DEVELOPMENT OF PAL-XFEL UNDULATOR SYSTEM*

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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 20 units of 5 m long hybrid-type conventional planar undulator and soft X-ray line requires 7 units of 5 m long hybrid type planar undulators. PAL is developing undulator magnetic structure based on EU-XFEL concepts. In this report, the results of final pole height tuning results, and magnetic measurement results will be presented.

INTRODUCTION

The Pohang Accelerator Laboratory (PAL) has been developing SASE based light sources since 2011 and final assembly of the linac and undulator line had completed on the end of 2015. The target wavelength is 0.1 nm 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 20 undulators for hard X-ray line and 7 planar undulators with additional two EPUs (Elliptically Polarized Undulator) are expected for soft X-ray line. 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. The number of required units for soft X-ray SASE line is estimated to be 7 units of 5 m long planar undulators with 2 additional EPUs. And schematic layout of hard X-ray, and soft X-ray undulator lines are shown in Fig. 1.

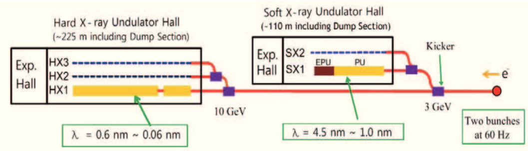

Figure 1: FEL undulator line plan of PAL-XFEL.

MEASUREMENT AND TUNING OF THE UNDULATOR

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 [4] and was successfully used for the production of 91 undulators for the EU-XFEL.

Table 1: Major Parameters of the PAL-XFEL Undulator System

Parameter	Unit	Value	Value
Undulator Line		HXU	SXU
Beam energy	GeV	10.0	3.15
Min gap	mm	8.30	9.00
Period	mm	26.0	35.0
Length	m	≃5.0	≃5.0
B_{eff}	T	0.812	1.016
K		1.973	3.321
Phase jitter	deg	< 7.0	< 7.0
Number		20	7

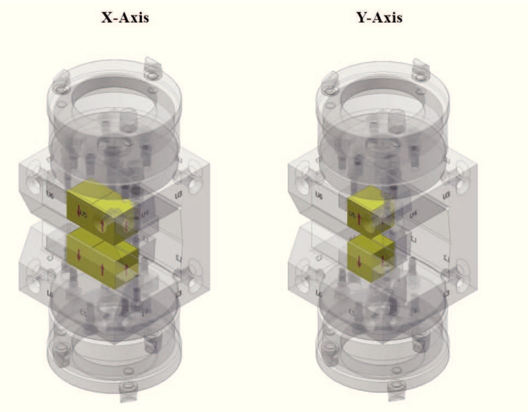

Figure 2: Schematic drawings of landmark magnet. Left is landmark magnet for X center measurement with normal quadrupole configuration. Right one is landmark magnet for Z center measurement with skew quadrupole configuration.

The tuning of an undulator needs precise alignment of the measurement bench and the undulator axis. Typically, the center of Hall probes sensor is known with errors far greater than ±0.1 mm which exceeds the required tolerance of the magnetic mid-plane measurement error. Furthermore, even the center marking is very difficult to translate to the real data. To overcome these difficulties, various schemes like using a wedge magnet have been utilized. The most systematic study is a development of a landmark magnet that have well defined measurable magnetic field center, and the mechanical centers [5]. The landmark magnet described in ref [5] is very useful, but placing both X (horizontal), Z (vertical) landmark

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in the same magnet needed scanning ranges exceeding the capabilities of our measurement system. To avoid this problem, X landmark magnet, and Z landmark magnet is splitted into two as shown in Fig. 2. Left landmark magnet for X center measurement with normal quadrupole configuration. Right one is landmark magnet for Z center measurement with skew quadrupole configuration. By measuring landmark magnet using a laser tracker in normal, and flipped position, we can define the center of a landmark magnet very precisely within $\pm 5\mu$m. By measuring the same landmark magnet with Hall probes in a normal and flipped position, we can find the magnetic center in normal, and flipped position. The average of the magnetic center in normal, flipped position should agree with the mechanical center. In this way, we can measure the offset between the mechanical center of a landmark magnet, and the magnetic center at normal scanning case. This offset is a landmark magnet characteristic and should not change with time. Repeated measurements of the landmark magnet shows that this offsets within ± 3 μm between measurements confirming the measurement reproducibility.

