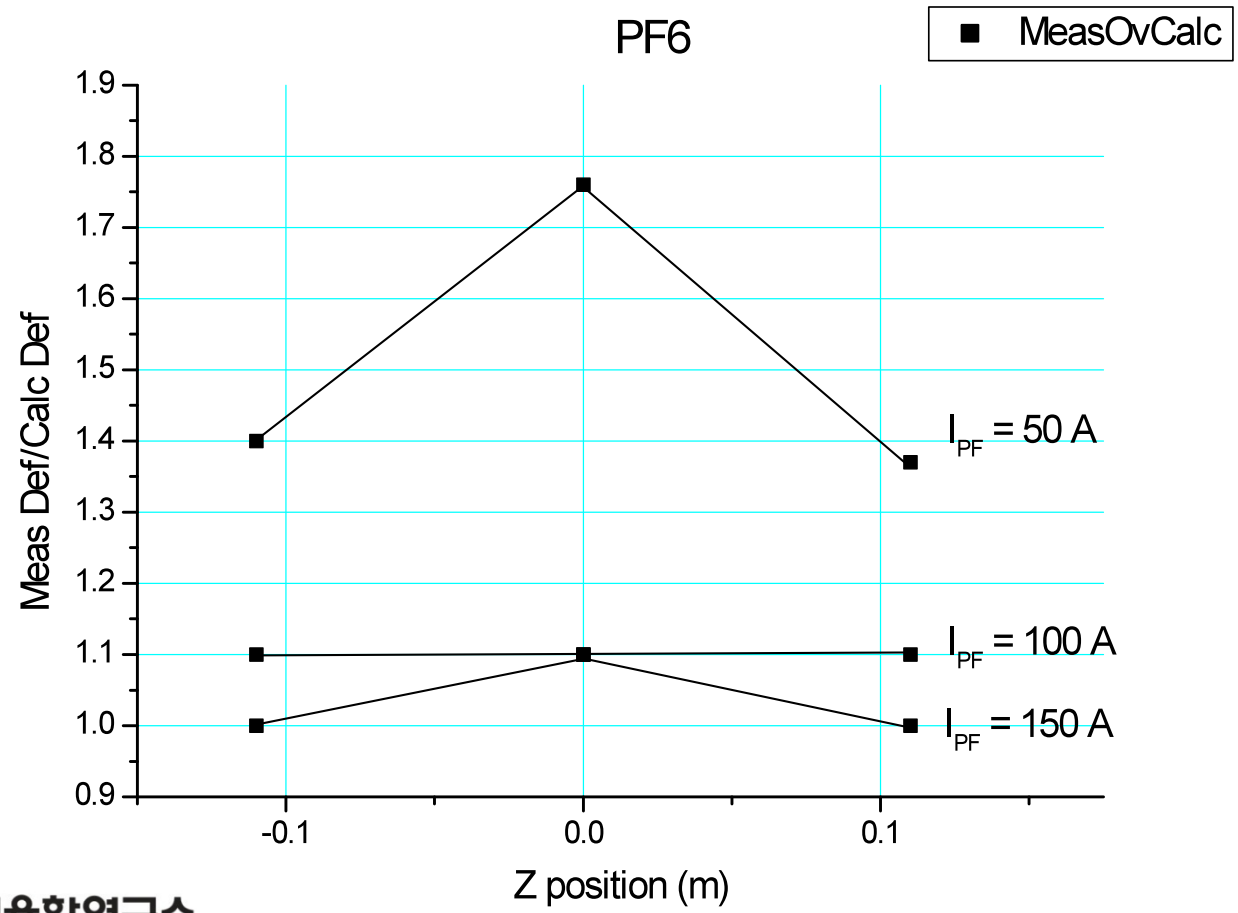
Results for PF6

The ratio of measured to calculated deflections. Three coil currents were used. The ratio decreases for higher coil currents indicating the approach to saturation. There is more variation due to the poor regulation in the current. The error bars are about +/- 0.1.



