ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPJE032

UPDATES OF THE PAL-XFEL UNDULATOR PROGRAM

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Abstract

Pohang Accelerator Laboratory (PAL) is developing a 0.1 nm SASE based FEL based on 10 GeV S-band linear accelerator named PAL-XFEL. At the first stage, PAL-XFEL needs two undulator lines for photon source. The hard X-ray undulator line requires 18 units of 5 m long hybrid-type conventional planar undulator and soft X-ray line requires 6 units of 5 m long hybrid type planar undulator with additional few EPUs for final polarization control. PAL is developing undulator magnetic structure based on EU-XFEL concepts. The key parameters are min pole gap of 8.3 mm, with period length 26 mm (HXU), 35 mm (SXU), and 5.0 m magnetic length. . In this report, the prototyping, and the development of pole tuning procedure, the impact of the background field error, and the effects of the girder bending on the optical phase error 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 µm) 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 undulators 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 parameters are 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. The number of required units for soft X-ray SASE line is estimated to be 6 5 m long planar undulators with 2 additional EPUs. The major parameters of the HXU undulator system is summarized in Table 1. 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 4.0 mm to secure the transverse roll off of Keff within 0.50 mm to 5.0×10^{-4} at helical mode where Kx=Ky. At non-planar mode, Keff is defined by the usual formula $Keff^2 = Kx^2 + Ky^2$. A detailed design and quoting is going on and the final contract is expected to be early 2015.

Among the available five undulator lines in the undulator halls, only two undulator lines will be prepared during the construction period of year 2011-2105: a hard X-ray FEL line (HX1) with 18 undulators and a soft X-ray FEL line (SX1) with 8 undulators are anticipated. HX1 covers the wavelength range of λ=0.06 - 0.6 nm using a 4 to 10-GeV electron beam and uses linear polarization, variable gap, out-vacuum undulators. SX1 covers the wavelength of λ = 1.0 - 4.5 nm using a 3.15-GeV electron beam. In SX1, two EPUs (Elliptically Polarized Undulator) following six planar undulators will be used for polarization control at the last stages of lasing. An enough space is reserved in the undulator halls for the future upgrade to accommodate a total 29 undulators for HX1 and 16 undulators for SX1.

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 7.0
Total number	EA	18

UNDULATOR SYSTEM

For the PAL-XFEL undulators, the EU-XFEL design and technology [2,3] was adopted and further developed. The EU-XFEL design is a well proven using standardization and optimization for mass serial production and was successfully used for the production of 91 undulators for the EU-XFEL

At PAL a full scale prototype undulator was built. It is based on the EU-XFEL concept with some modification reflecting different magnetic periods and pole gaps. In addition, precision tilt meters were attached to the girders to monitor the tilting and tapering of the undulator. Also the control systems are developed to be used in EPICs environment. A prototype is based on the old magnetic periods of 24.4mm and old magnetic gap of 7.2 mm had

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been developed and used extensively to test the manufacturing procedure, and the pole height tuning technology. Serially produced undulator that will be used for the X-ray SASE FEL line is being delivered. In this report, we summarize the 1st results of the measurement/tuning efforts for the 1st serially produced undulator.

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. Pole height tuning scheme using local-K is developed and used successfully for EU-XFEL [4,5,6]. A local-K is defined for each pole using following definition.

$$K_j = \frac{2e}{mc} \int_{z_j-\frac{\lambda_u}{4}}^{z_j-\frac{\lambda_u}{4}} B_y(z)\,dz$$

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. Several measurements are carried out to extract the impact of a pole tuning on the changes of local K for 100 µm pole height tuning. In Fig. 1, the results of the magnetic measurements are shown. Measurements were done at 5 different places and all of the results are plotted in the same figure. The spread in the plot shows the measurement error. The measurement data are processed by averaging. Also the data are symmetrized to eliminate a slight error. The measured signature is mostly diagonally dominant and the necessary pole height tuning is calculated by iteration. The matrix is diagonally dominant and the iteration converges in 5 iterations. Using the measured signature, the required pole height tuning is calculated and applied to the undulator. The results of the tuning in phase jitter is shown in Fig. 2 for the tuning gap of 9.5 mm. The optimum phase jitter is 2.6 degree rms. But the phase jitter increase as we move away from the tuning gap. This results is also measured in EU-XFEL undulator and is coming from the uncompensated parabolic girder bending.

SUMMAR BACKGROUND FIELD AND GIRDER BENDING IMPACT

We estimate the impact of the girder bending as follows. We assume that the undulator is perfectly tuned at the tuning gap of 9.5 mm with ideal field. With this ideal undulator, the orbit is completely flat and the optical phase error is practically zero for all poles. As we move the operation gap out of the tuning gap, the girder deforms in parabolic shape with maximum deformation of approximately 30 µm at the ends of the undulator. To simulate the parabolic bending of the girder, the ideal field is modified reflecting the local change in the gap. With the modified field, the optical phase jitter is calculated as usual, and the result is shown in Fig. 3. In summary, even if the undulator is tuned perfectly at the tuning gap, the optical phase error increases when the undulator changes the operation gap. For our case, the maximum increase in the phase error is about 2 degree which is acceptable. Finally, the gap dependent optical phase error is plotted in Fig. 4. The two measurements shows similar behaviour. The shape represents the optical phase error coming from the girder bending.

