HGVPU: LONG PROTOTYPE MEASUREMENTS AND TUNING

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Outline

The stages of tuning:

1. New magnetic measurement system
2. 3 m long device. Magnetic structure →3m, Springs→2.8 m. Strong deflection
3. 2.8 m long device magnetic structure: measurements and tuning
4. Future plans: 3.4 m device

Motivation for the development of a new type of undulator

- Deliver vertically polarized x-rays.
- Compactness; simplified fabrication and assembly.
- Compatibility of new undulator with the existing mechanical, vacuum, and control systems of the LCLS-I.

Introduction

The absolute majority of synchrotron radiation (SR) sources, including free electron lasers (FEL), utilize IDs with a vertically oriented magnetic field. New SR machines promise to operate with round e-beams and execute on-axis injection. Therefore developments of novel planar IDs with horizontal magnetic fields become a practical matter both for SR and FEL.

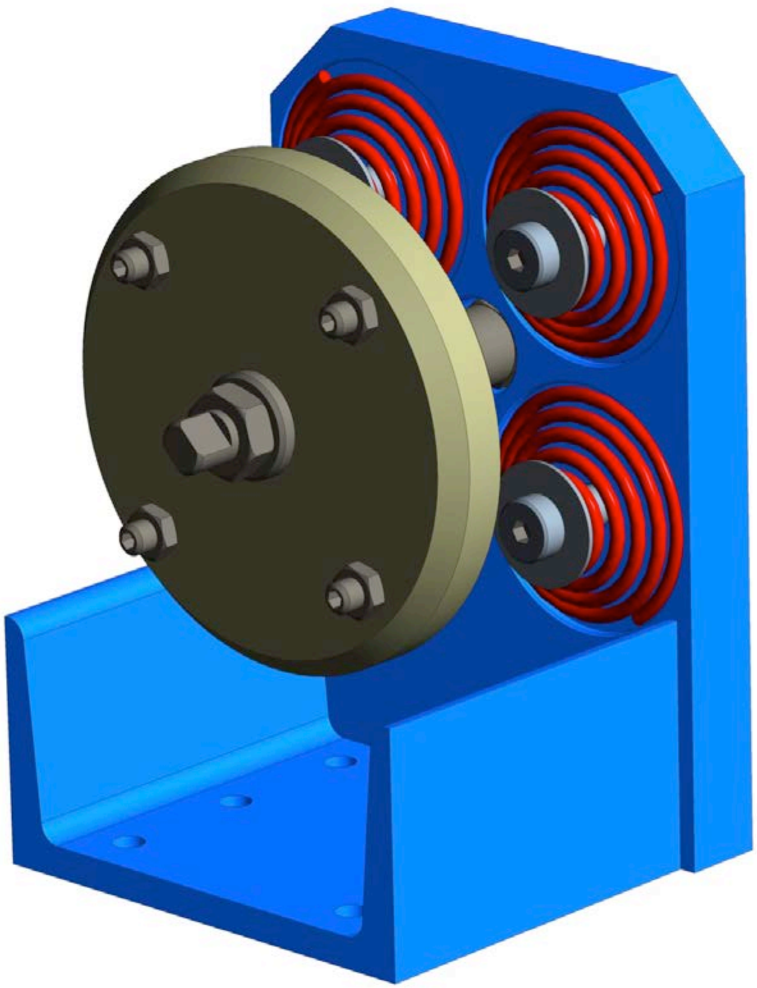
At least two major advantages of rotating ID geometry by 90 degrees:

1. Rotation of the polarization plane of emitted radiation, which results in the transformation of monochromators and experimental set-ups to the “gravity neutral” systems;
2. Combined with the magnetic force compensation system, the ID gap drive mechanism could become quite compact.