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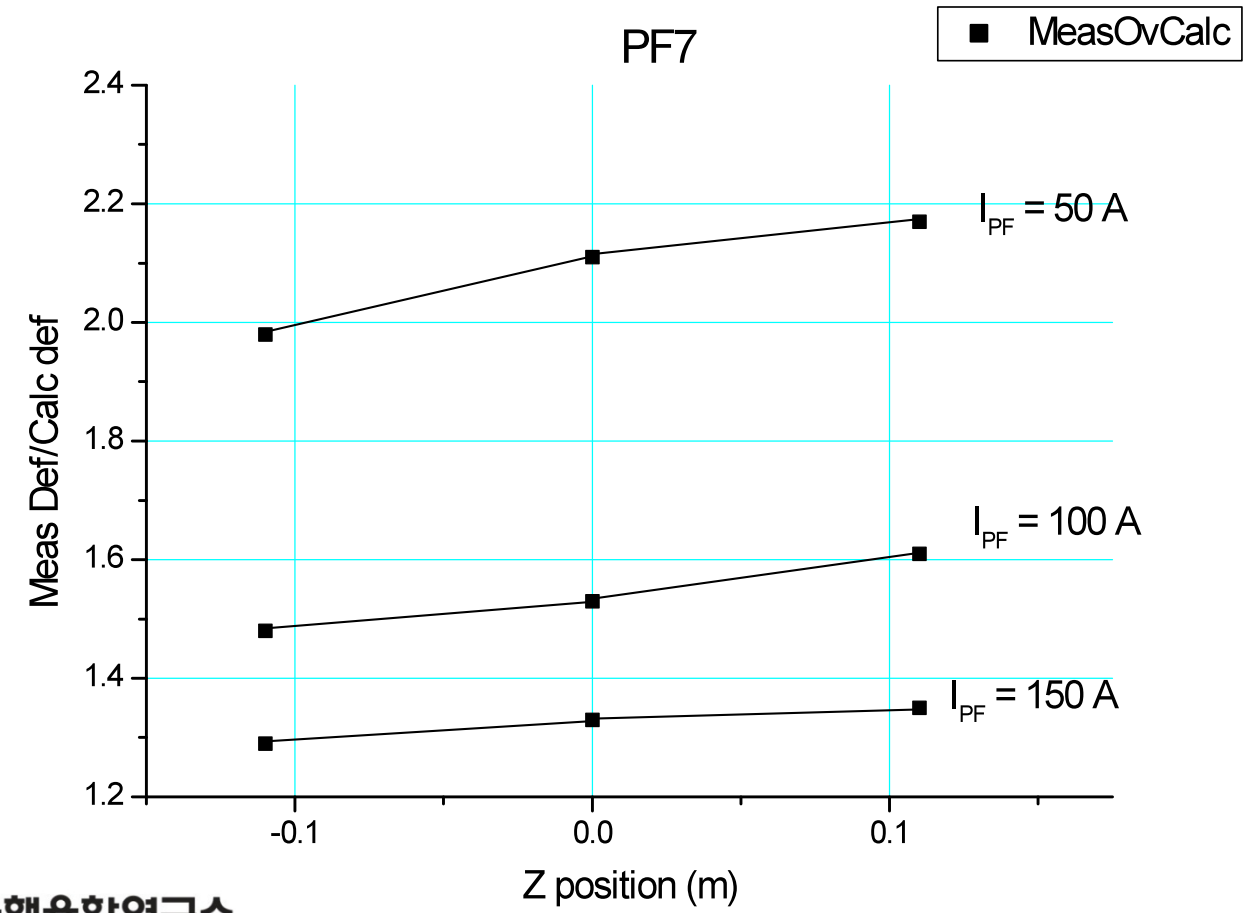
Results for PF7

The ratio of measured to calculated deflections. Three coil currents were used. The ratio decreases for higher coil currents indicating the approach to saturation. As with PF6 there is more variation due to the poor regulation in the current. The error bars are about +/- 0.1.



