ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRO039

STATUS OF PAL-XFEL UNDULATOR PROGRAM*

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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. Recently, the hard X-ray undulator changed its minimum magnetic gap to 8.3 mm from the previous 7.2 mm to alleviate the wake field impact, and to increase the allowances for the re alignment. Accordingly, the period is also changed from 24.4 mm to 26.0 mm to generate 0.1 nm at 10 GeV electron energy. In this report, the modification efforts and the progress on the prototyping of hard x-ray undulator system will be presented.

INTRODUCTION

The Pohang Accelerator Laboratory (PAL) has been developing SASE based light sources since 2011. The target wavelength is 0.1nm for hard X-ray SASE radiation, with 10 GeV class S-band linear accelerator. For soft X-ray SASE, 3.0 nm FEL radiation using 3.15 GeV electron beam is assumed. To achieve this target, a few key components like low emittance (0.5 um) photo cathode RF gun, and EU-XFEL style out vacuum undulator system are being developed[1]. For undulator system, there will be 18 undulators for X-ray line and 6 planar undulatorss with additional two EPUs (Elliptically Polarized Undulator) are expected. The EPUs will be used for polarization control at the last stages of lasing. The major parameters of the X-ray FEL and undulator line is slightly changed recently and the updated parametersare shown in Table 1. A minor changes were the magnetic gap and period. The gap was changed from old 7.2mm to 8.3 mm resulting period change from 24.4 mm to 26.0 mm maintaining 0.1 nm SASE lasing at 10 GeV electron beam energy. For same consideration, the minimum pole gap of soft X-ray undulator line is changed from 8.3 mm to 10.0 mm which also requires to change the magnetic period from 34.0 mm to 37.0 mm. The number of required units for soft X-ray SASE line is estimated to be 6 with 2 additional EPUs for the final lazing state which controls the radiation polarization. The major parameters of the soft X-ray undulator system is summarized in Table 2. The parameters of the EPUs are under study now, and the magnetic pole gap is 10.0 mm with 44.0 mm magnetic period to match the resonance condition with the conventional hybrid undulator for soft X-ray undulator lines. The horizontal space between magnetic arrays are tuned to 2.0 mm to secure the transverse roll off of K_{eff} within 0.25 mm to $5.0X10^{-4}$ at helical mode where K_x=K_y. At non-planar mode, K_{eff} is defined by the usual formula $K_{eff}{}^2 = K_x{}^2 + K_y{}^2$. A detailed design and quoting is going on and the final contract is expected to be early 2015.

*Work supported by MEST of Korea.

Table 1: Major Parameters of the HXU Undulator

Symbol	Unit	Nominal value
E	GeV	10.000
g	mm	8.30
λ_u	mm	26.0
L_{und}	5	5.0
λ_r	nm	0.100
B_{eff}	Tesla	0.8124
K		1.9727
Optical phase error	degree	Less than 5.0
Total number	EA	18

Table 2: Major Parameters of the SXU Undulator

Symbol	Unit	Nominal value
E	GeV	3.15
g	mm	10.0
λ_u	mm	37.0
L_{und}	5	5.0
λ_r	nm	3.00
B_{eff}	Tesla	0.9299
K		3.2134
Optical phase error	degree	Less than 5.0
Total number	EA	6 (Planar)+2(EPUs)

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

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nature and tuning range is not continuous. With this unique tuning scheme, the supplier can manufacture the undulator meeting the requirements. The detailed tuning and pole corrections can be done in house. In this way, the cost can be lowered.

PAL built a prototype undulator based on the EU-XFEL concept with some modification reflecting different magnetic periods and pole gaps. In addition, a precision tilt meter is added to cross-check to gap encoders at the both ends of the undulator. This prototype is based on the old magnetic periods of 24.4mm and old magnetic gap of 7.2 mm. But it's good enough to check the mechanical integrity and to develop all the pole tuning schemes. The prototype undulator is shown on the measurement bench in Fig. 1. The completed undulator was mechanically tested by installing precision external gap sensor by comparing the rotary encoder values and the actual gaps.