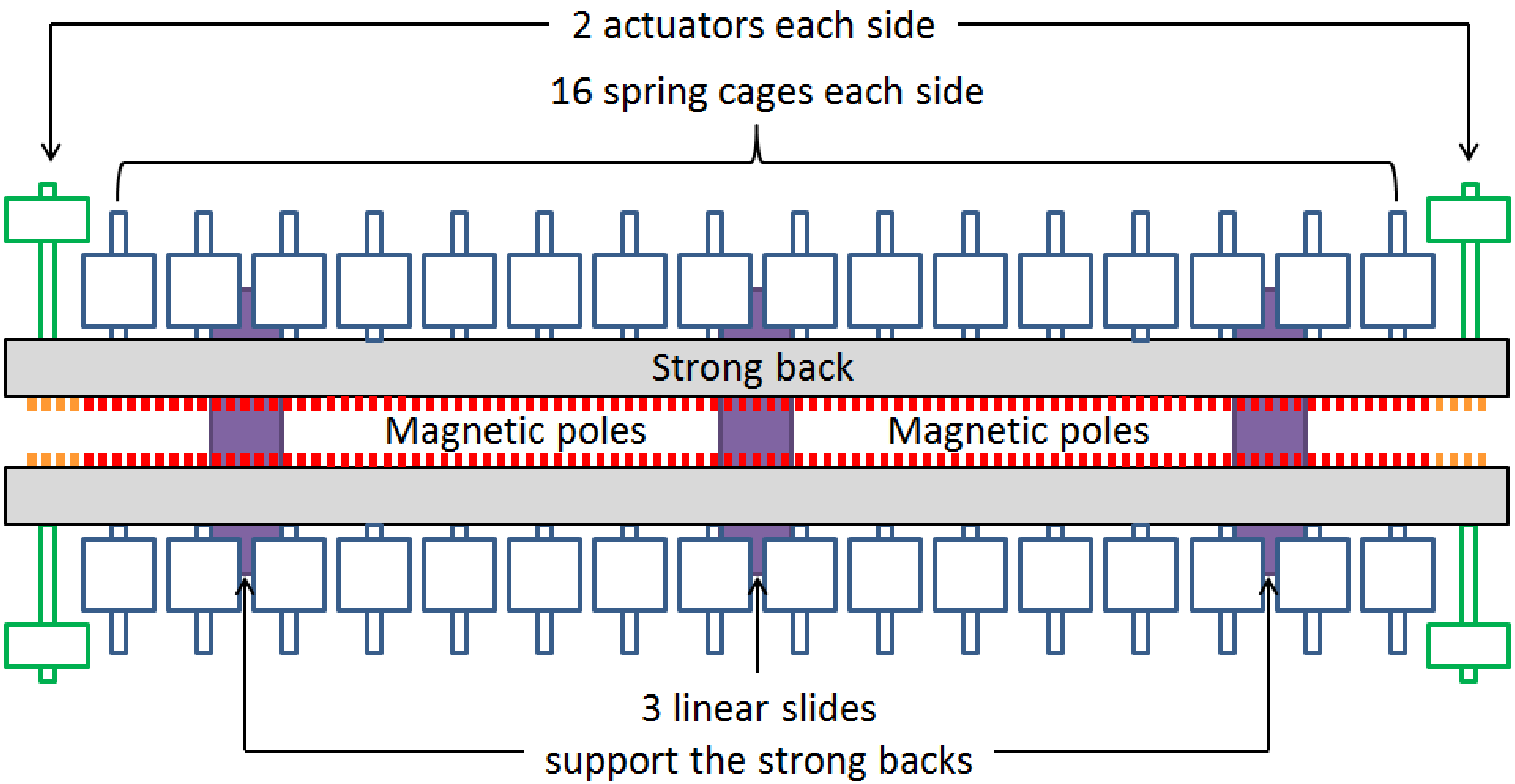
3m-long prototype in MM1

Conical Spring

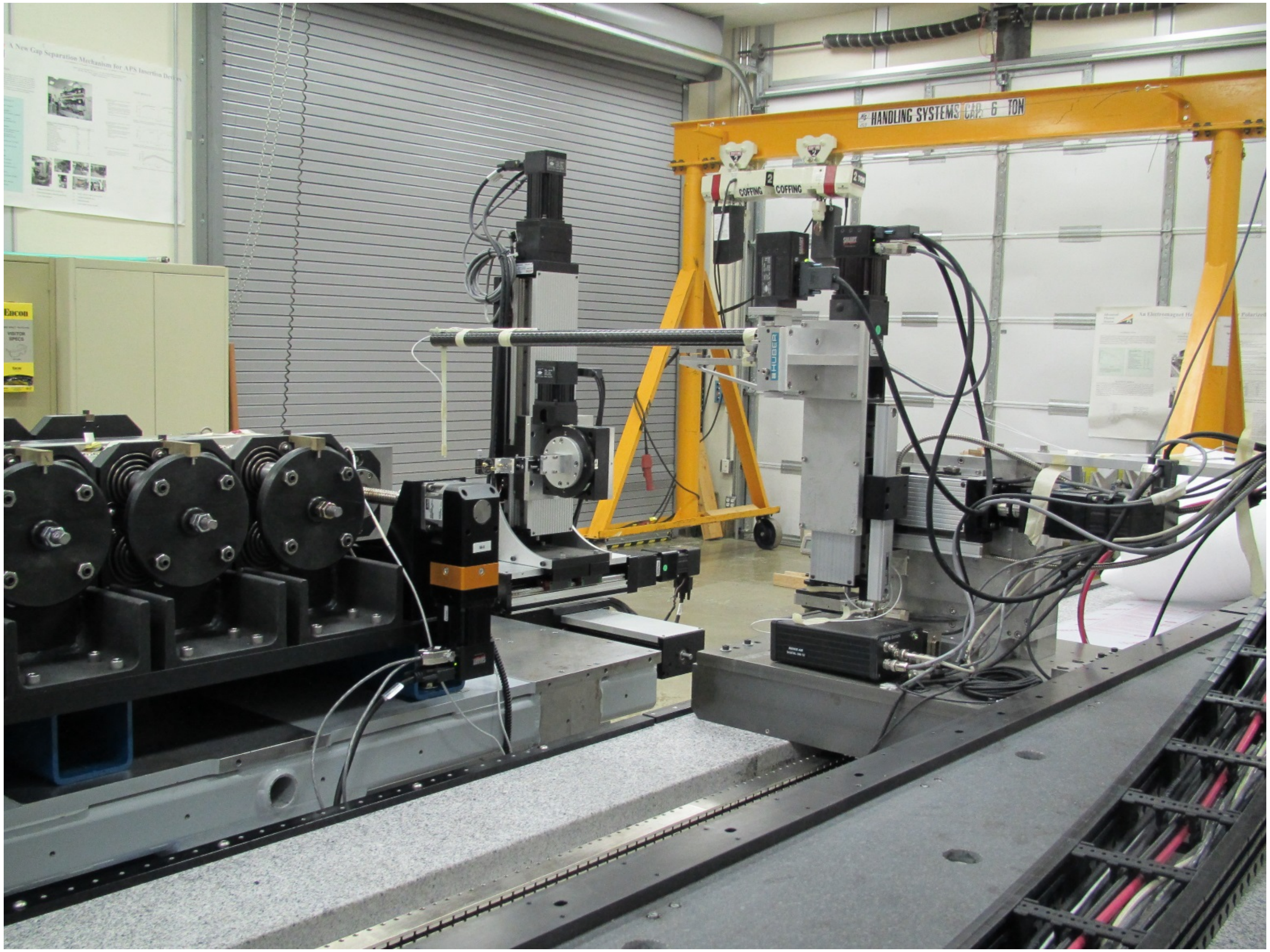
Spring Cage



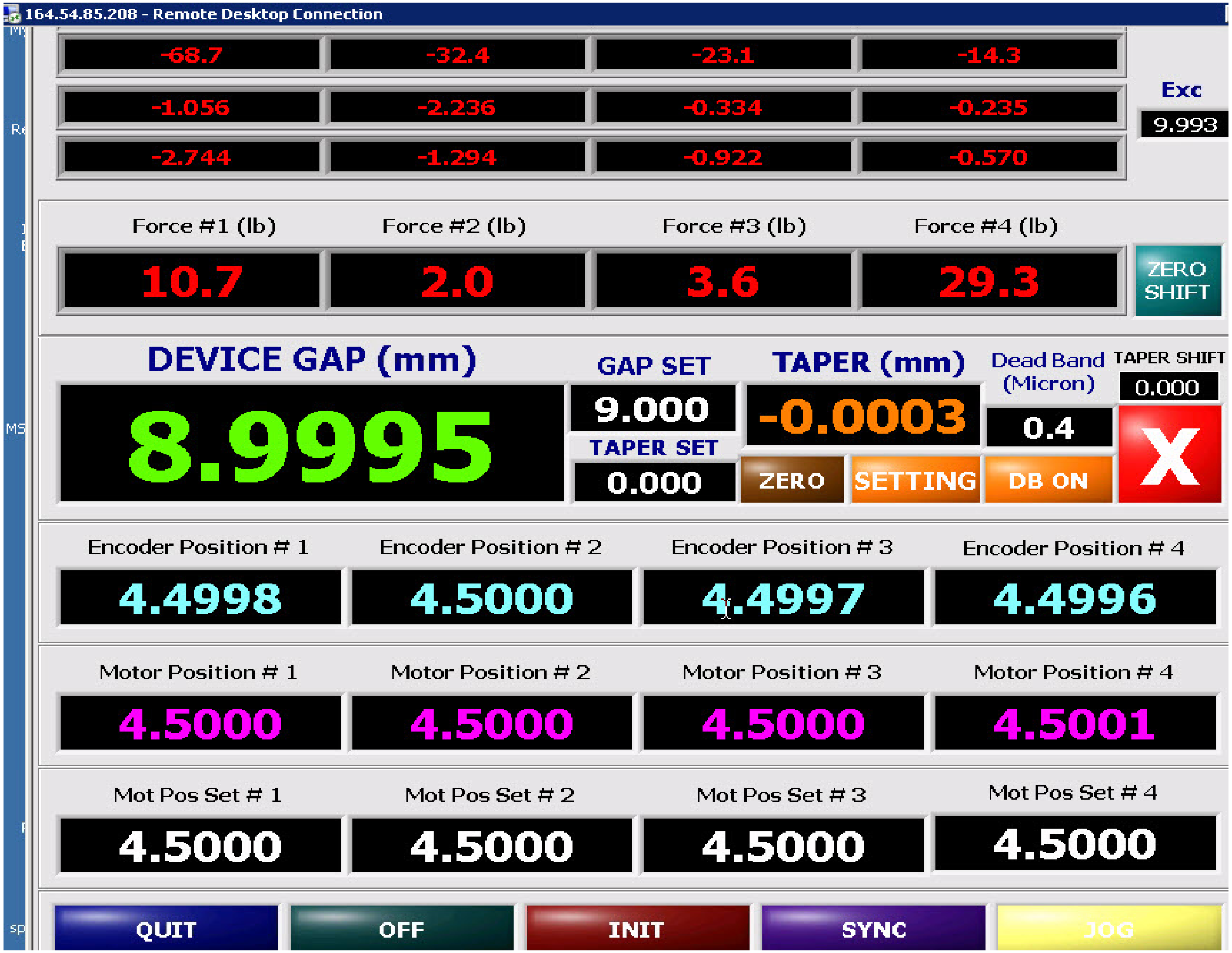
Top view of the LCLS II undulator prototype schematics



Hall Probe system upgrade



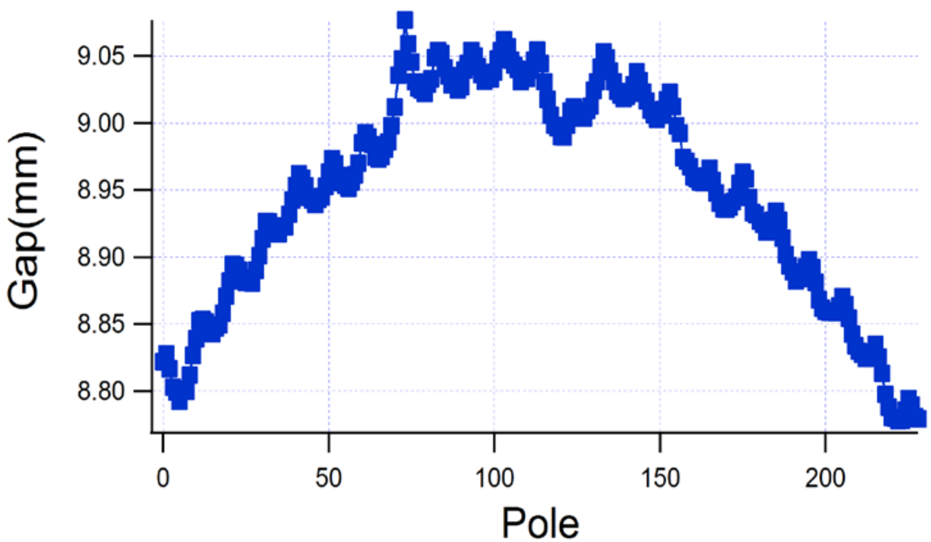
Gap control window at 9.0 mm

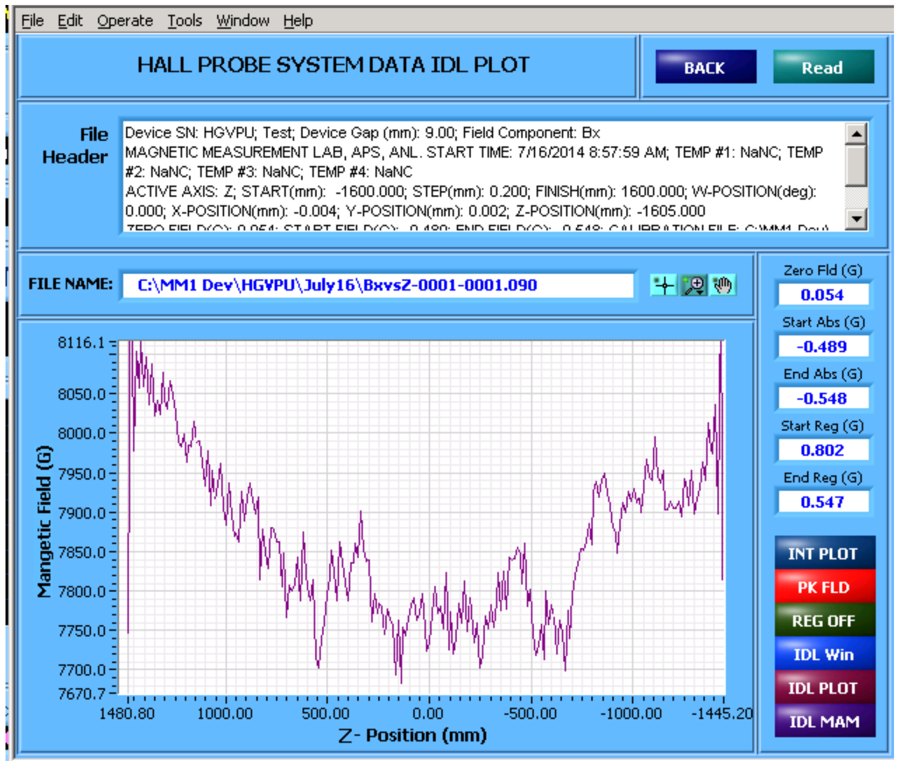


Undulator requirements

Parameter	Values	Units
Undulator parameter tolerance Δk/k	±2.3*10^{-04}	
Cell phase error	±4.0	deg
First field integral of B_y per cell (abs)	<40	μTm
Second field integral of B_y per cell (abs)	<150	μTm^2
Field integral quadrupole (abs)	<0.01	T
Field integral sextupole (abs)	<2	T/m
Field integral octupole (abs)	<400	T/ m^2