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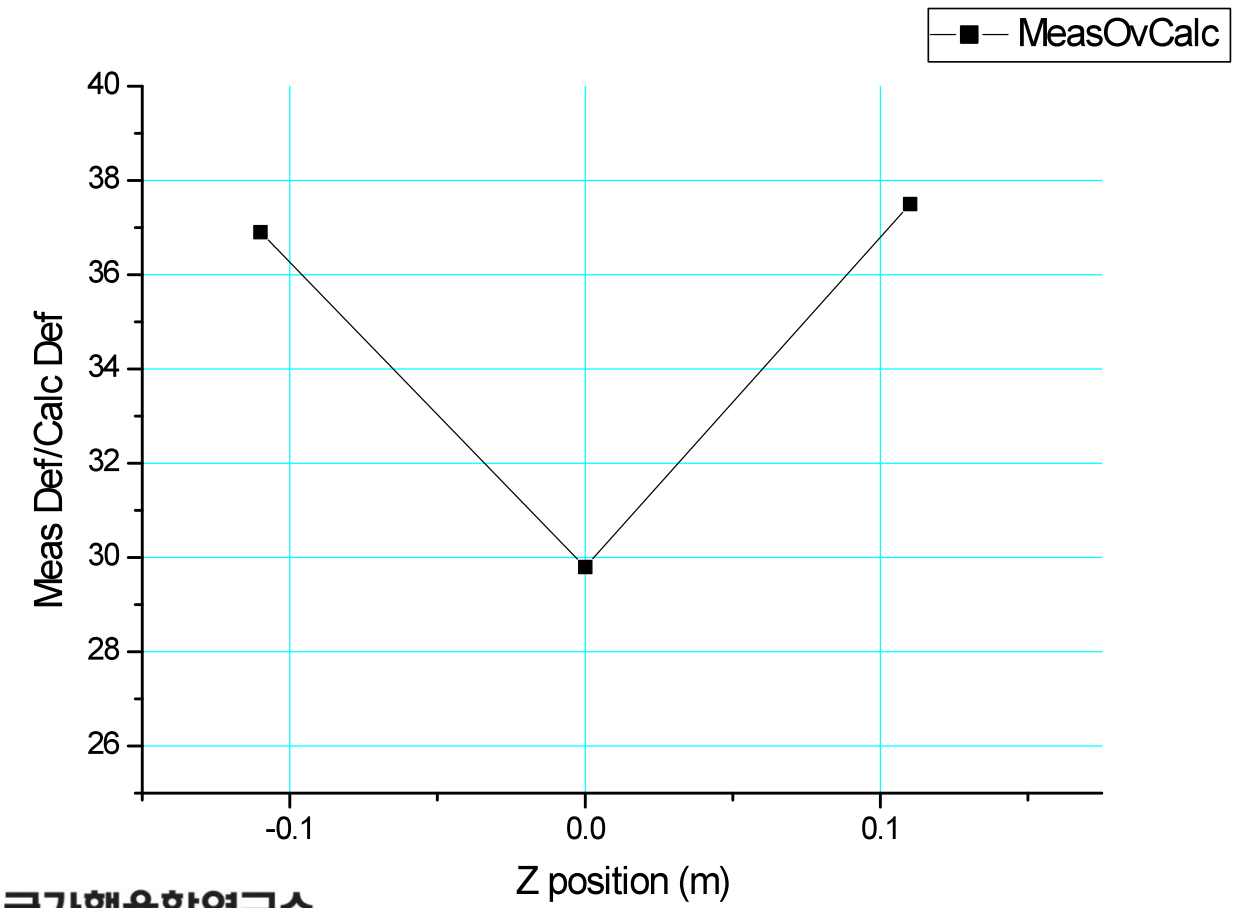
Results for Scenario R = 2.02 m

The ratio of measured to calculated deflections. Only one set of coil currents was used. There is a very large difference between the calculated and measured deflections indicating that the field null is not near the gun.