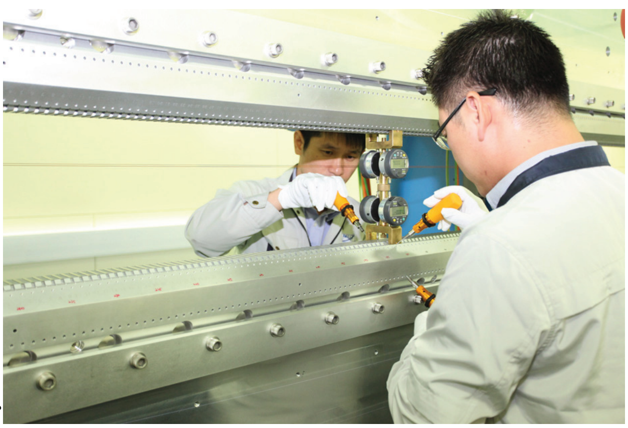

Figure 1: Prototype HX undulator under pole tuning procedure.

MAGNETIC MEASUREMENTS AND CORRECTIONS

Hall scanning measurements and experiments to acquire the pole tuning signature, and pole tuning experiments to improve the orbit and optical phase errors are carried out. Figure 2 shows the field change for pole tuning, Measured and calculated correction signature for 50µm, and 100 µm pole tuning are shown. The solid lines show the calculation from RADIA[3] and shows good values which is about 20% larger than the measurement. Also, residual errors between the two measurements where there were no corrections are also identified. The difference between two scans come from the longitudinal positional error of probe position during the scanning. The difference between the two scans depends on the peak field. When the gap is small and peak field is high, the difference between the two scan is large, while for larger gap when the field is low, the difference between the two scan decrease. Estimation shows than the longitudinal positional errors about 3.0 um can explain the errors. The impact of the this error on the calculation of orbit and optical phase error is rather small due to the random nature of the problem. But anyway, it's exceeding our requirement of 1.0um and we are seeking a way to improve the situation..

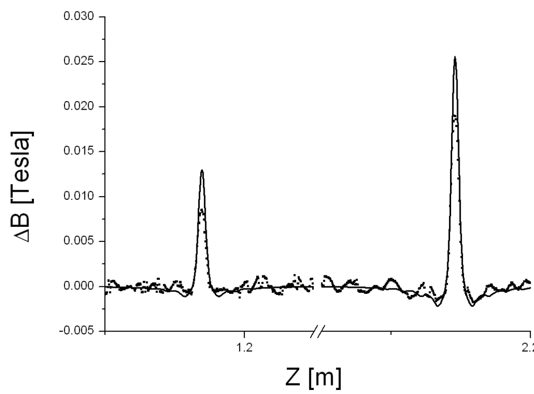

Figure 2: Measured and calculated correction signature for 50um, and 100 um correction. The residual fluctuation comes from the longitudinal positional error at the probe position which is estimated to be about 2.0 um.

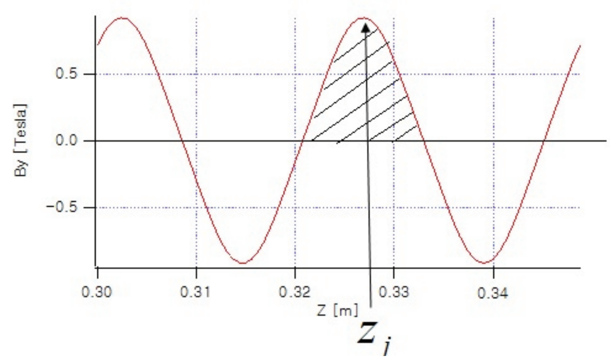

Figure 3: Definition of local-K. Integration of a half period around the j-th peak position.

A local-K is defined for each pole using following definition.

$$K_j = \frac{2e}{mc} \int_{z_j - \frac{\lambda_u}{2}}^{z_j - \frac{\lambda_u}{2}} B_y(z)\, dz$$

It is basically integrating a half period around j-th peak of the field profile. Fluctuation of local K from ideal one describes the error. The situation is shown in Fig. 3.

