Constructing a permanent magnet phase shifter

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Abstract

A permanent-magnet (PM) phase shifter has been constructed for tandem elliptically polarizing undulators (EPU) at the TPS. To increase the magnetic field reproducibility and to allow installation in a limited space, a robust mechanical structure is desired. To decrease multipole errors and optimize the magnetic field, algorithms for magnet sorting were used and magnetic field shimming was done. The start-to-end construction of a PM phase shifter will be discussed and explained in detail.

Introduction

- A phase matching radiation between segmented undulators by a phase shifter is then required to provide a tunable phase delay between electrons and photons.
- A chicane can serve as a phase shifter for the electron beam, by changing the excitation current in electro magnets (EM) or by varying the gap in a permanent magnet device (PM).
- The electro magnet (EM) type has the advantage of a high switching rate capability, it needs more space and has more extended fringe fields than a PM type, leading to crosstalk effects with nearby magnets. The crosstalk can perturb the existing lattice and requires extra efforts for correction which convinced us to the construction of a PM-type device.
- The PM-type is of an anti-symmetric design instead of being symmetric so that the first field integral is inherently zero and only correction of the second field integral is required. To reduce the fringe fields, a termination with vertical end poles and displacement free are implemented.
- The linear motion of the magnetic blocks can be driven by a step motors through the two-way ball screw and linear guide so as to keep the mechanical center unchanged. The gap of the phase shifter is adjustable between 20 and 130 mm.

Mechanical Consideration And Verification

- The gap tolerances for the permanent magnet phase shifter need to be controlled within 5 μm to meet the requirements of magnetic field quality, available space and ease of installation.
- A C-shaped frame support and a two-way ball screw design were the main design features for this phase shifter.
- The assembly of the permanent magnet phase shifter including vacuum chamber is shown in Fig.1.
- To minimize the deformation of mechanical parts, the magnetic force is calculated as a function of the magnetic field with Radia [12] and the results are shown in Fig. 2.
- Figure 3 shows the simulation results for the deformation of the magnetic frame at a gap of 20 mm (Maximum magnetic strength 420 N), indicating a maximum deformation of 4.885 mm.
- Figure 4 shows a special fixture that was developed to define the mechanical center by the CMM.
- The influence of the magnetic forces in the Z direction becomes evident from Fig. 5. The maximum deformation occurs at a gap of 20 mm due to the magnetic force being larger than the weight of the lower frame, which leads to a back-lash of the ball screw at a gap smaller than 30 mm and where the magnetic force increases to 420N at a gap of 20 mm.
- In spite of the magnetic forces in the Z direction at a gap of 20 mm, we need to ensure the reproducibility of the C-frame motion. Therefore, gaps between 20 and 40 mm in intervals of 5 mm were checked 5 times and the results are shown in Fig. 6. Parallelisms and reproducibility are within 5 μm.