3m long prototype gap vs. Z at 9 mm gap





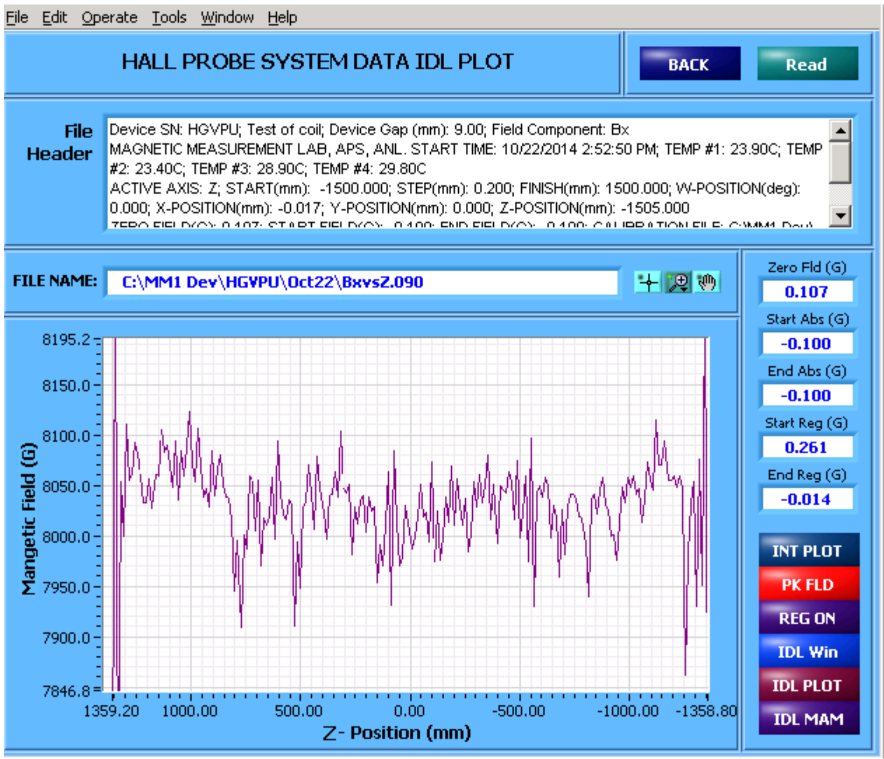
Capacitec

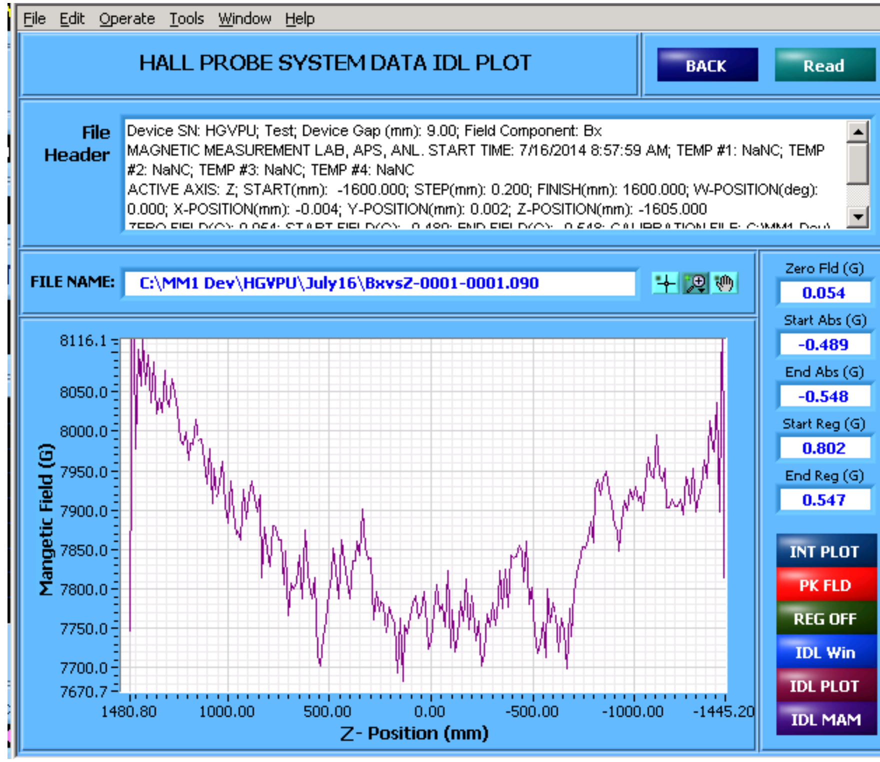
Hall Probe

2.8 m

device

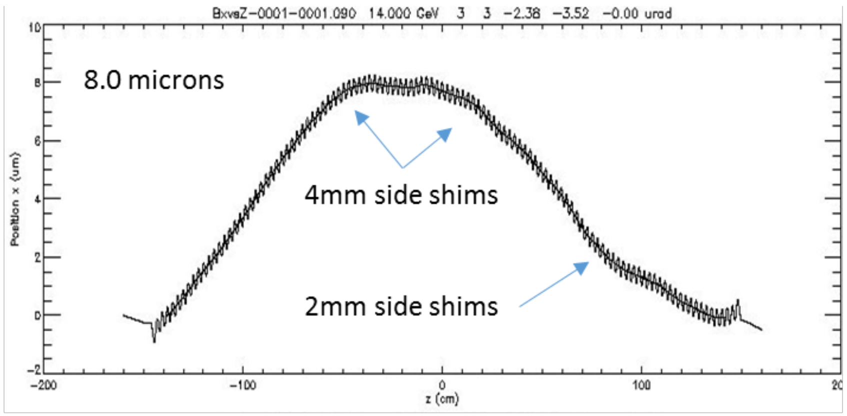
Comparison of 3 m vs. 2.8 m. peak field at gap 9 mm

