FIRST RESULTS OF THE PAL-XFEL PROTOTYPE UNDULATOR MEASUREMENTS

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Abstract

Pohang Accelerator Laboratory (PAL) is developing 10 GeV, 0.1 nm SASE based FEL for high power, short pulse X-ray coherent photon sources named PAL-XFEL. At the first stage PAL-XFEL needs two undulator lines for photon source. PAL is developing undulator magnetic structure based on EU-XFEL design. The hard X-ray undulator features 7.2 mm min magnetic gap with 24.4mm magnetic period, and 5.0 m magnetic length with maximum effective magnetic field larger than 0.908 T to achieve 0.1nm radiation at 10 GeV electron energy. A prototype for PAL-XFEL Xray undulator line is completed and the preliminary measurement, correction results are summarized.

INTRODUCTION

The Pohang Accelerator Laboratory (PAL) has been developing SASE based light sources since 2011. The key features are 0.1nm class SASE radiation, and 10 GeV class S-band linear accelerator, low emittance (0.5 um) photo cathode RF gun, and EU-XFEL style out vacuum undulator system[1]. There will be 22 undulators for X-ray line and 14 undulators and a few EPUs for polarization control for Soft X-ray line are expected. The major parameters of the X-ray FEL and undulator line are shown in Table 1.

Table 1: Major Parameters of the PAL-XFEL Undulator

Symbol	Unit	Nominal value
E	GeV	10.000
g	mm	7.20
λ_u	mm	24.4
L_{und}	5	5.0
λ_r	nm	0.1000
B_{eff}	Tesla	0.9076
K		2.0683
Optical phase error	degree	< 5
Total number	EA	22

EU-FEL TYPE UNDULATOR

The key features of the EU-XFEL undulator design are an economic design using standardization and optimization suited for mass serial production [2]. The PAL-XFEL undulator is benchmarking the conceptual details of EU-XFEL undulator. It features (a) 4 independent spindle movement for the gap control using easily accessible commercial parts. These 4 motors are electronically synchronized by a control system. (b) strong girder system designed for the worst case magnetic load that can be used for all other cases. (c) unique pole tuning system. The poles can be tuned and locked using tuning studs and notches in the poles. This scheme simplifies the tuning procedure and a big improvement compared to the usual copper shims which are clumsy in nature and tuning range is discrete. With this unique tuning scheme, the supplier can manufacture the undulator meeting the requirements. The detailed tuning and spectrum shimming can be done in house. In this way, the cost can be lowered.

PAL built an undulator based on the EU-XFEL concept with some modification coming from different magnetic properties. The assembled undulator on the measurement bench is shown in Fig. 1. The completed undulator was mechanically tested by installing precision external gap sensor, and comparing the rotary encoder values and the actual gaps. The detailed experiment showed a few 100 um tilting in the mechanical structure while the gap is closed. Some loose tolerances in the assembly is identified and corrections are planned. Fortunately, the mechanical gap movement had a repeatability and it's decided the solve the mechanical glitches after testing the undulator.

Figure 1: HX undulator prototype on the measurement stage.

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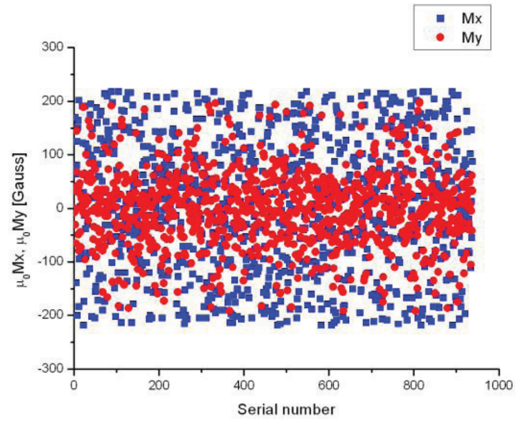

Figure 2: The fluctuation of the transverse components of the blocks measured by Helmholtz coil system.

