STATUS REPORT OF PAL-XFEL UNDULATOR PROGRAM

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Abstract

PAL-XFEL is a SASE based FEL using S-band linear accelerator, photo cathode RF Gun, and hybrid undulator system for final lazing. The undulator system is based on EU-XFEL undulator design with necessary modifications. The changes include new magnetic geometry reflecting changed magnetic requirements, and EPICs based control system. The undulator system is in measurement and tuning stage targeting to finish installation within 2015. In this report, the development, tuning, measurement efforts for PAL-XFEL undulator system will be reported.

INTRODUCTION

The Pohang Accelerator Laboratory (PAL) has been developing SASE based light sources since 2011. 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 18 undulators for hard X-ray line and 6 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. 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 units of 5 m long planar undulators with 2 additional EPUs. The major parameters of the undulator system is summarized in Table 1. And schematic layout of hard X-ray, and soft X-ray undulator lines are shown in Fig .1.

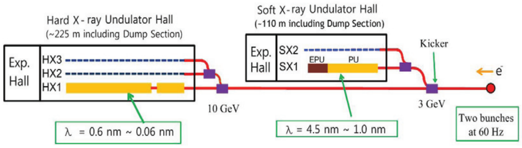

Figure 1: FEL undulator line plan of PAL-XFEL.

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	8.30
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		18+α	6+α

UNDULATOR SYSTEM

For the PAL-XFEL undulators, the EU-XFEL design and technology [2-4] was adopted and further developed. The EU-XFEL design is a well proven using standardization and optimization for mass serial production [3,4] and was successfully used for the production of 91 undulators for the EU-XFEL. The schematics and major subsystems are shown in Figure 2.

Following EU-XFEL, pole height tuning is used. The poles can be shifted by about ±150 μm in vertical direction and tilted by ±2 mrad using tuning studs and locking screws. This is a big advancement as compared to using conventional magnetic and/or non-magnetic shims. In contrast to shims, Pole Height Tuning is bi-polar and continuous. Magnetic shims are unipolar and only weaken poles. In addition they are only available in discrete steps. By using Pole Height Tuning an undulator can be readily assembled at a supplier. Provided that suitable a magnetic measurement facility is available the tuning is readily done in house.

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 parallel motion. Unfortunately this prototype is based on the old magnetic periods of 24.4 mm and old magnetic gap of 7.2 mm. But it is, however, a good test bed to check the mechanical integrity and to develop the entire pole tuning schemes. The completed undulator was mechanically tested by installing precision external gap sensor by comparing the rotary encoder values and the actual gaps

POLE HEIGHT TUNING

For deeper analysis field measurements need to be analyzed. First, for each pole a local-K is defined for each pole using the following definition [5]. This is a half period field

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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 pole height corrections are calculated as described in ref. [6]. A linear system of equations is set up connecting the pole shift on a pole with index j to the local K change on a pole with index i. For HXU which has 191 periods, there are 382 poles resulting in a 382 by 382 system matrix. Since only three next nearest neighbors are used the matrix is diagonally dominant and there are only six side diagonals. This facilitates the solution and allows an iterative solution.

In Fig. 2, the calculated corrections from the measurement of as assembled undulator is shown in red circles. The blue circle represents that calculated pole height tuning from the measurement after 1st pole height tuning campaign. As shown in the figure, as assembled undulator requires maximum 40 μm corrections for each upper/lower magnet structures. After the 1st correction, the residual corrections are usually less than 5 μm which shows the impact and efficiency of the pole height tuning. The phase jitter of as assembled undulator is about 12-15 degrees. After the 1st implementation of the pole height tuning, the phase jitter reduces to 1-2 degrees.

The expected operating gap of the PAL-XFEL hard X-ray undulator (HXU) is between 8.3 mm to 12.5 mm producing 0.1 nm to 0.06 nm SASE radiation at 10 GeV e-beam energy. The undulator tuning gap is decided to be 9.5 mm balancing the errors for both extreme of the operating undulator gaps. Therefore, the HXU undulator is very optimal at the tuning gap, and deviates from the best condition as we move away from the tuning gap. In Fig. 3, the gap dependence of the phase jitter is shown. As can be seen in the Fig. 3, the phase jitter is lowest at the tuning gap and increases as we deviates from the tuning gap. But the phase jitters are within the requirements for all operating gaps. Note that in Fig. 3, phase jitter is shown up to 20 mm which is very large gap compared to the maximum operating gap.