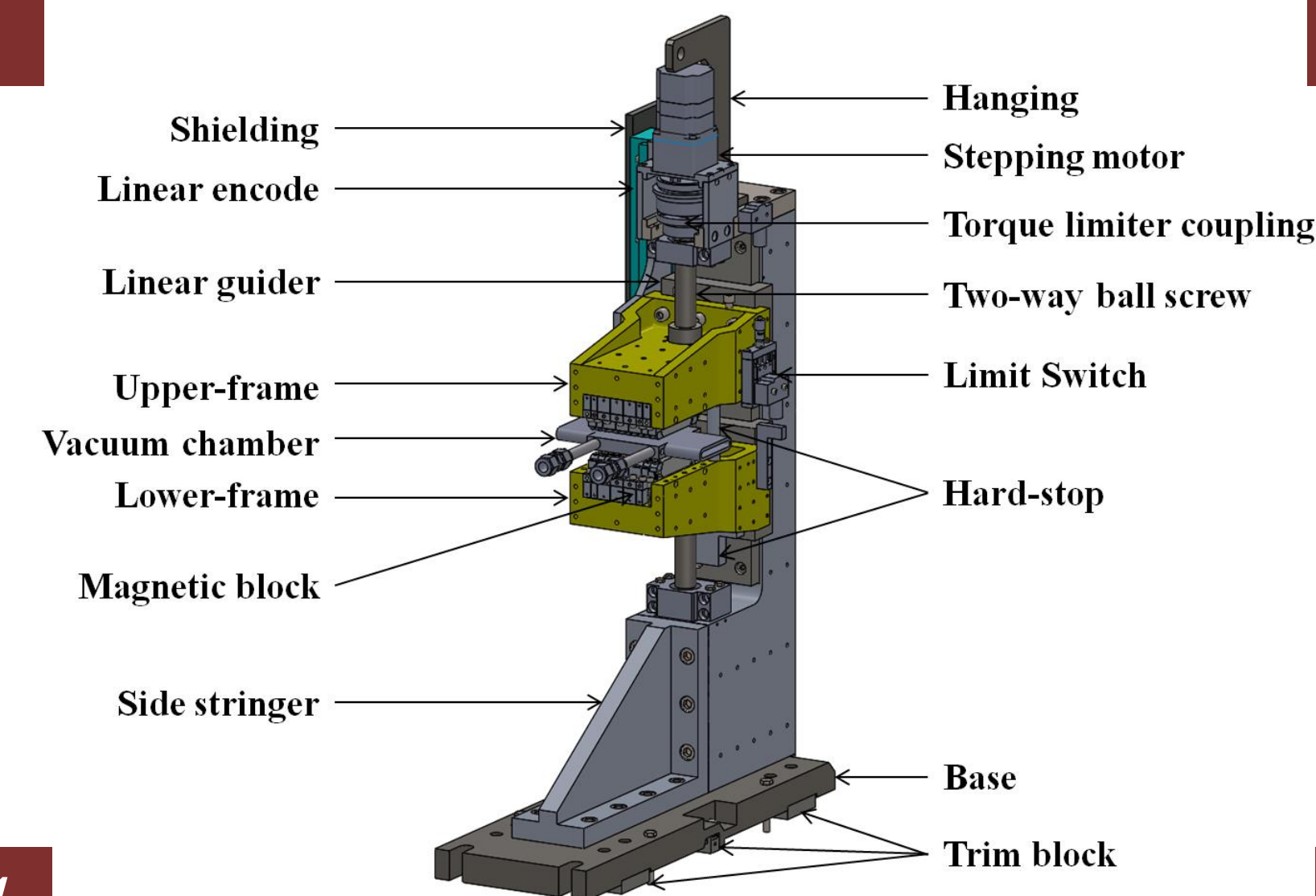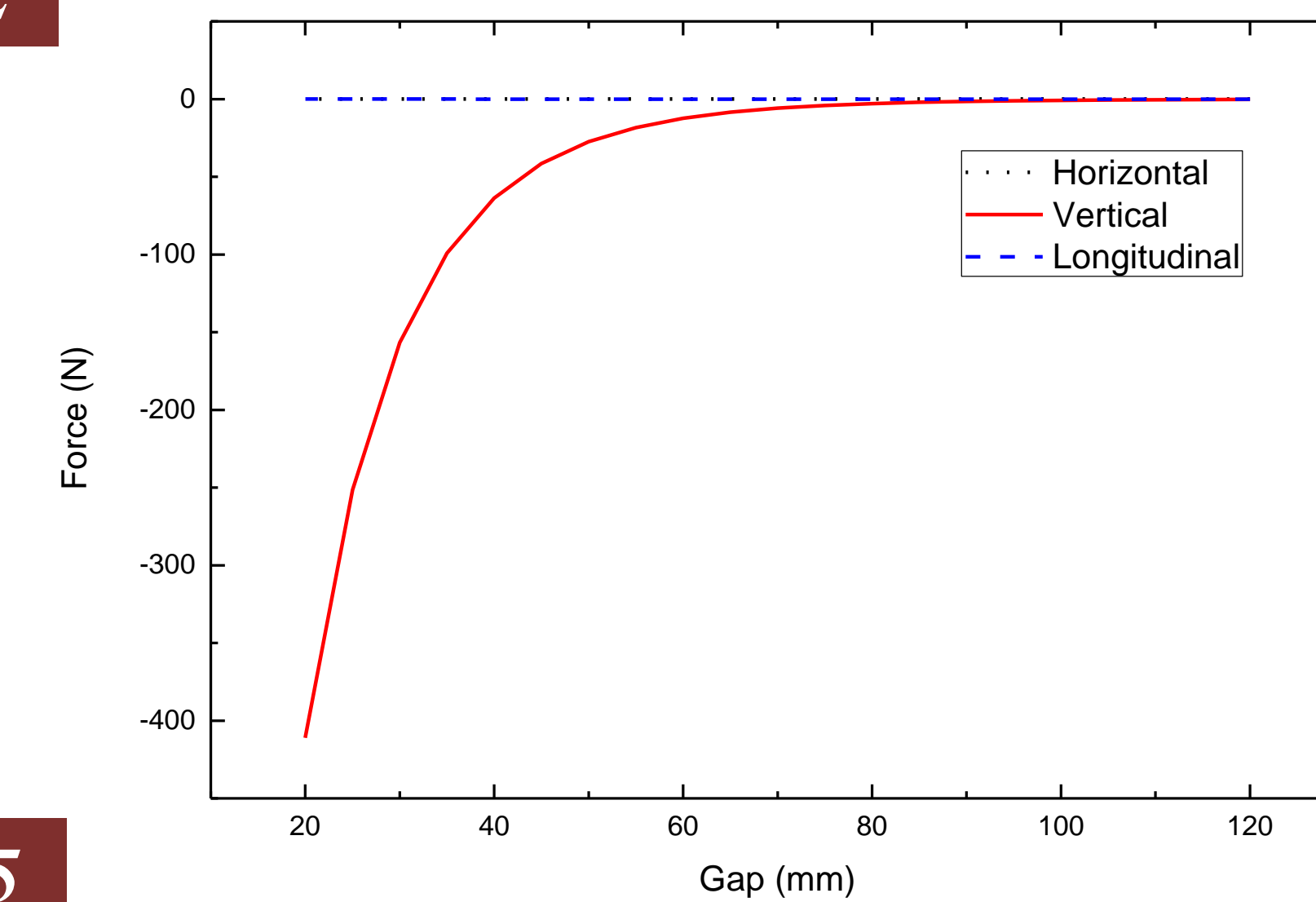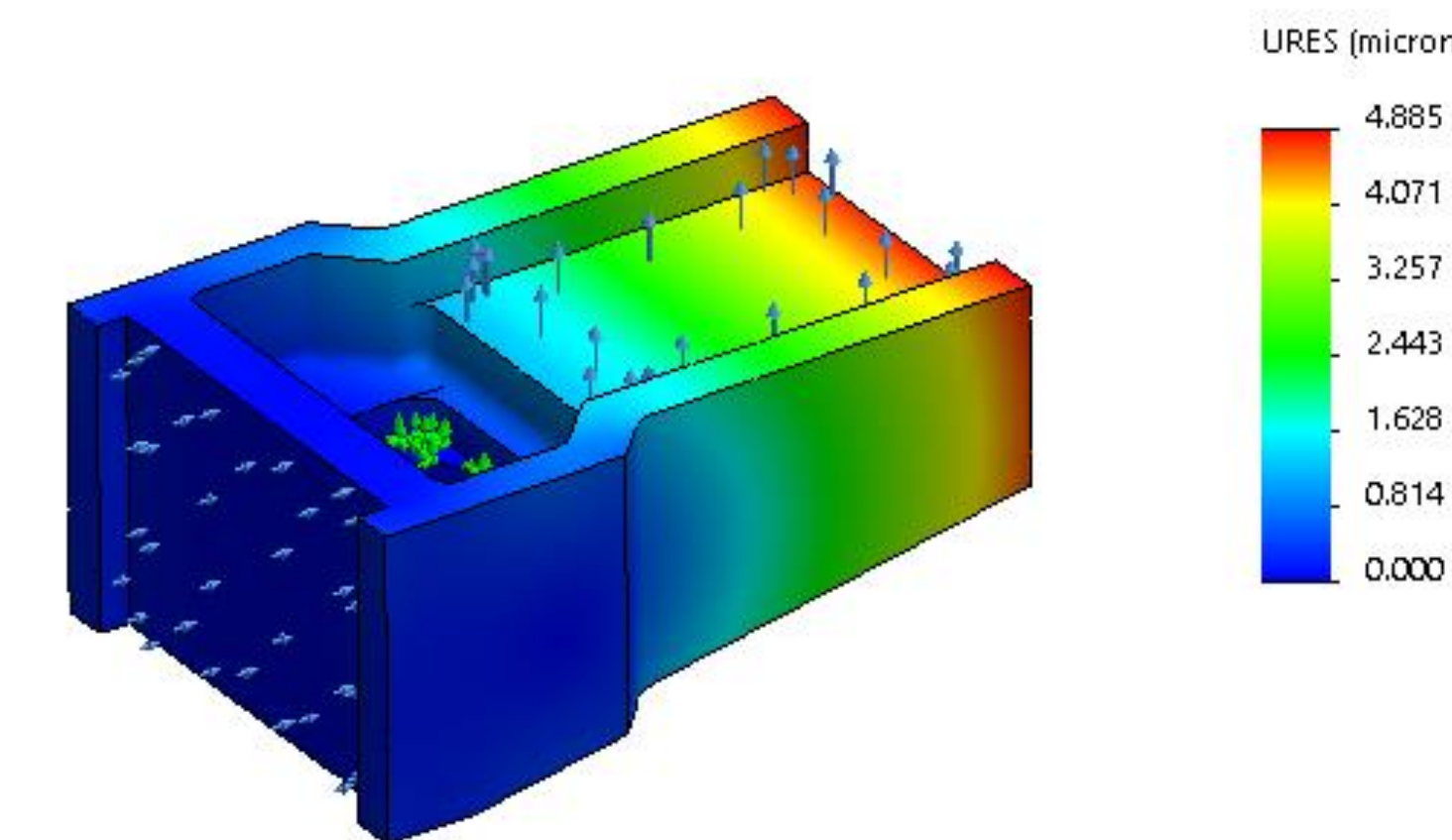
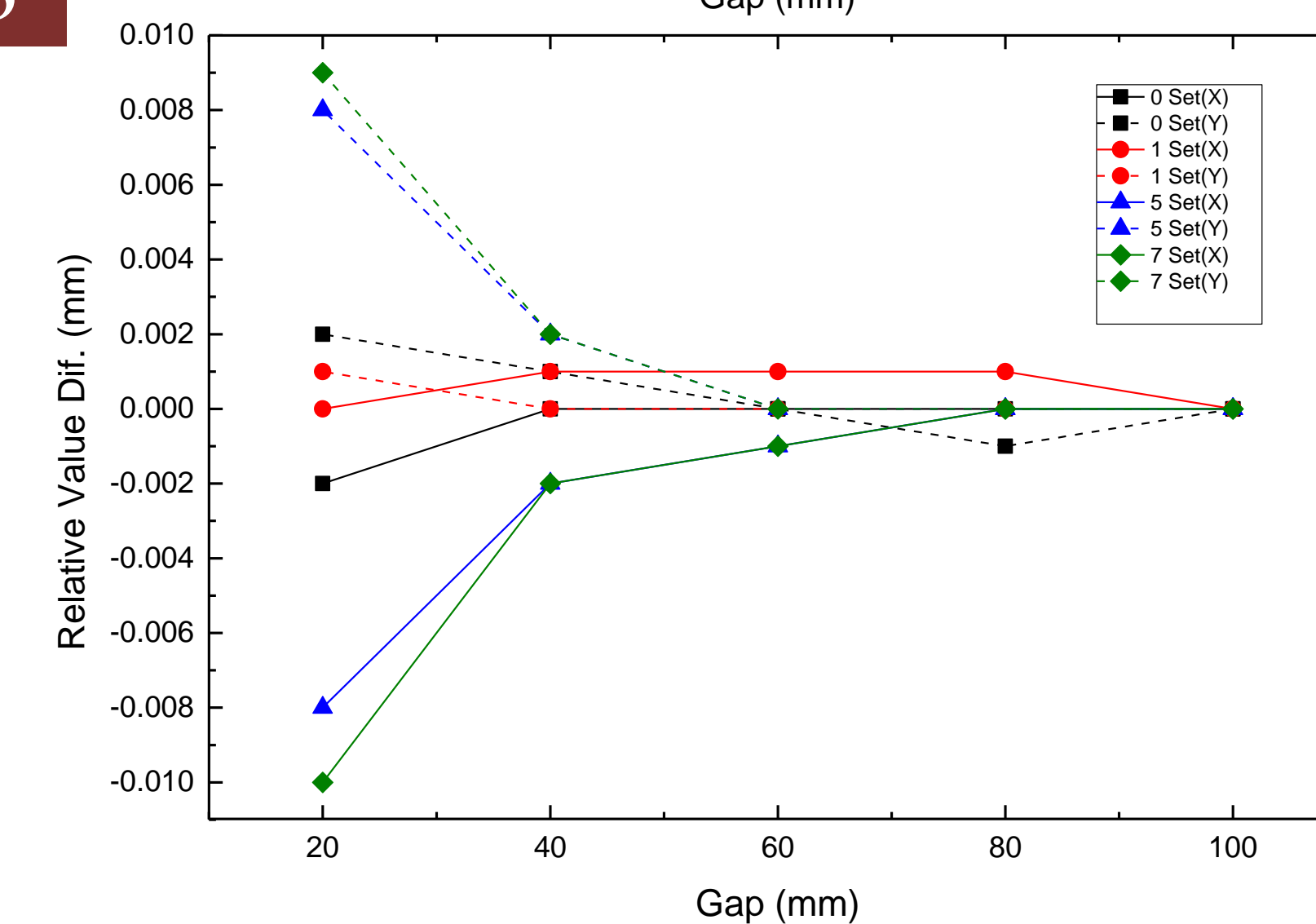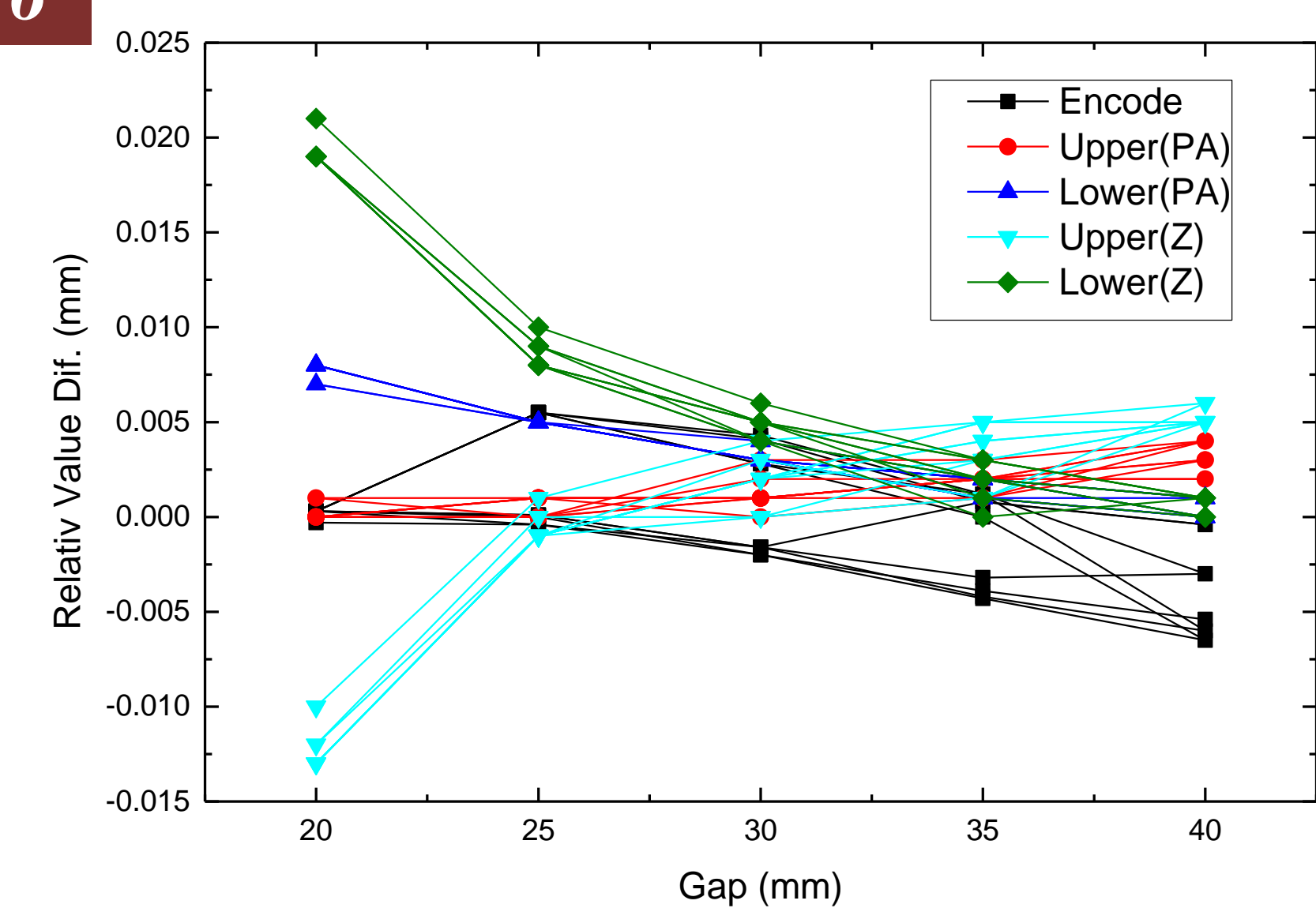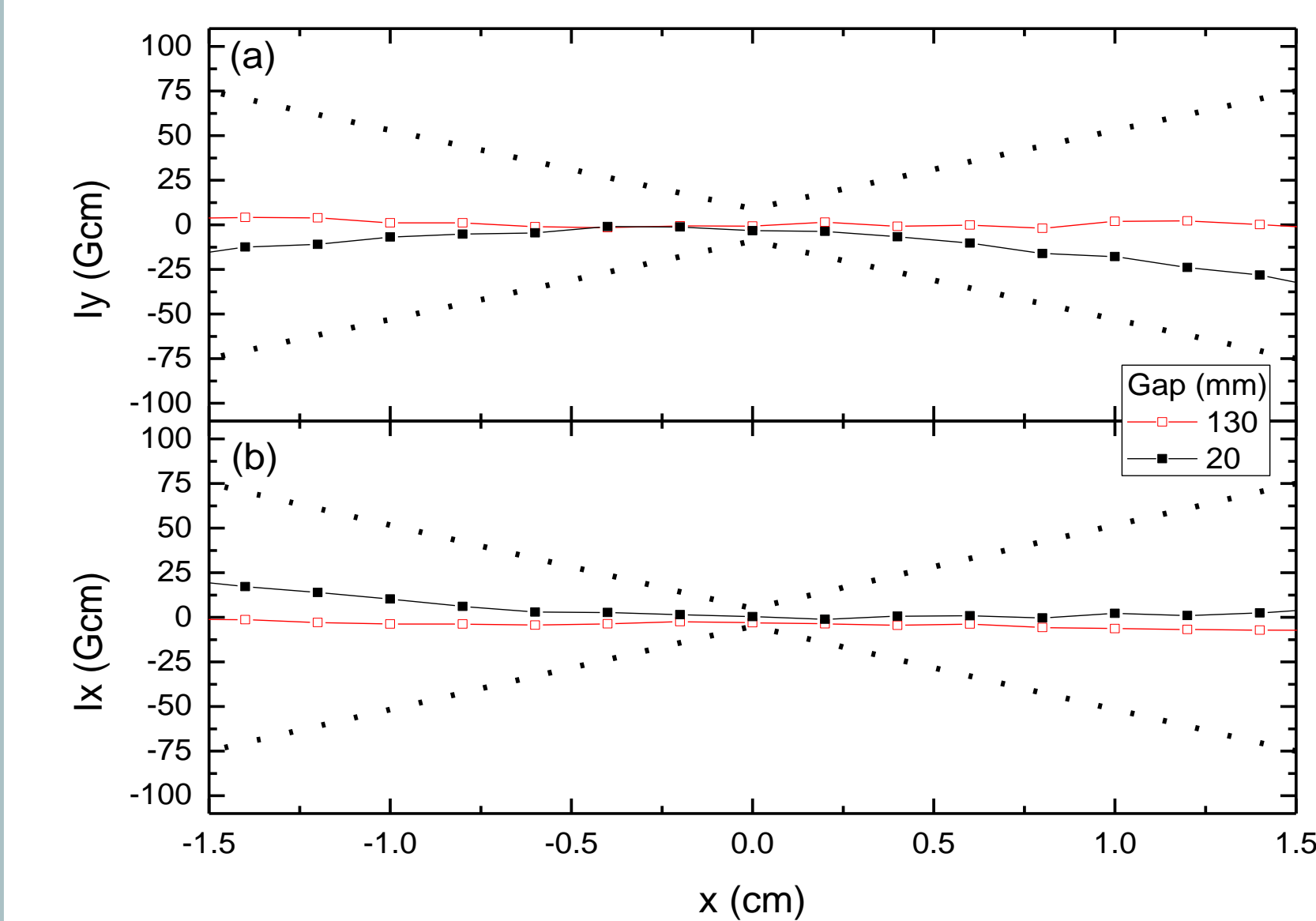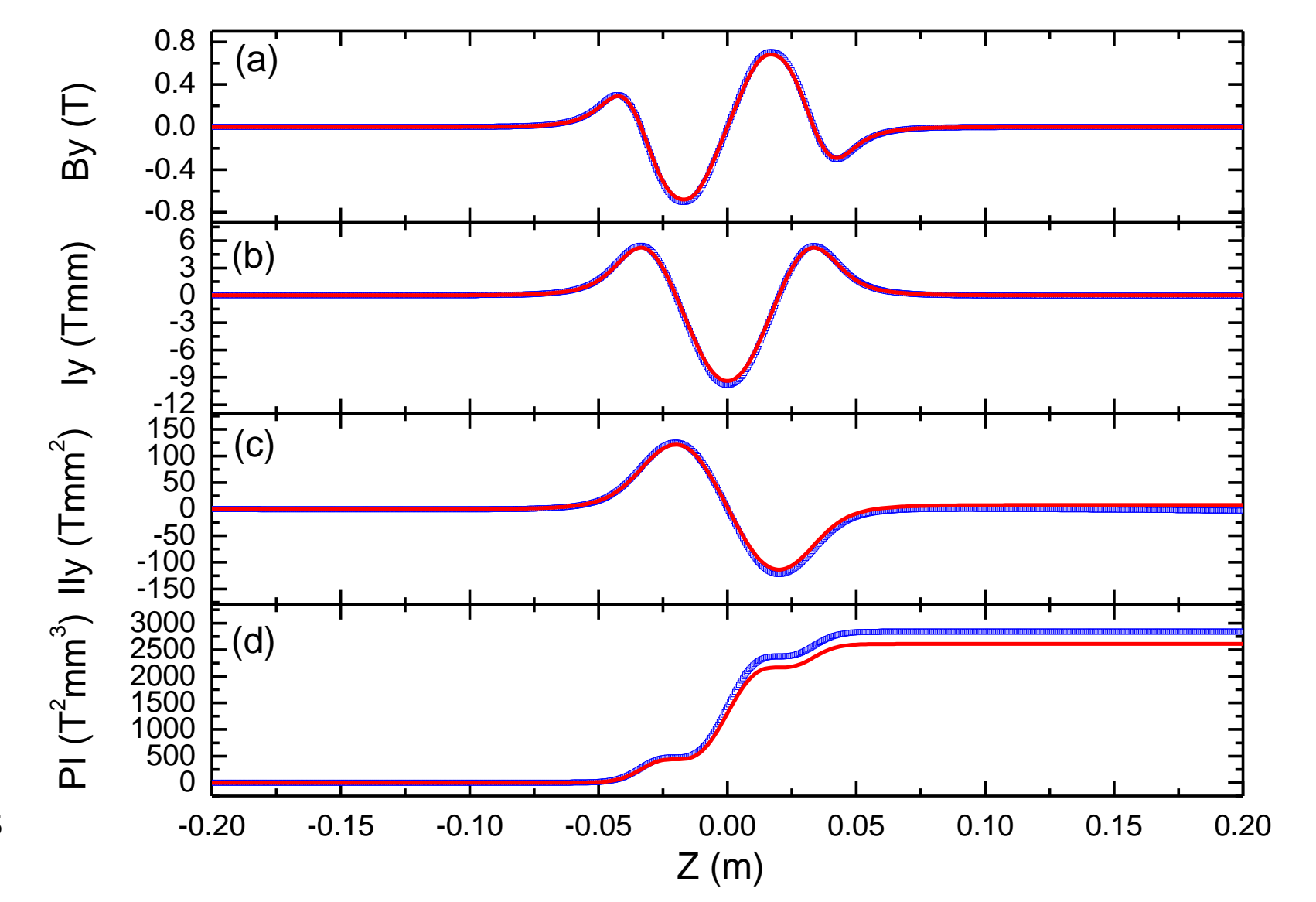## Magnetic Field Optimization