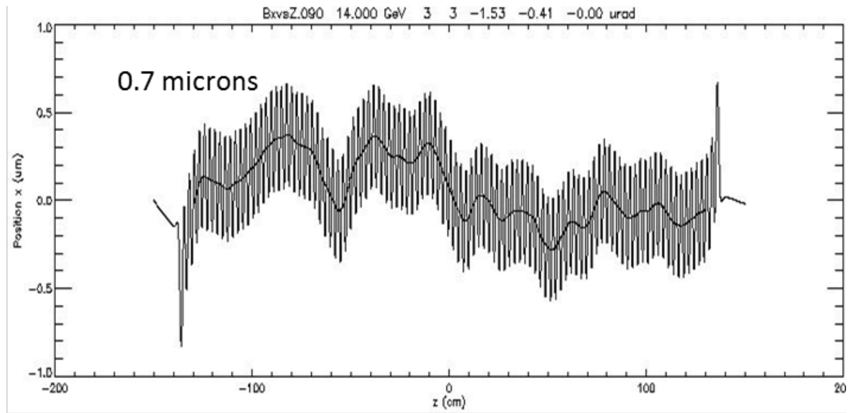


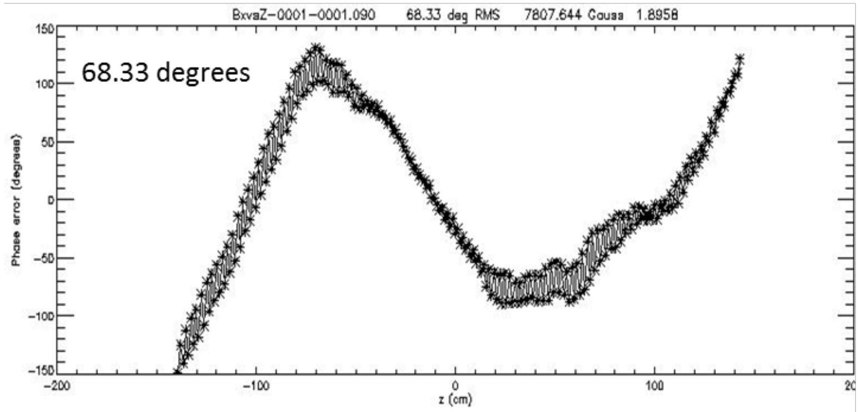


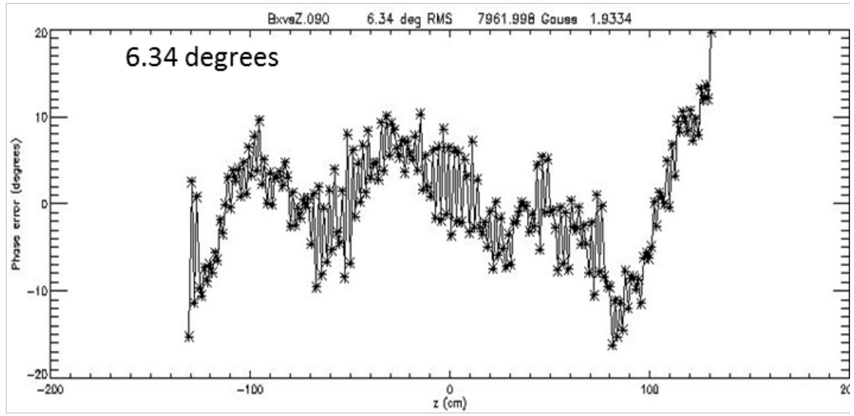
ΔB=400 G

Straightness of trajectory at Gap 9 mm





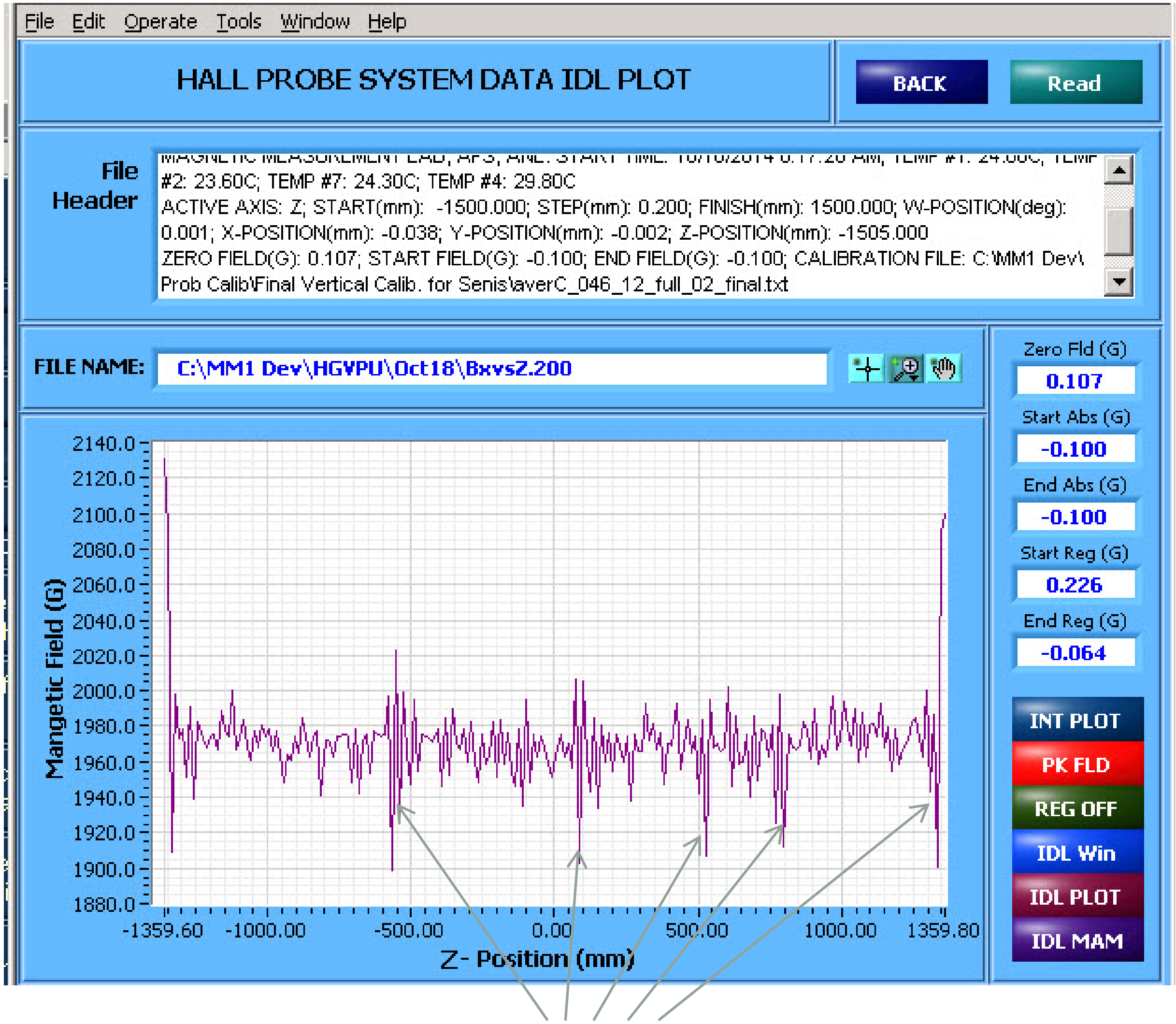




Initial

Final

Peak field vs. Z at gap 20 mm

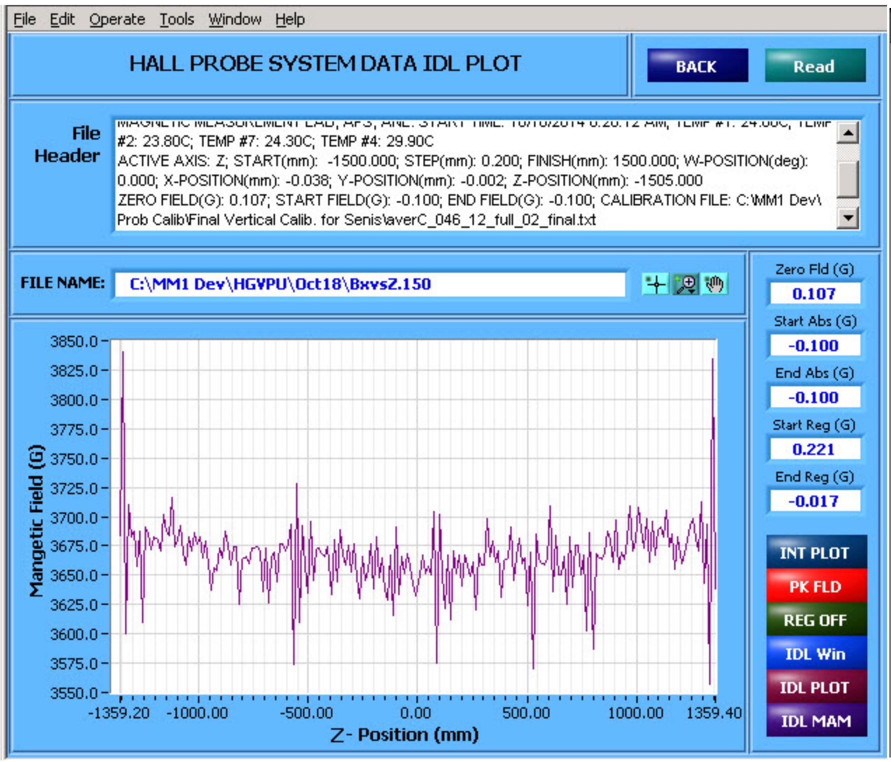


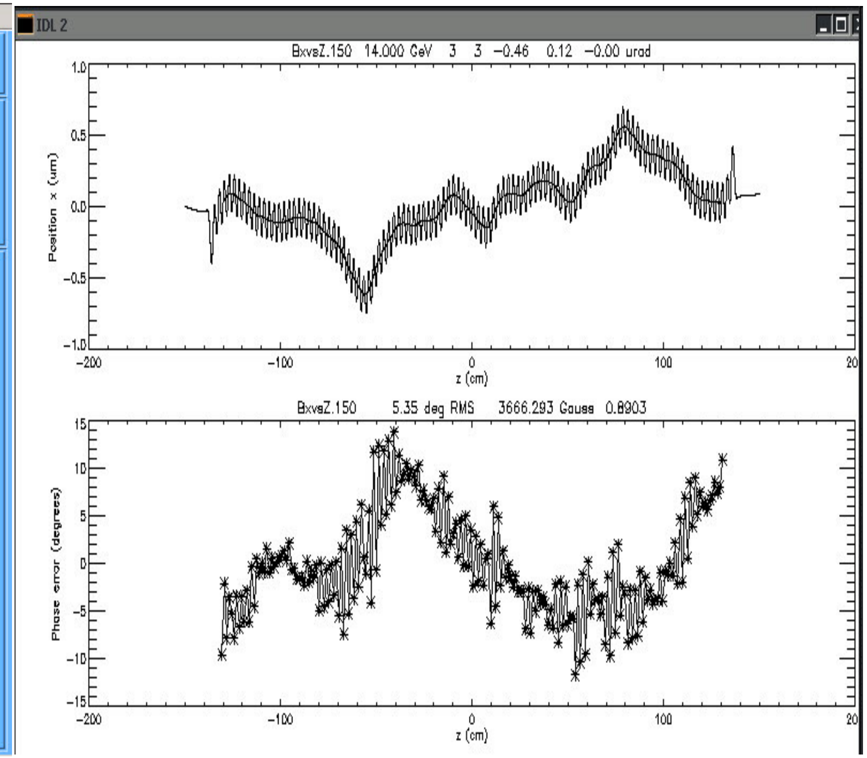
Location of side shims

After alignment with mechanical shims

Gap/field ratio is 4 µm/G

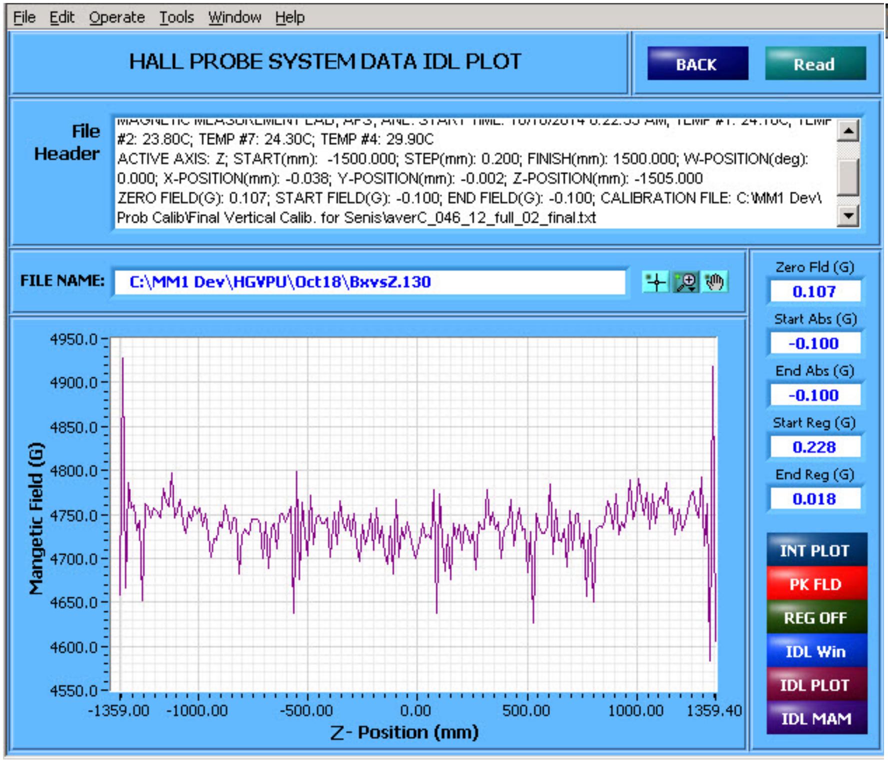
Gap 15 mm. magnetic force > spring force

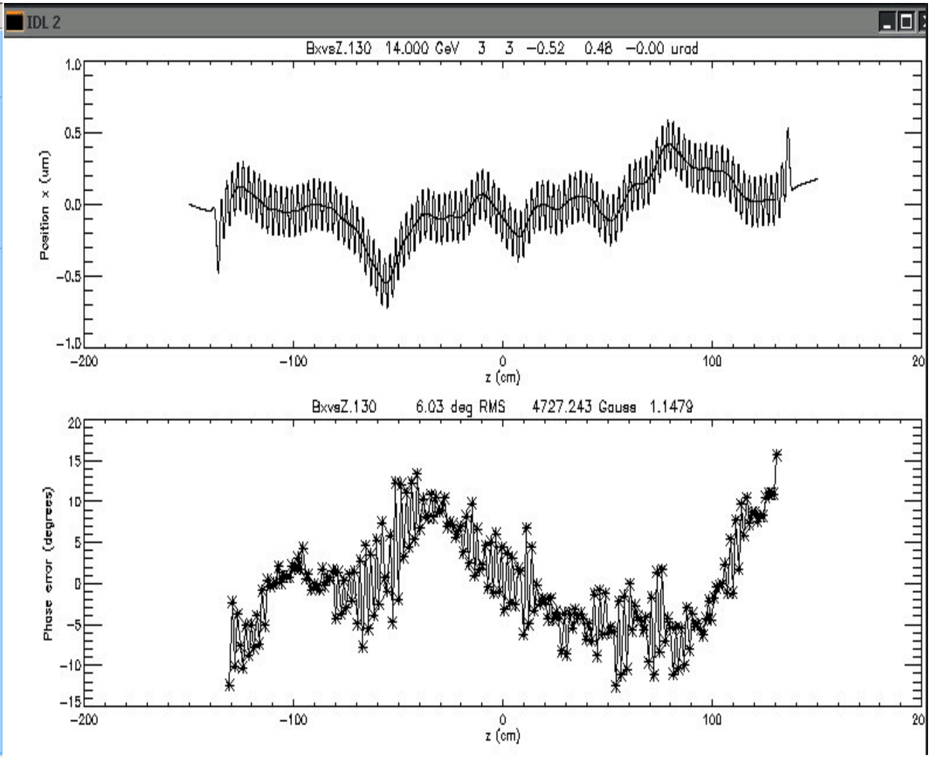




Parabolic taper. Device is still sensitive to errors in matching of magnetic force by springs.