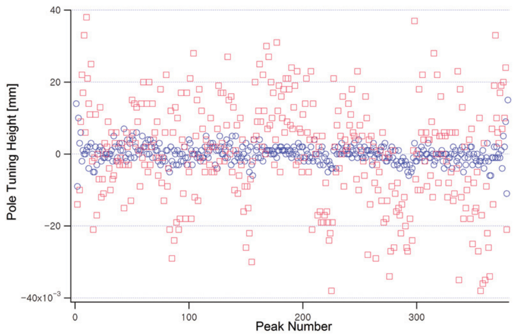

Figure 2: Calculated undulator pole height corrections. Red circles are correction data from as assembled. Blue circles are the calculated correction data based on the magnetic measurement after 1st pole height correction.

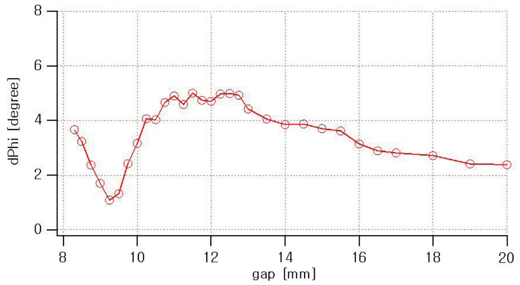

Figure 3: RMS phase jitter as a function of undulator gap. It's minimum at the tuning gap of 9.5 mm and increases as gap deviates from the tuning gap. The expected operating gap is from 8.3 mm to 12.5 mm.

In Fig. 4, the phase jitter distribution for several gaps are displayed. At tuning gap, the phase jitters are relatively flat and small. As gap deviates from the tuning gap, the phase jitter distribution shows typical S-structure which implies that the phase jitter error comes from the parabolic bending of the magnet structure. It's also evident that the polarity of the S-shape are opposite for minimum 8.3 mm gap and maximum operating gap of 12.5 mm. This means that the bending of the magnet structure is in opposite sign for minimum gap and maximum operating gap which is obvious from inspection. Also in Fig. 5, the orbits for several key gap within the operating gap range is shown.

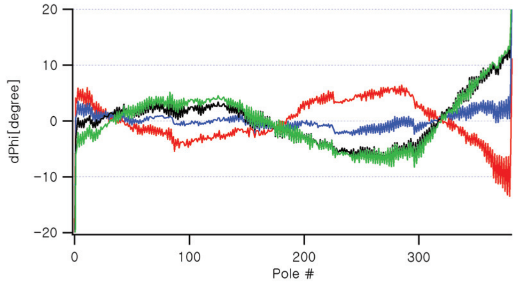

Figure 4: Phase jitters calculated at the several key gaps within the working gap ranges. The measured gaps are 8.3, 9.5, 11.0, 12.5 mm.

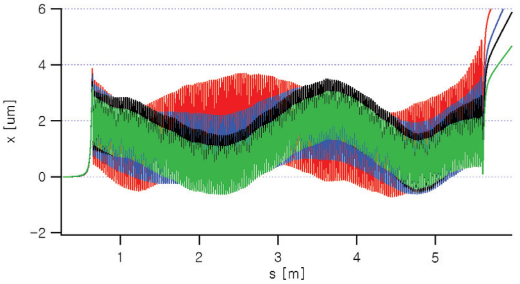

Figure 5: Selected x-orbits at undulator gaps g = 8.3 mm, 9.5 mm, 11.0 mm, and 12.5 mm.

Figure 6: Two undulators installed at the hard X-ray undulator hall. They are 1st undulator line and facing the wall.

CONCLUSIONS

PAL-XFEL is developing undulator system for its hard Xray undulator line, and soft undulator lines based on EU-XFEL undulator structure. Our modifications are redesign of the magnetic structure reflecting different magnetic gap, and periods including end sequences. Another modification includes the adaptation of the control system to EPICs.

An undulator prototype based on EU-XFEL design and modified for PAL-XFEL was built and tested. The local-K pole tuning procedure was developed and tested. For the field corrections the three next nearest neighbors were included into the correction signatures. Tuning was very effective, and a single iteration of pole height tuning could reduce the local-K fluctuations by one order of magnitude. The optical phase error at the tuning gap after pole height tuning is between 1 and 2 degrees. At the tuning gap, the undulator structure is well optimized. However, as we deviate from the tuning gap, the girder deforms in parabolic shape and the phase jitter shows typical S structure which is signature of the parabolic bending. For all operating gap range which is 8.3 mm to 12.5 mm for HXU undulators, the phase jitter meets the specification of 7 degrees. All other undulator properties, like entrance/exit kicks are also calculated from the magnetic measurements. All operation related data are tabulated, and fitted within the tuning gap range.

Currently, the measurement and correction procedures are setup and production measurements are going on for all undulators. And two undulators are installed in the undulator hall as shown in Fig. 6. Upto the end of Aug 2015, 8 undulators are expected to be ready for the HXU installation. With optimistic estimation, all 18 HXU undulators are expected to be installed in the undulator hall within 2015.

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