- This note details the construction of a permanent magnet phase shifter in terms of mechanical and magnetic field optimizations.
- According to the linear characteristics of permanent magnets, the field integral of the phase shifter is optimized by the superposition of each magnet.
- With shimming, the performance of the phase shifter is within specifications as demonstrated in Fig. 7 showing the field integrals (Ix) and Iy along the horizontal direction for maximum (130 mm) and minimum (20 mm) gaps. The gap dependence of Iy and Ix on the axis (x=0) were controlled to within 9 Gcm.
- Higher order multipoles are negligible. Even for the observable sextupole error, the value of 10 G/cm^2 is trivial for operation. On-axis magnetic field strengths and phase integrals are shown in Fig. 8, where (a)-(c) show that the measurement results match well with simulations.
- The phase integral is slightly larger than simulation, as seen in Fig. 8 (d), which is attributed to a better grade of remnant fields in the magnets.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

(a) the vertical field integral (b) the horizontal field integral versus the horizontal axis at the gap 130 mm (open symbol) and 20 mm (solid symbol). The dotted line indicates specification.

Figure 8

(a) Antisymmetric profile of the magnetic field. (b) First field integral (*Iy*). (c) Second field integral (*IIy*). (d) Phase integral (PI).

Conclusion

- This note details the construction of a permanent magnet phase shifter in terms of mechanical and magnetic field optimizations. The phase shifter was installed and commissioned in the TPS storage ring.
- There are negligible effects on the ring operation which is consistent with measurement results and proves the desired performance. Commissioning with the beam line will be done during this year.
- To further improve the robustness of the mechanical structure against magnetic forces at small gaps, a spring system on the phase shifter will be designed as a next project.