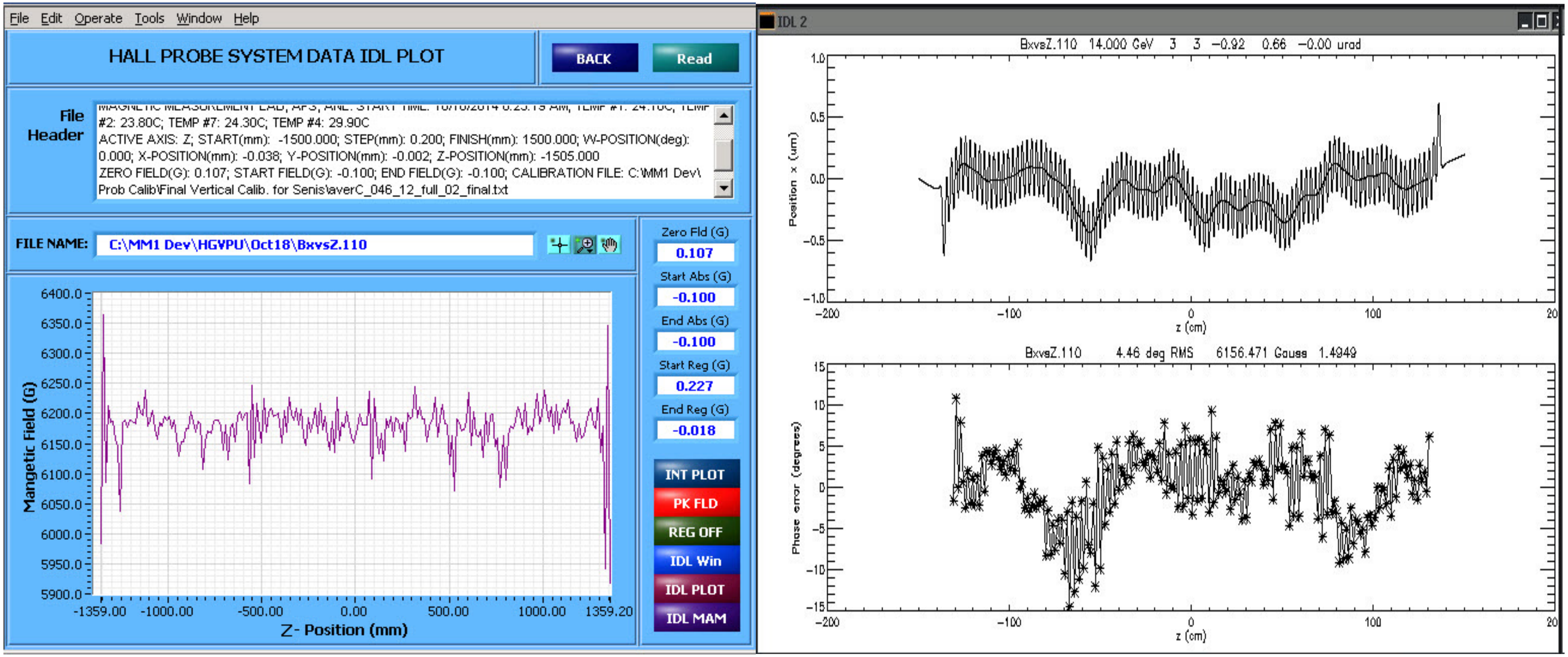
Gap 13 mm. magnetic force > spring force





Gap in the middle larger than at the ends. Parabolic taper.

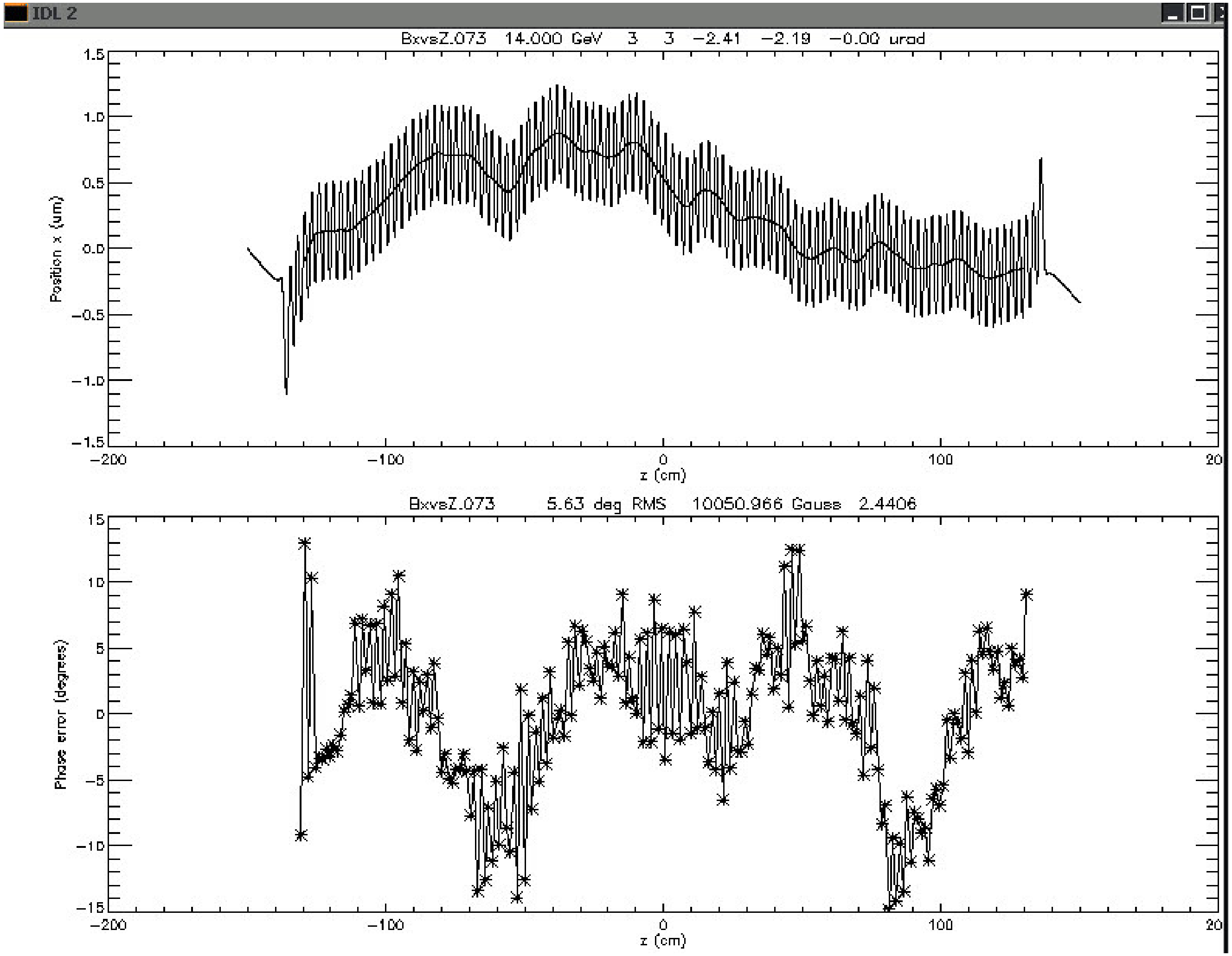
Gap 11 mm. Local distortions



Tuning with springs was done at this gap. No taper.

Local distortions only. RMS phase errors 4.46 deg.

Gap 7.2 mm. Local distortions



RMS phase errors 5.6 deg.

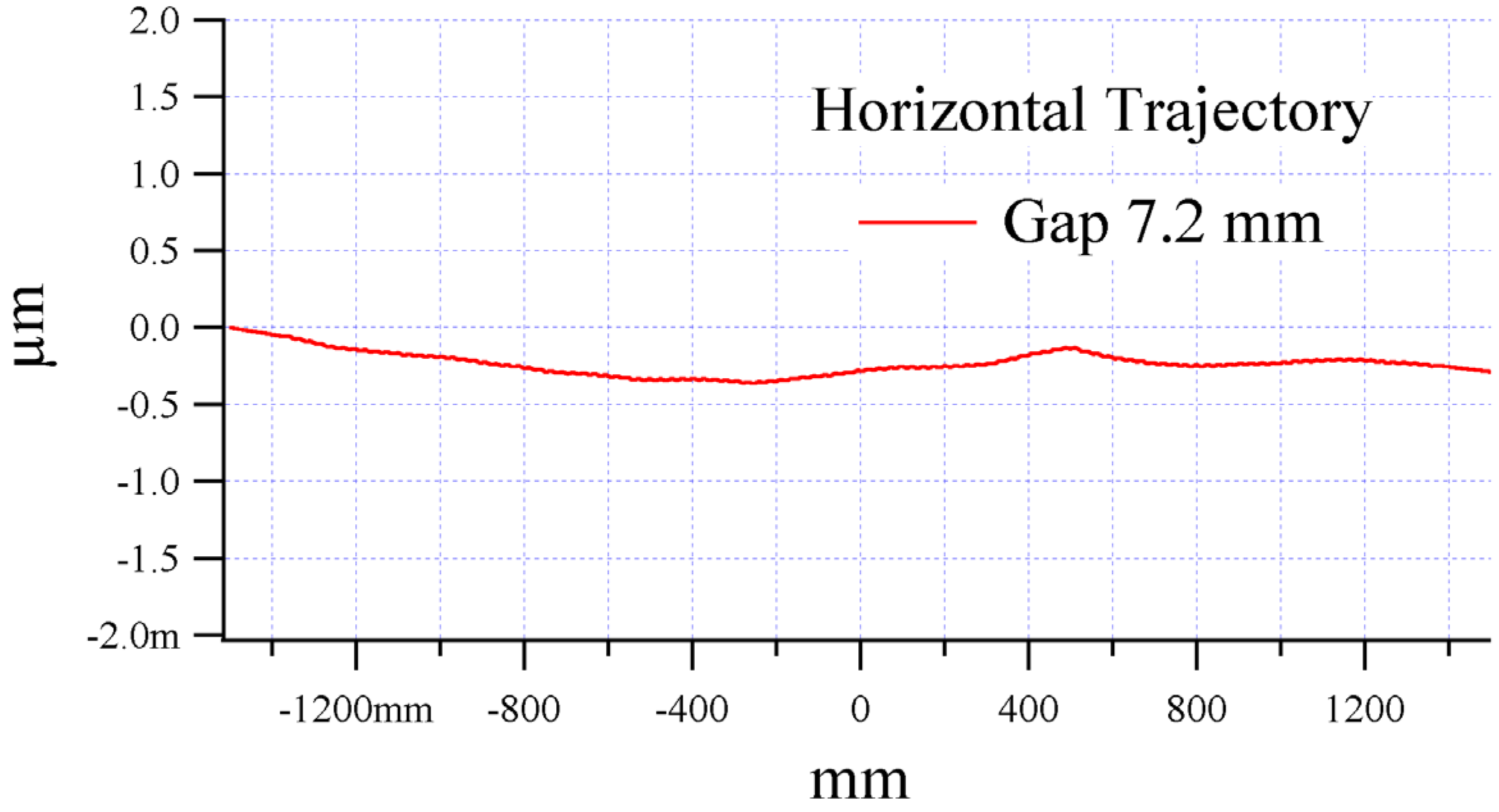
Discussion

- Bow was corrected by mechanical shimming at gap 20 mm and adjusted at 11 mm by tuning of the springs.
- At gaps less than 11 mm no bow exists, at gaps more than 11 mm up to 15 mm there is a bow.
- Accordingly, the best rms phase error was obtained at 11 mm. At smaller gaps rms increases due to local errors that depend on undulator parameter *K* (see below).
- Main part of the phase errors according to equation below (R. Walker) is decreasing with gap, so sensitivity to the errors is maximum for a small gap:

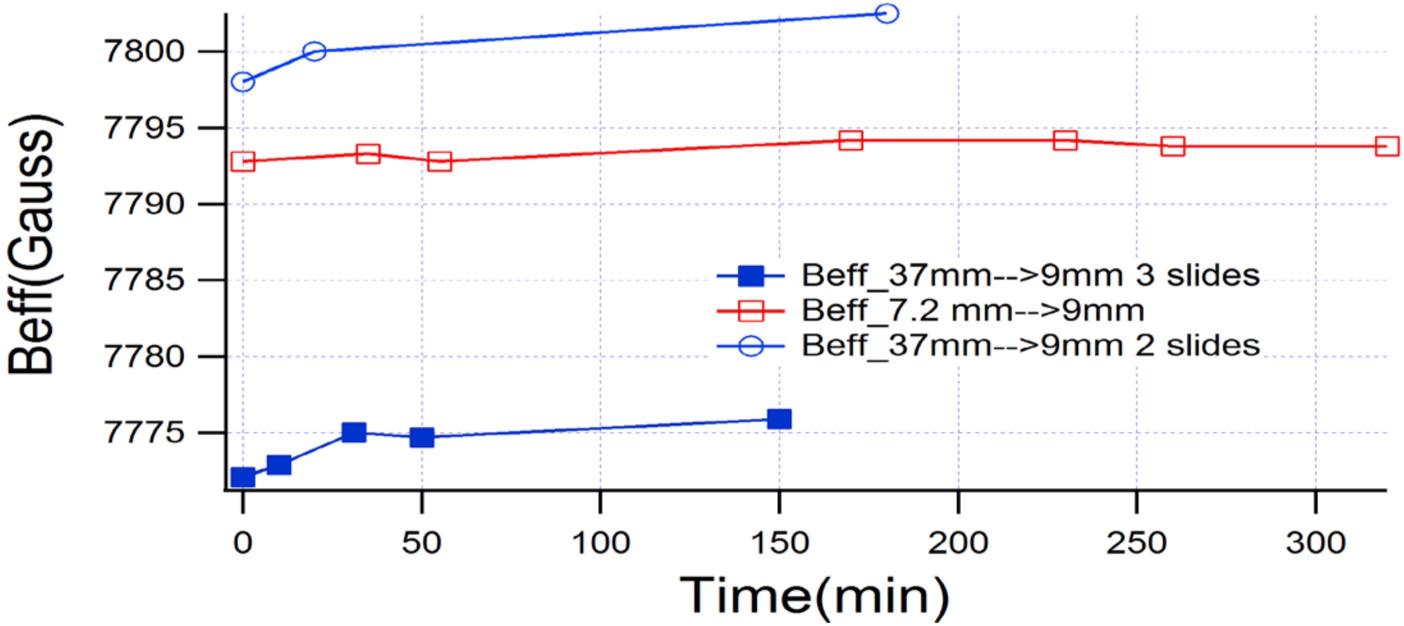
$$\psi_i = -\pi \frac{K^2}{1+K^2/2} * \frac{\pi \Delta g_i}{\lambda_0}$$

here Δg_i *-gap error*

Horizontal Trajectory at 7.2 mm gap



Effective Field Time Dependence



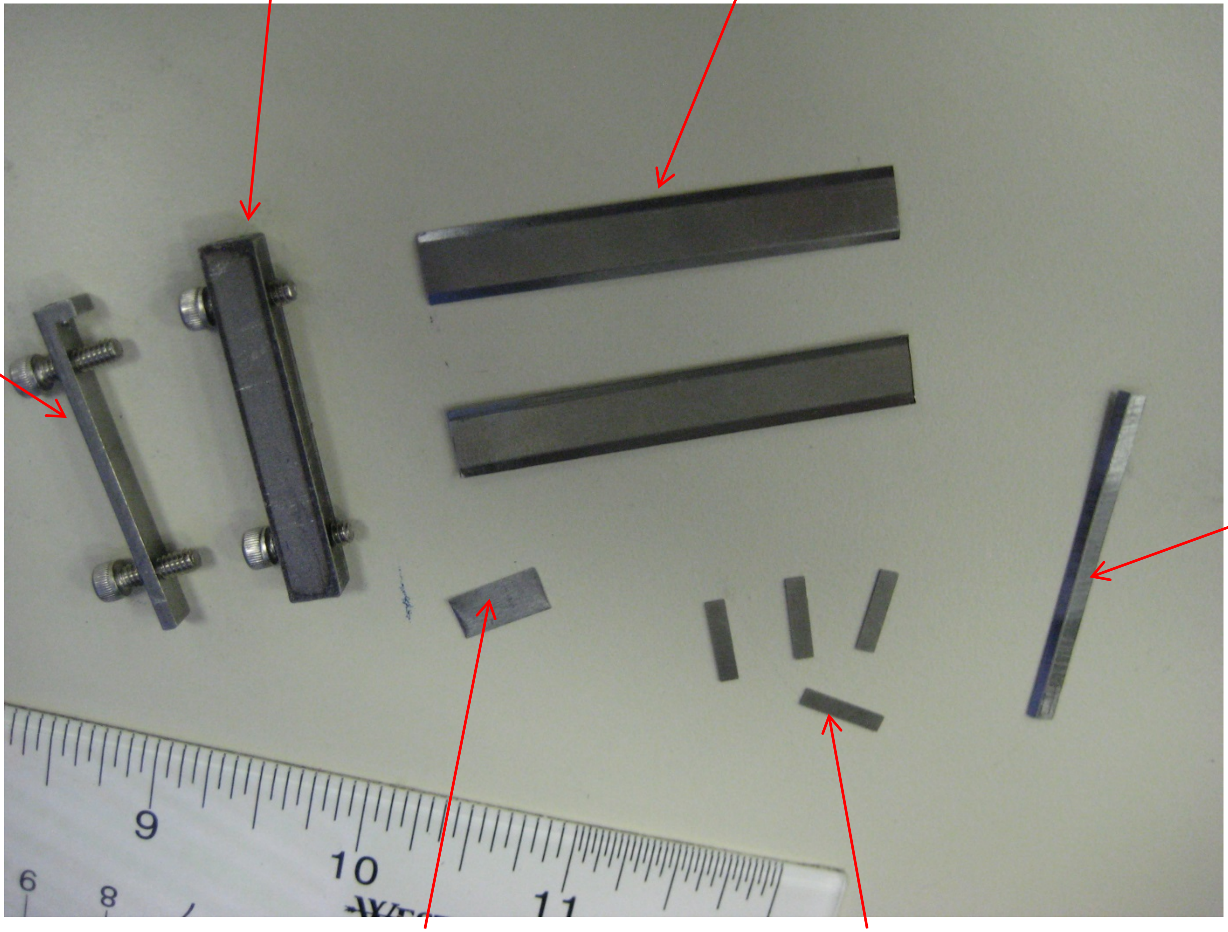
Evidence of friction. Red line: friction released.
Requirements: ± $2.3*10^{-04}*7800$= ±1.8 Gauss