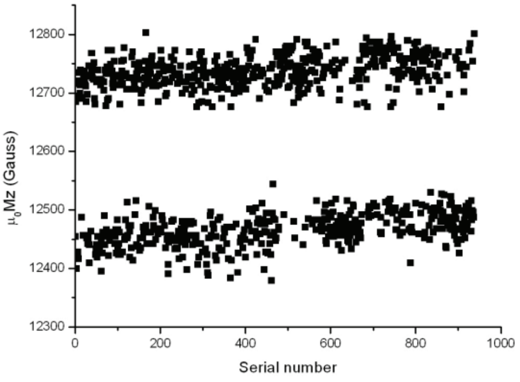

Figure 3: The fluctuation of the main components of the magnet block. A finite offset about 2% between the batches are visible.

MAGNETIC MEASUREMENTS AND CORRECTIONS

All of the magnets blocks used for PAL-XFEL prototype were measured using Helmholtz coil system. The specification for the fluctuation of the main component of the magnetization is ±1%, and the angular error of the magnetization is ±0.5 degree. The dimensional tolerance in the thickness direction is 50 µm, while the tolerance for two other directions are usual 100 µm. The blocks should be coated with non-organic material without using non-electro plating technology. The non-organic requirement comes from the concern for the long term radiation damage, and the requirement for non-electro plating comes from the concern for the edge over-coating which is a issue of the electro plating procedure.

The mechanical tolerances and the coatings were all met the specification. However, the block measurement results are summarized in Fig. 2 (transverse component), and Fig. 3 (main components). Many blocks exceeded the requirements of the transverse components which is ±0.5 degree and translates to ±100 Gauss in $\mu_0 M_{x,y}$. Also, the main components showed big scatter suggesting the supplied blocks. It's found that the blocks consists of two different batches. Due to the schedule restriction, we had to select better blocks for the assembly. The supplier promised to improve the procedure to improve the problems.

A new 7.0 m long measurement bench is ordered to Brucker and we are waiting for the delivery. Until then, the assembled undulator is measured using the existing 5.0 m long measurement bench which was used to characterize insertion devices for PLS-II. Since the scanning length is not enough to fully characterize the undulator, only partial Hall scanning measurements and experiments to acquire the shimming signature, and shimming experiments to improve the orbit and optical phase errors are carried out. Figure 4 shows typical field profile, for clarity only initial part of the profile is displayed. Figure 5 shows the field change for pole shimming,

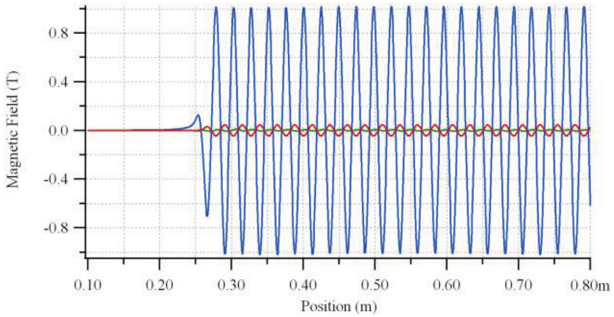

Figure 4: Typical measured B profile of the HXU prototype undulate. Blue lines are By, green lines are Bx, red lines are Bz. Auxiliary components mostly comes from the probe misalignment. For clarity, only partial profile is shown.

Measured and calculated correction signature for 50µm, and 100 µm correction. The residual fluctuation comes from the longitudinal positional error at the cantilever probe position which is about 2.0 um. The solid lines show the calculation from RADIA[3] and shows good agreements. The residual fluctuation comes from the longitudinal positional error at the cantilever probe position which is about 2.0 um. Figure 6 shows the changes in the field integral for 50µm, 100 µm pole height changes. Blue line represents the calculation from RADIA. The calculation results agree very well with the measurements. After acquiring these correction signatures, pole heights were adjusted to straighten the orbit and tune the optical phase errors. The measurement accuracy or repeatability is checked first and it's found that the measurement accuracy is about ±1.5 G in peak field.

After correcting the poles for orbit and the optical phase errors, the orbit is calculated and shown in Figure 7. After correcting the poles for orbit and the optical phase errors, the orbit is calculated and shown in Figure 7. To clearly see the effects of correction, the orbit is corrected only up to 1.8 m and the effects of the shimming to straighten the orbit is obvious.