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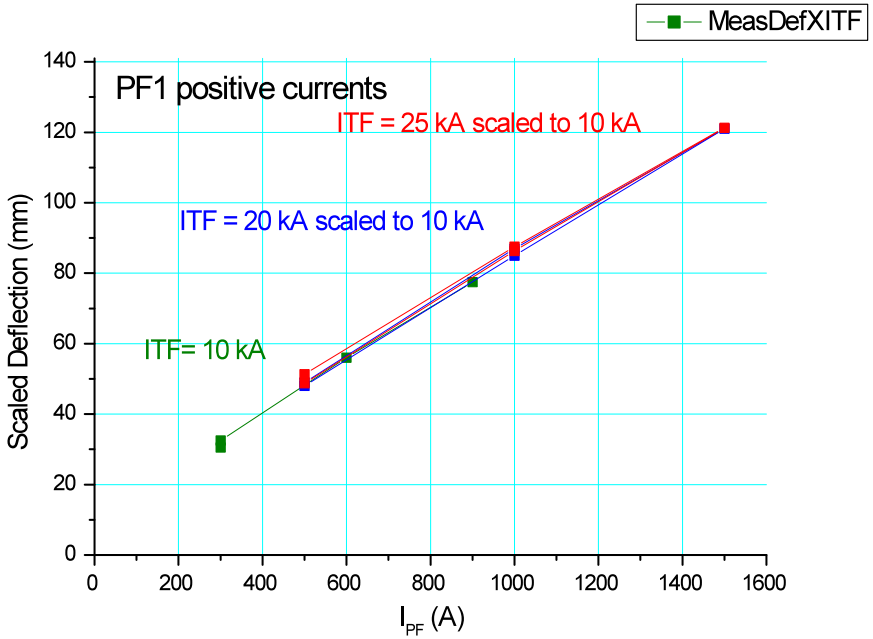
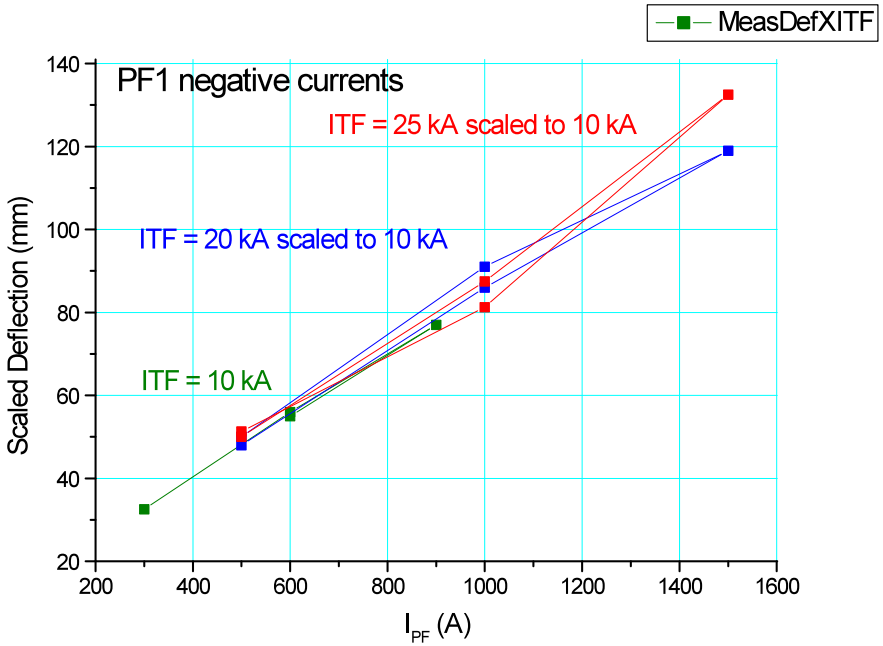
Results for the TF scan

The toroidal field (TF) current was varied from 10 kA to 20 kA and to 25 kA. The calculated and measured deflections from PF1 became smaller as the current was increased. Scaling the deflections by the current showed that the measured deflections were almost the same indicating that the TF has only a small effect on the PF saturation. On the left side below are the results for positive PF currents and on the right are the results for negative PF currents.