HGVPU magnetic shims

6 mm thick

Phase shims

2 mm
thick

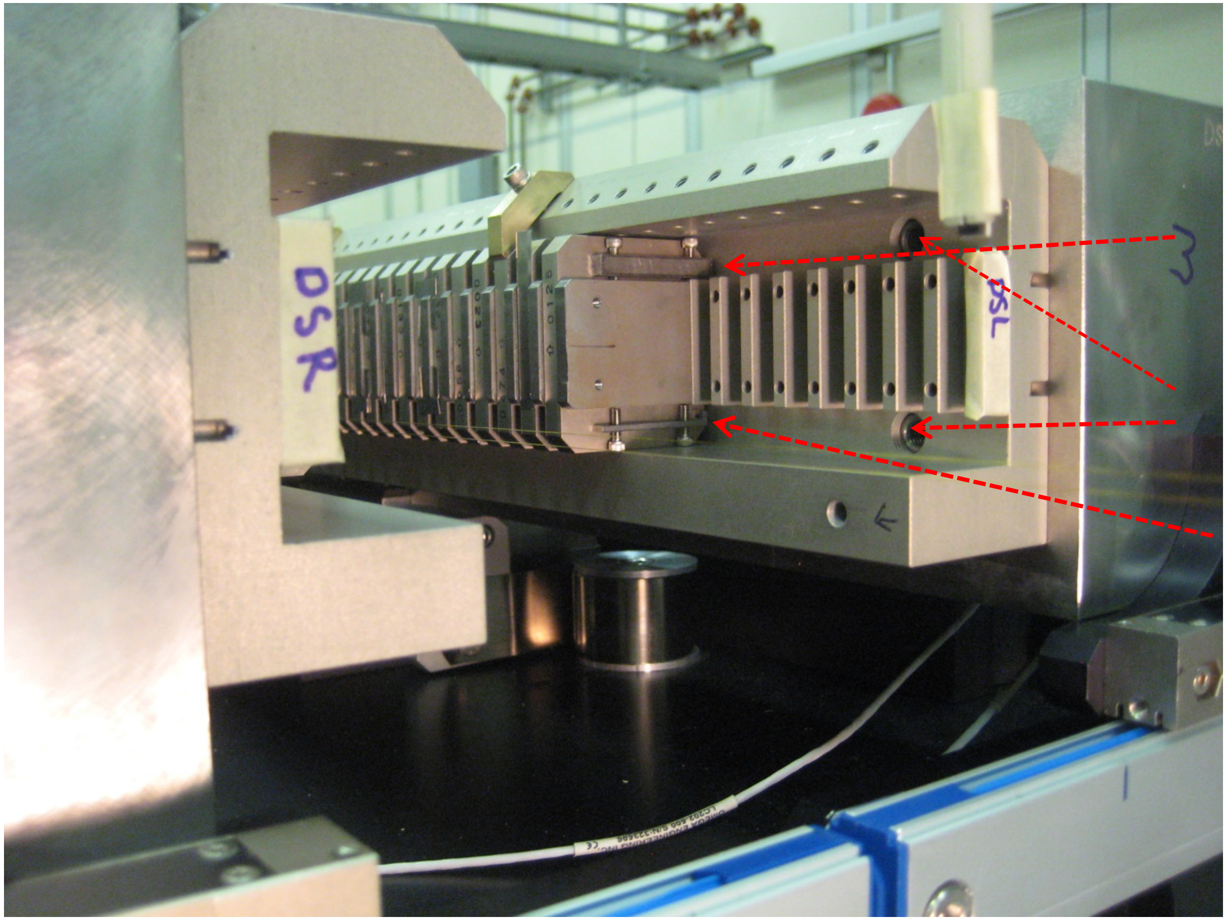


Long
trajectory
shim

Foil

Short trajectory shims

Side shims in place

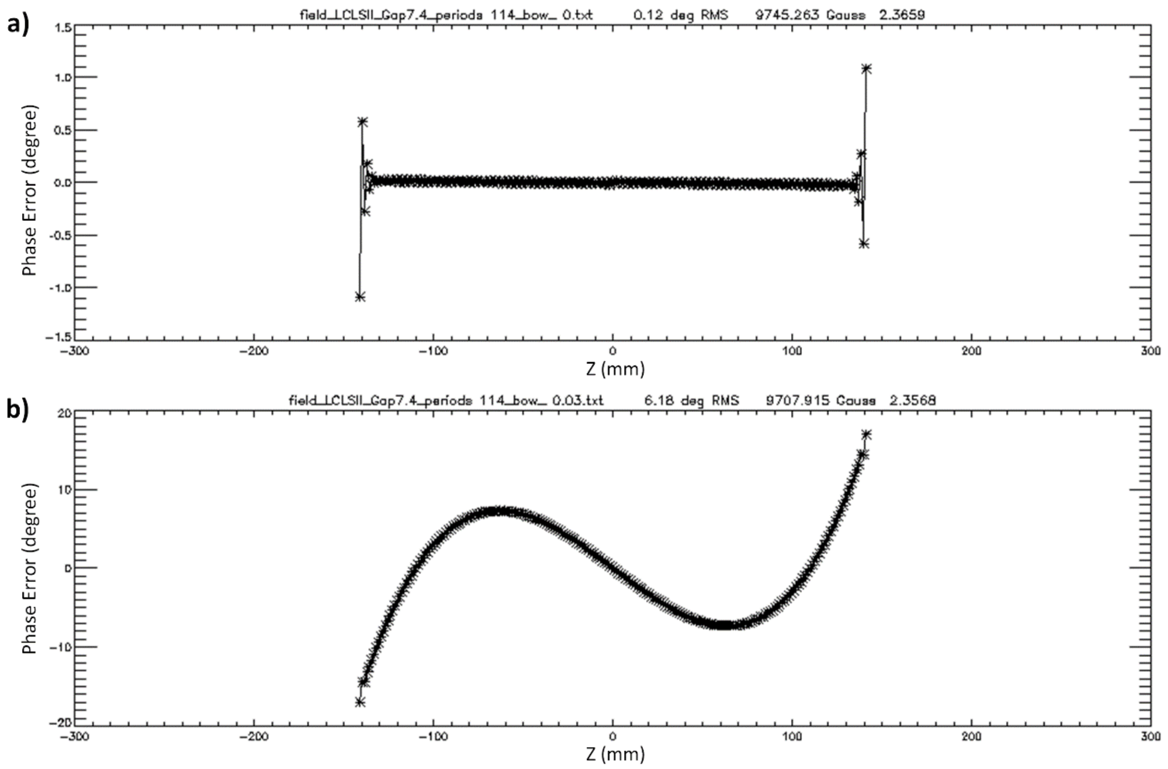


6 mm thick shim

Bolts

2 mm thick shim

RMS Phase Errors



_Roy R Craig Jr., "Mechanics of Materials", John Willey &Sons, 2nd Edition,2000

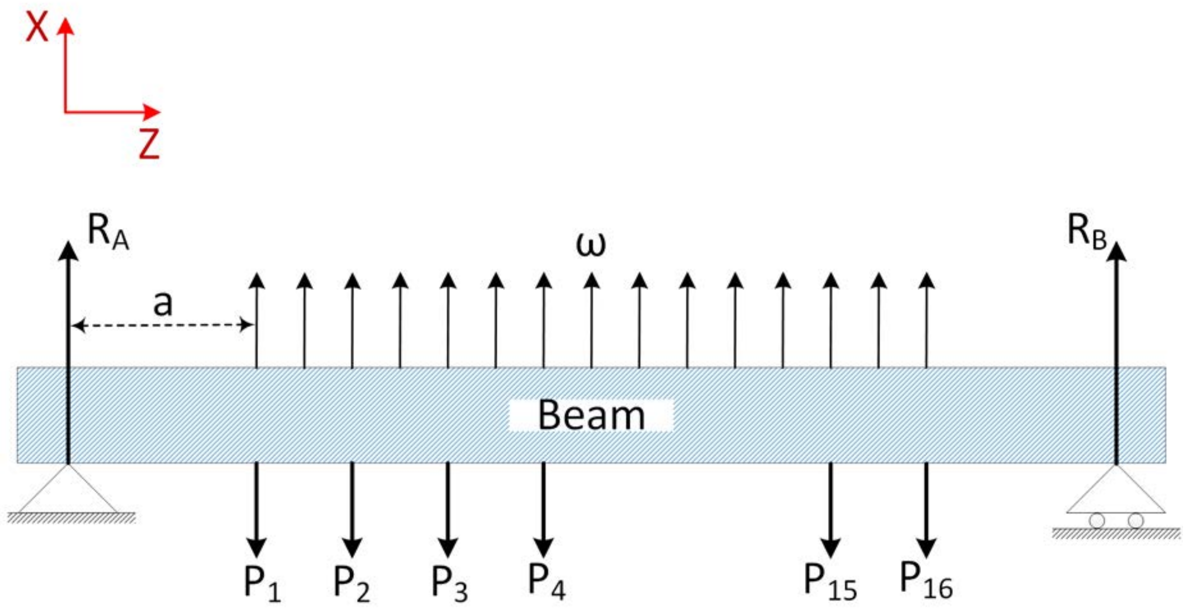
P_i-spring cage forces, w-magnetic distributed force

EI-rigidity

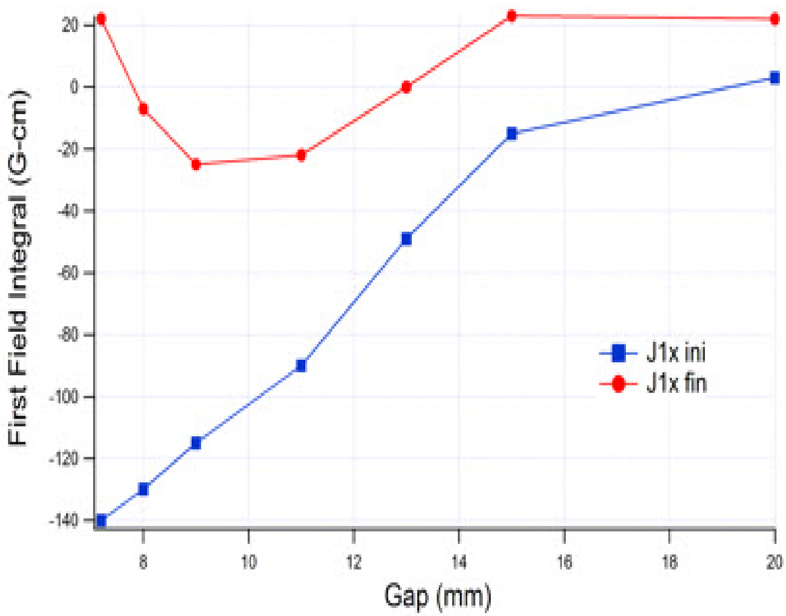
$$\frac{d^2x}{dz^2} = \frac{1}{EI}\left[R_A z - \frac{\omega(z-a)^2}{2} + \sum (z - z_i) P_i U(z - z_i)\right]$$

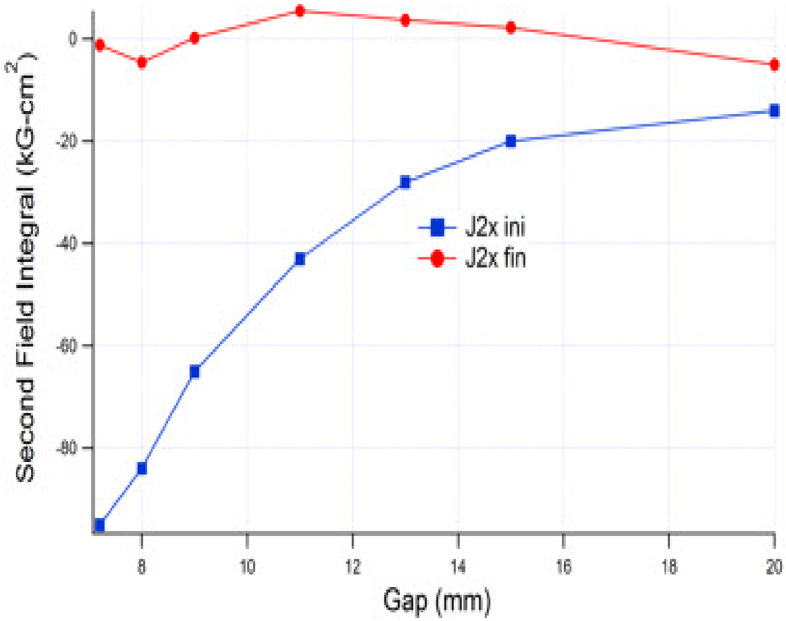
Top: 0 bow, 0.25º, bottom 30 µm bow, 6.2º

Beam deflection 1D case



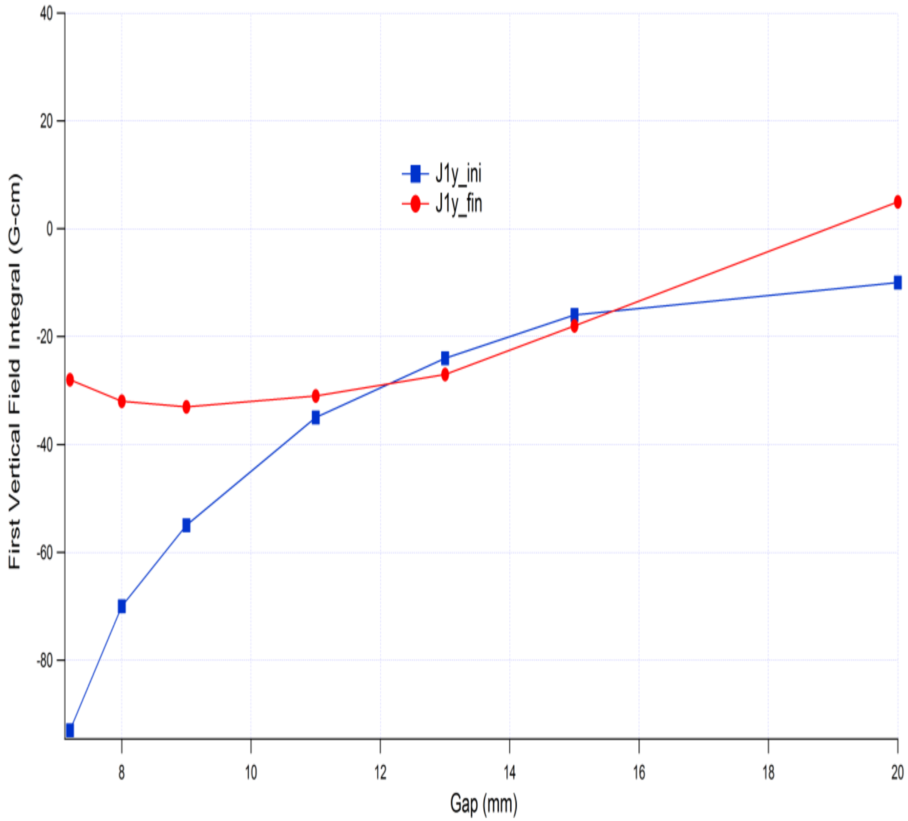
First and second Horizontal Field Integrals vs. Gap