Several measurements are carried out to extract the impact of a pole tuning on the changes of local K. In Fig. 4, the calculated local K changes due to the pole tuning of 50 um, and measured local K changes from the magnetic measurements are shown. Red line is from the RADIA calculation and the blue ones are from the magnetic measurements. The change at the pole tuning position agrees with the calculation within 10%. Howevery, off diagonal terms shows bigger error. Due to the fluctuation

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in the longitudinal positional errors of the probe, the measurement accuracy of the local-K is about 3.0 X 10-4. In our case, the calculated signatures are used to calculate the required corrections.

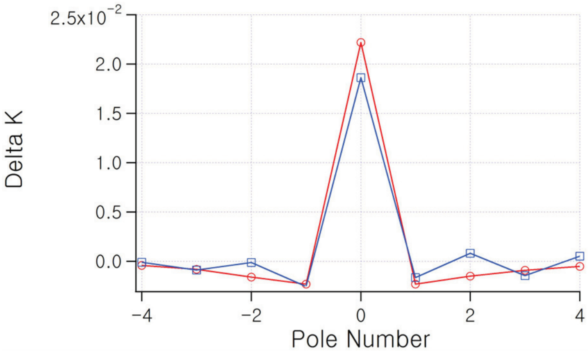

Figure 4: Calculated and measured local K changes due to the 50 um pole correction The red line is the calculated local K changes and the blue line is the measured one.

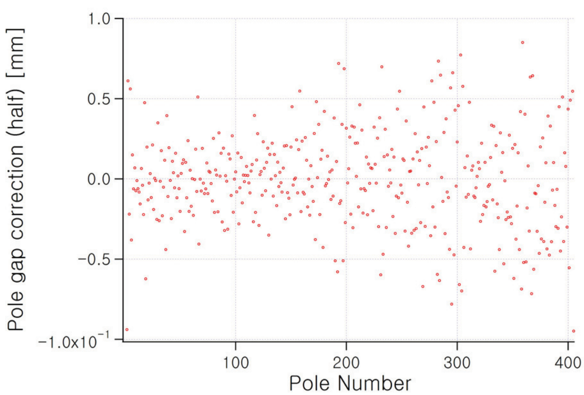

Figure 5: Calculated pole gap correction based on the initial magnetic measurement and local-K deviation. Most of poles need correction. Majority of the poles need correction which is less than 50um, some of them needed 100 um correction.

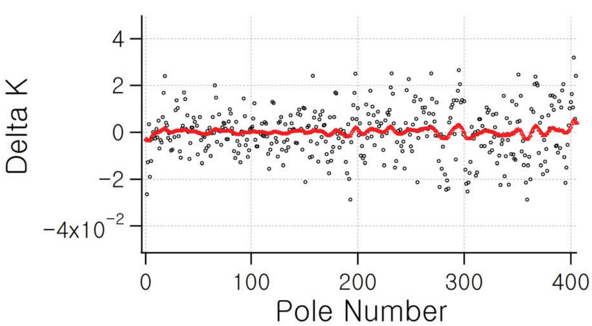

Figure 6: Deviation of local K for each pole before (black), and after pole tuning (red). The standard deviation before correction was 1.32X10-2 and it is reduced to 1.3E-3 after correction.

In calculating corrections, off-diagonal components are used to calculate the required pole height corrections. Basically, we'are assuming a pole tuning is only affecting the neighbouring 3 poles . Large matrix (406 X 406) is solved to calculate the required pole tuning heights. Since the matrix is diagonally dominant, iterative solution is selected for solutions. The results of the calculation is shown in Fig. 5. Most of the poles need correction within 50um, small portion of the poles need up to 100 um pole correction. The impacts of pole tuning is measured and summarized in Fig. 6. The rms variation of the local-K was 1.32 X 10^{-2} before correction, and the fluctuations improved to 1.3 X 10^{-3} after the correction. The accuracy of the final K fluctuation depends on the measurement accuracy and accuracy of the pole height tuning. Both of them need to be improved.

SUMMARY

An undulator prototype based on EU-XFEL design modified for PAL-XFEL is built and tested. Local-K pole tuning procedure is developed and tested. Upto 3 off-diagonal components of the correction signatures are used for correction. Significant (90%) of the reduction of the local-K fluctuation is observed. But the measurement of local-K not precise enough. The major source of errors are coming from the longitudinal positional error of the probe, and the impact should be carefully assessed.

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