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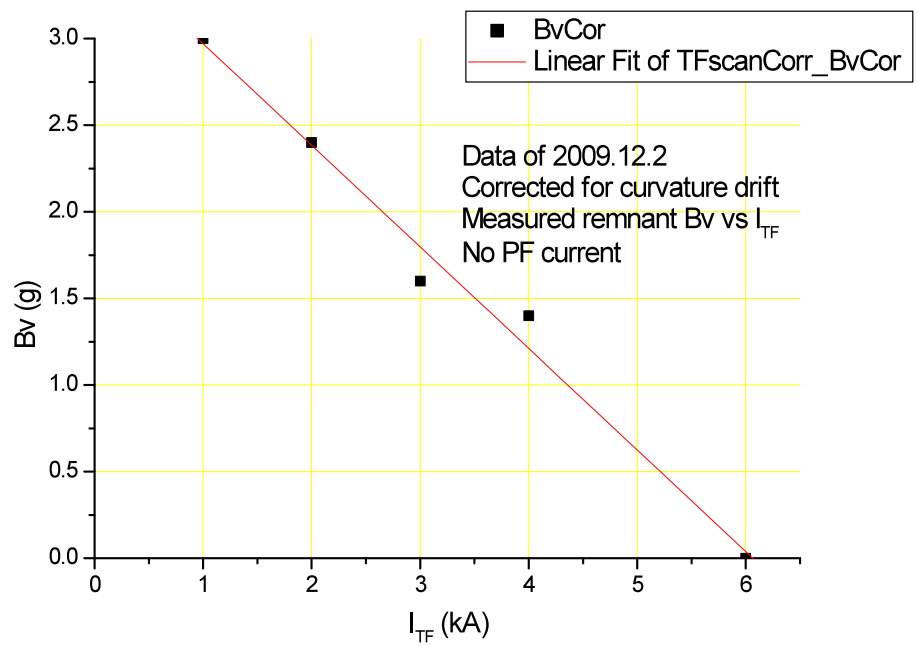
Remnant field

Prior to the excitation of the PF coils, the TF was energized with currents in steps of 1 kA, 2 kA, 3 kA, 4 kA, 6 kA, 8 kA, and 10 kA. For 1 kA, the e-beam initially appeared above and radially inward from the beam center at high field and moved down and outward as the TF current increased. The Br and Bv values were measured as the field was raised by measuring the deflections. The data were corrected for the calculated curvature drift which is significant for the lower fields. The value of Br was 0.3 g at I_{TF} = 1 kA and diminished to zero for I_{TF} = 2 kA. The value of Bv decreased approximately linearly from 3 g as I_{TF} increased from 1 kA to 6 kA as shown below. The remnant vertical field in the vacuum vessel at the midplane location of the e-beam is reduced to zero with I_{TF} = 6 kA (~0.6 T). This is a very small remnant field and is not expected to have a significant effect on the plasma performance.



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Summary

The individual PF coils 1, 2, 3, 4, 6, and 7 show the deflection of the e-beam is larger than the calculations. This appears to be due to the magnetization of Inconel908.

For higher PF currents the beam deflections are smaller implying that the Inconel908 is saturating. However, we never observed full saturation.

For PF coils 3 and 4 the deflections are much larger than calculated. These two coils produce by themselves field nulls on the mid-plane near the e-beam location. The magnetization of the Incaloy908 has apparently either moved or eliminated the field nulls and hence the observed fields are very large. For PF3 the deflection is about 2.5 times calculated and for PF4 the deflection is about 7 times calculated.

For PF 5 the deflections are smaller than calculated. This is probably also due to the magnetization of Incaloy908 in the central solenoid that reduces the field near the gun. Further study and calculations are needed.

Summary continued

The R= 2.02 m scenario shows very large deflections compared to the calculations. The typical amount is a factor of 30 to 40. This is also probably due to the Incaloy908 magnetization and implies that the calculated field null has either been moved or eliminated by the effects of the Incaloy908.

There is no clear difference between the measurements above and below the mid-plane so it appears that there is no significant up-down asymmetry. Similarly there is no significant difference between the positive and negative current measurements for each coil.

The most variation is seen for PF6 and PF7. Because of the large size of the coils, they are very strong so that only small currents can be used. The regulation of the current is not good under these circumstances so there is much variation in the measurements.