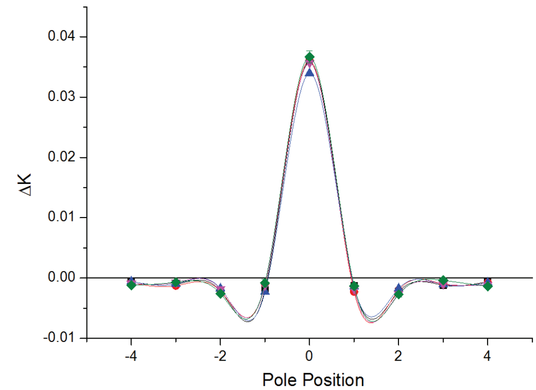

Figure 1: The measured local K changes due to a 100 µm pole correction at the 9.5 mm tuning gap. The abscissa denotes the distance to the pole: 0 is the tuned pole itself, ±1 the two next neighbouring poles etc.

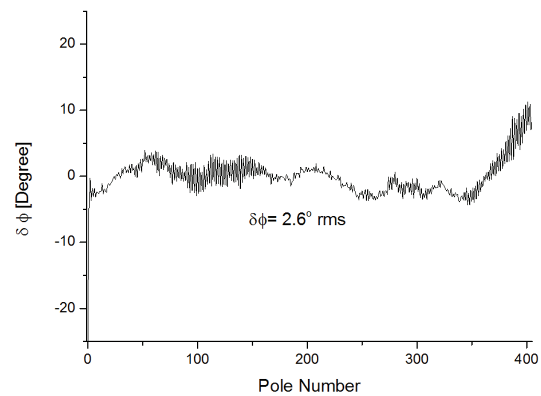

Figure 2: Optical phase error at the working gap of 9.5 mm. The rms phase jitter is 2.6 degree which is within the specification of 7.0 degree.

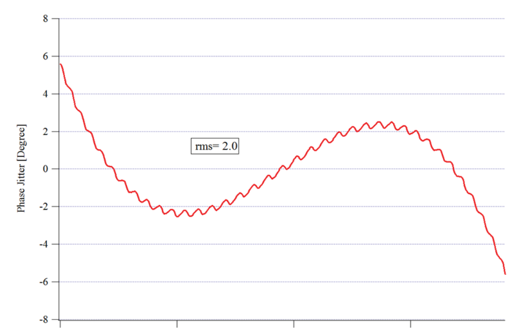

Figure 3: Calculated phase jitter when the undulator girder is deformed by 30 µm in parabolic shape. The girder is expected to be flat at the tuning gap and deforms when gap is changed from the tuning gap.

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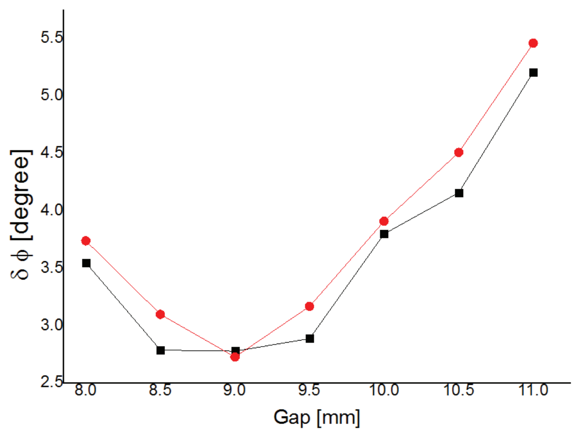

Figure 4: Optical phase change with the gap. The change in optical phase error mostly comes from the girder deformations. Two independent measurements are shown to express the measurement accuracy of the optical phase error.

Since the undulator for PAL-XFEL is 5.0 m long, the impact of the background is important. In practice, the environmental earth magnetic field at the exact installation site is measured, and the measured background field is set-up at the measurement bench using horizontal/vertical Helmholtz coils. However, since the background field is usually small (from 0.1 G to 0.4 G), there exists possibility of error or change in the background field after installation due to the other equipment. To assess the impact of the background field error, uniform background field is added to the ideal field, and the orbit is calculated. The orbit is locked to the cavity bpm position located between the undulator by orbit feedback, and the corrected orbit looks like the parabolic shape with maximum deviation of 4.0 µm. The calculated rms phase error is about 4.22 degree which is big portion of the tolerance 7 degree. Furthermore, it is calculated that the vertical background field is amplified by 2.5 times at the mid plane because of the ferromagnetic pole structure while the horizontal background field is decreased by 30%. Therefore, if we accept 4.22 degree phase error increase due to the background field, the error in the background field is 0.5 G/2.5 = 0.2 G. Actually, the background field should be matched between the installation site and the measurement bench better than this

SUMMARY

An undulator prototype based on EU-XFEL design and modified for PAL-XFEL was built and tested. For the field corrections, the impact of the three nearby neighbours were included into the correction. Tuning was very effective reducing the local-K fluctuations by one order of magnitude. The final gap dependent phase jitter were within the requirement for all working gap range. Also the impact of the vertical background field error is analysed to be around 0.2 G while horizontal background field error is rather relaxed. And impact of the girder bending on the optical phase error due to the girder bending is estimated. Optimum girder deformation 30 µm looks acceptable meeting PAL-XFEL undulator phase error requirements.

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