The mid-plane of undulator is determined by measuring the undulator in several vertical positions which are close to the approximate mid-plane. For each scan, the peak field of each pole is calculated. With several scans we can the fit peak field data for each pole with the vertical position and calculate the position for minimum peak field which is the measured mid-plane at the specific pole. In reality, measurements at 3 vertical positions with 1.0 mm spacing around the approximate positions are carried out and the midplane data are extracted. Vertical scans at 5 positions with 0.5 mm step is also carried out but the difference is very negligible and not worth extra measurement efforts. Therefore, 3 measurements at 3 vertical positions with 1.0 mm step is routinely used to determine the vertical position. To estimate the reproducibility of the midplane measurement, two measurements are done and the differences are calculated. The results are shown in Fig. 3 showing accuracy of maximum 10 μm error. For horizontal measurement, the mechanical center of an undulator is measured and the probe position is determined to measure at the transverse mechanical center.

To tune the undulator, local-K correction schemes [4, 6] is used. Basically, local K is a a half period field integral around j-th pole of the field profile. Fluctuations of local K from the average describe the error. The difference of local K to the ideal K indicate error in the undulator field and by correcting local K to ideal K for each pole allows us to tune the undulator systematically. The impact of a pole height tune is measurement by signature measurements and the impact to the side poles are measured. The required pole height corrections are calculated based on the required corrections and the tuning matrix. To estimate the accuracy of measured pole height tuning, two independent measurements are analyzed to calculate the require corrections. The two corrections are subtracted to get estimates of the error in measured tuning data. The measured pole height tuning error does not exceeds ± 5 μm (Fig. 4)which is nearly same order with the mechanical tuning accuracy (± 2 μm). Pole height tuning is done at a specific tuning gap, and when one deviates from the tuning gap, the error usually increases.

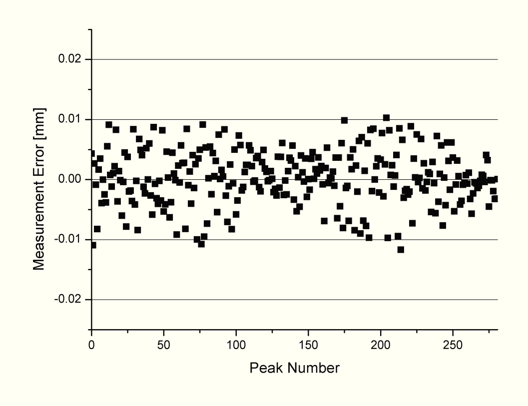

Figure 3: An error in midplane measurement. Two measurements are subtracted to estimate the reproducibility of the measurements.

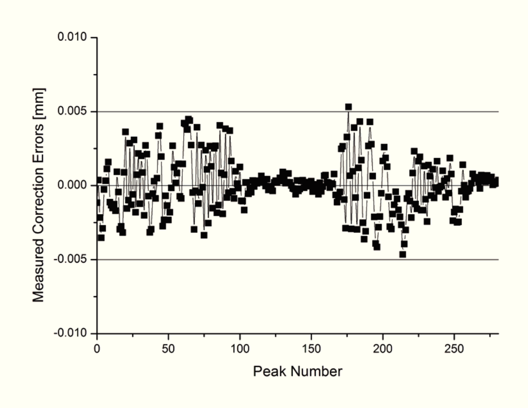

Figure 4: An error in pole height tuning measurement. Two measurements are subtracted to estimate the reproducibility of the required pole height tuning.