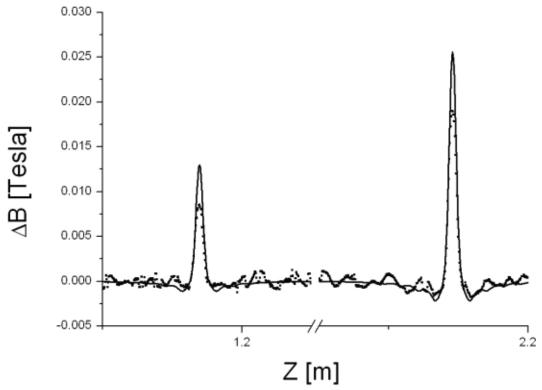

Figure 5: Measured and calculated correction signature for 50um, and 100 um correction. The residual fluctuation comes from the longitudinal positional error at the cantilever probe position which is about 2.0 um.

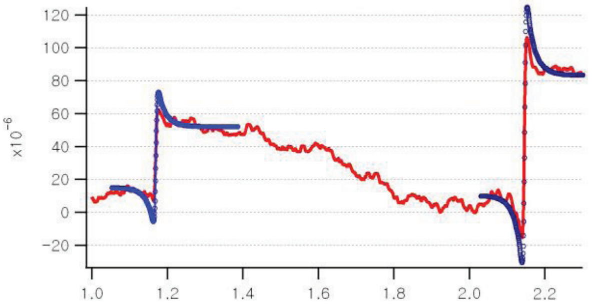

Figure 6. Calculated and measured field integral changes for 50 um, 100um pole corrections.

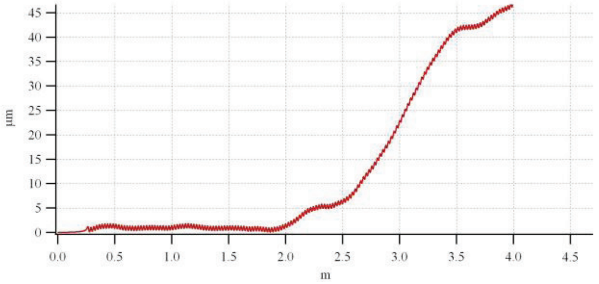

Figure 7: Electron x-orbit based on the magnetic measurements. The undulator is tuned upto 1.8 m to show the effects of the tuning.

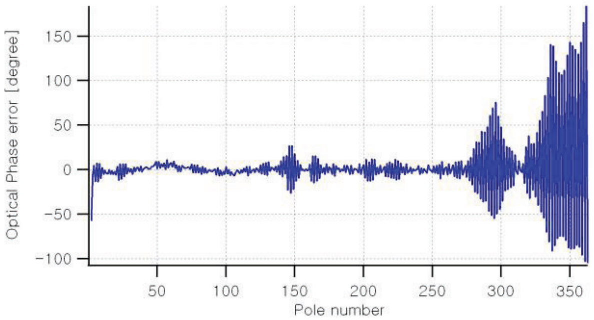

Figure 8: Optical phase errors after partial tuning. The poles are corrected upto 220th poles. The rms optical phase errors for the corrected regions are about 4.5 degree.

Also the optical phase errors are calculated and shown in Fig.8. It is also seen that the optical phase errors for the corrected region is far smaller than the un corrected parts. The rms optical phase errors in the corrected region is 4.5 degree meeting the requirements of 5.0 degree.

SUMMARY

An undulator prototype based on EU-XFEL design modified for PAL-XFEL is built and tested. The delivered magnet blocks were out of specification, and the assembly was done using the delivered blocks to check the tuning scheme. Correction signatures are acquired and applied to correct the orbit and the optical phase errors. Using the corrections, the orbit and phase errors could be corrected within the specifications. The undulator will be re-characterized after delivery of 7.0m long measurement bench.

REFERENCE

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[3] http://www.esrf.eu/Accelerators/Groups/InsertionDevices /Software/Radia , ESRF.