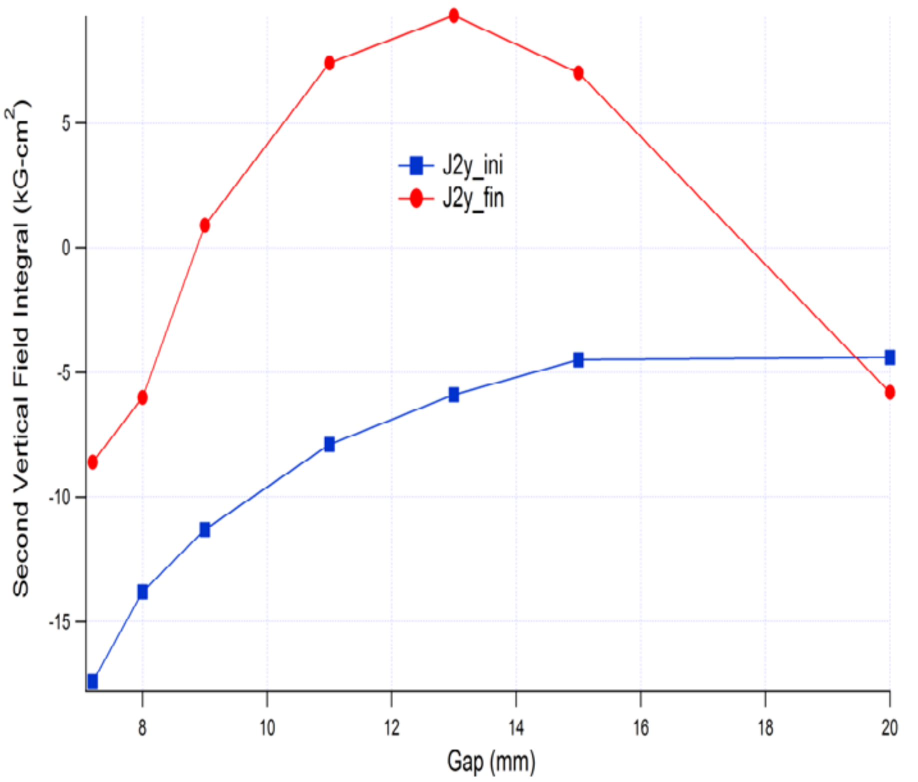


Vertical Field Integrals tuning

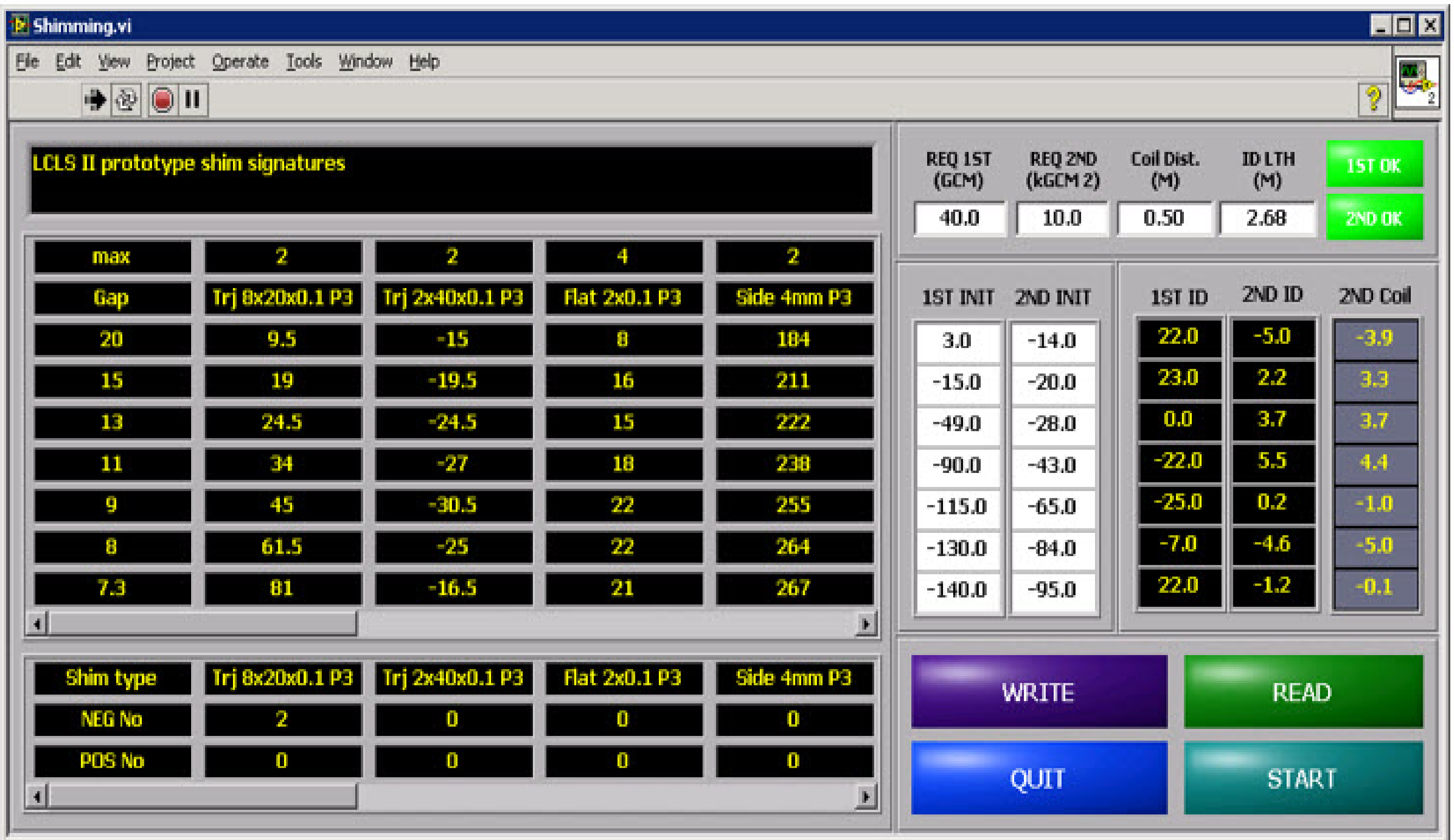
First Field Integral



Second Field Integral



Algorithms, the interface

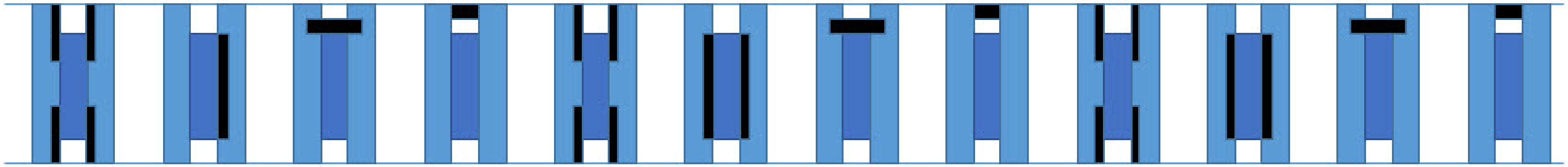


Tuning procedure

- Figure at slide 28 shows the interface of the algorithms. Clicking the READ button reads the magnetic shim signature (change of the 1^{st} field integral) file as shown in slide 30. Users have to enter the 1^{st} integral requirement in G-cm, the 2^{nd} integral requirement in kG-cm^2, as well as the measured 1^{st} and 2^{nd} initial integral values for each gap of interest.
- Click the START button and the system calculates all the combinations starting with the 2^{nd} integrals. If the 2nd integral requirement can be met, the 2nd indicator turns from red NA to green OK. It then moves on to the 1^{st} integral calculation. If the 1st integral requirement can be met, the 1st indicator turns from red NA to green OK.

READ the shim types and signatures

/*												
LCLS II prototype shim signatures												
*/												
max	2	2	4	2	2	2	4	4	2	2	4	4
Gap	Trj 8x20x0.1 P3	Trj 2x40x0.1 in P3	Flat 2x0.1 P3	Side 4mm P3	Trj 8x20x0.1 P4	Trj 4x40x0.1 P4	Flat 2x0.1 P4	Side 4mm P4	Trj 8x20x0.1 P5	Trj 4x40x0.1 P5	Flat 2x0.1 P5	Side 4mm P5
20	9.5	-15	8	184	-10.5	24	-13	-195	7.5	-30	8	196
15	19	-19.5	16	211	-29	14	-17	-223	21	-26	13	227
13	24.5	-24.5	15	222	-42	5	-23	-232	30	-24.5	13	234
11	34	-27	18	238	-55	1.5	-22	-241	48	-15	19	236
9	45	-30.5	22	255	-72	-4	-23	-252	66	-8	20	239
8	61.5	-25	22	264	-79.5	-8	-23	-257	74.5	-4	20	241
7.3	81	-16.5	21	267	-86	-8	-24	-258	81	-2	20	245



Effective Field and Phase error Gap Dependence

Gap (mm)	RMS phase error	B effective (T)
7.2	5.63	10051
8.0	5.78	9145
9.0	6.34	7962
11.0	4.46	6156
13.0	6.03	4727
15.0	5.35	3666
20.0	2.99	1983

Discussion

- 15 kG-cm^2 second field integral and 40 G-cm of $J1_x$ requirements were satisfied during this tuning.
- Initial tuning was done with step by step shimming. After implementation of the algorithm for automation, all procedures require ~1-2 day.
- Main challenge is phase errors. It is possible to satisfy the requirements for only one particular gap for this device due to gap dependent bow.

Conclusion

- Magnetic measurements and tuning revealed issues that have to be addressed during design of next full length prototype:
  1. Deflection of strong backs. Proper location of actuators, putting actuators and slides on the same axis will help.
  2. Deflection of magnetic structure base.
  3. More reliable design of spring cages setup providing easier tuning during installation and providing the same conditions during calibration and operation to avoid mismatch of the spring and magnetic force.
  4. Most critical issue is effective field long time stability.
- Even in recent conditions it is possible to tune device very close to specifications.

Conclusion (cont).

- 3.4-m-prototype design, which takes into account all the lessons learned, is ready, and fabrication is on the way. This prototype has to be measured and tuned by August, 2015.