After the pole height tuning, production measurements are carried out at 34 gaps with more densely spaced gaps within the working gaps. 5 cycles of measurements are repeated, the each data are analyzed to extract, effective K, optical phase jitter, phase integral, entrance/exit horizontal/vertical kicks, peak fields, etc. The results for 5 sets of measurements are averaged to compile the final data. Fig. 5 shows the variation of optical phase jitter with gap. The phase jitter is minimum at the tuning gap of 9.5 mm reaching 1.0–2.0 degrees, and increases as undulator gap deviates from the tuning gap. This phenomena is related to the parabolic bending of undulator girder and will be discussed later. Note that, the working gap rang is from 8.5 mm to 13.0 mm, and for clarity only 4 undulators are shown among 20 undulators. In Fig. 6, the required x-kicks (horizontal) in Gm is shown. The requirement is 1.5 Gm and they are within the specification in the working gap range. For space reason, only x-kicks are shown, but the required vertical kick is very small compared to X-kicks.

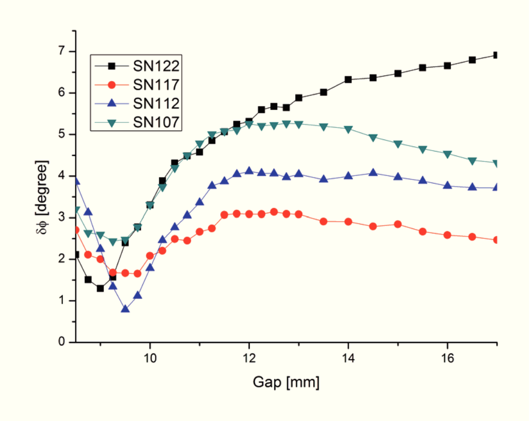

Figure 5: Measured optical phase jitter vs undulator gap. The optical phase jitter is minimum at the tuning gap and increases as gap is deviated from the tuning gap. For clarity, only 4 undulators among 20 are shown.

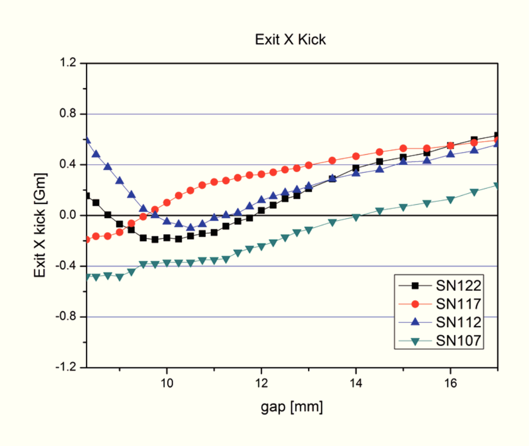

Figure 6: Required exit x-kicks for horizontal plane. For clarity, only 4 undulators among 20 are shown.

DISCUSSION AND SUMMARY

During undulator commissioning, we need to change the undulator midplane to confirm the magnetic measurements [7]. To achieve this, we tweaked the controller enabling to change the undulator midplane by ±0.3 mm. To check the controller implementation, the midplane measurements are carried out while setting the midplane. The results is shown in Fig. 7 showing very good agreement with control set value and magnetic measurement results. It proves also that the magnetic midplane measurement is very accurate.

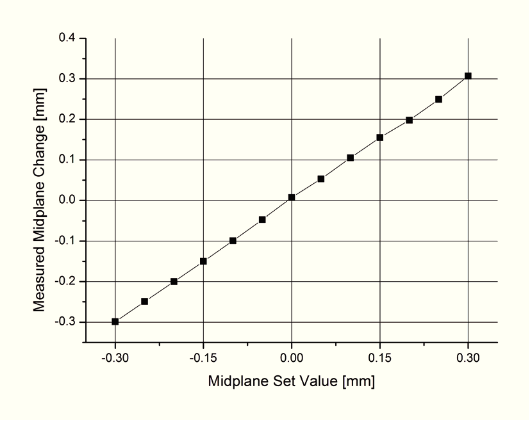

Figure 7: Midplane change experiment. Horizontal axis is the set value, and vertical is the change of midplane by measurement.

1st stage of PAL-XFEL requires 20 units of HXU undulators for hard x-ray undulator line. All the undulators are measured and tuned, and installed in the undulator hall. 7 SXU undulators which will be used for soft x-ray undulator line is also prepared and they are scheduled to be installed in the tunnel by the end of April 2016. The 10 GeV linac is under commissioning, and the undulator commissioning is expected soon.

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