STATUS OF PAL-XFEL UNDULATOR SYSTEM

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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, 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. Soft X-ray undulator system has 8.3 mm undulator gap with 33.4 mm magnetic period. In this report, the status of the undulator project including mechanical design, magnetic design, 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]. It's targeting 60Hz operation with optional 120 Hz operation. In addition to this, 1.0nm~3.0 nm VUV SASE line is also planned. The total length of the PAL-XFEL building will reach 1,100 m including about 120m undulator lines. 22 undulators for X-ray line and 14 undulators for Soft X-ray line is expected. The schematic layout of the linear accelerator and undulator line is shown in Fig. 1. 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	Min gap	Max gap
E	GeV	10.000	10.000
g	mm	7.20	9.90
λ	mm	24.4	24.4
L_{und}	5	5.0	5.0
λ_r	nm	0.1000	0.0600
B_{eff}	Tesla	0.9076	0.5833
K		2.0683	1.3293
Lg	m	2.88	5.34
Lg/Lg1D		1.36	1.98
Pbeam	TWatt	30.0	30.0
Psat	GWatt	13.7	5.1
Lsat	m	52.8	92.4
Lg	m	2.88	5.34
Lg/Lg1D		1.36	1.98

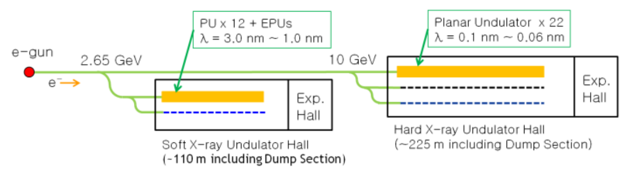

Figure 1: Schematic layout of the PAL-XFEL and undulator line.

EU-FEL 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 generator structure of the PAL-XFEL undulator design is shown in Fig. 2 and it 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.

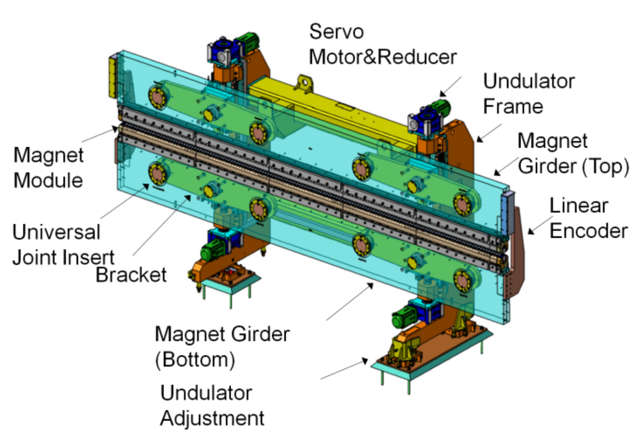

Figure 2: Schematic structure of PAL-XFEL undulator system.

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MAGNETIC STRUCTURE

PAL-XFEL undulator magnetic structure is mostly based on the EU-XFEL undulator design. But since the magnetic period, and minimum working gap are different, customized design is needed. As usual, FE-Co pole material which has a saturation magnetization larger than 2.3 Tesla is used to achieve higher effective field at a given geometry. For magnetic material, NdFeB rare earth magnet having remanence bigger than 1.25 Tesla, and coercivity 11.9 kOe is adopted. To minimize the long-term radiation damage by high electron bombardment, high intrinsic coercivity of 25 kOe are required [3]. Analysis of the periodic part of the undulator was done using commercial finite element (FEM) program ANSYS [4]. Using symmetry of the problem 1/4 period is analyzed. The thickness of the pole and blocks are optimized to get a higher effective peak field. As usual, the effective field is defined by the Fourier component of the vertical field:

$$B_y(z) = \sum_{n=1,3,5,..}^{\infty} B_n \sin(\frac{2\pi nz}{\lambda_u})$$

$$B_{eff}^2 = \sum_{n=1,3,5,...}^{\infty} \frac{B_n^2}{n^2}$$

Here we set the origin at the center of the longitudinally asymmetric undulator, and z is the longitudinal coordinate and λ_u is the undulator period. In Fig. 3, the dependence of the peak field and effective field on the pole thickness is shown. As expected, the content of the higher harmonic increases as pole thickness gets thinner and the difference between the effective field and peak field becomes larger. The effective field reaches a maximum when the pole thickness is about 3.6 mm. However, the transverse roll-off was compared for 7.2 mm and 9.9 mm (which is the maximum expected working gap), and the good field region was smaller at 9.9 mm due to excessive saturation. To solve this problem, The pole thickness was increase to 4.4 mm slightly compromising the effective field. At this thickness the transverse roll-off is shown at Fig. 4.

TRANSITION PARTS

For the transition calculations, Radia is used [5]. Since Radia is not sensitive to boundary conditions it's useful for transition sequence while ANSYS is more accurate for well defined boundary conditions. In Fig. 5 we compare the results of ANSYS and Radia calculation for 1/4 period. Same magnetic materials are applied including the parallel permeability of 1.06 and perpendicular permiablity of 1.17. But there is small difference of about 1.0% in the calculate field. It may be attributed to the different character of the programs and different element numbers. The transition parts are designed using the adjustment of vertical position of the end magnet and controlling the thickness of the next magnet. In this way, the initial kick can be control to achieve parallel orbit for most of the working gaps.

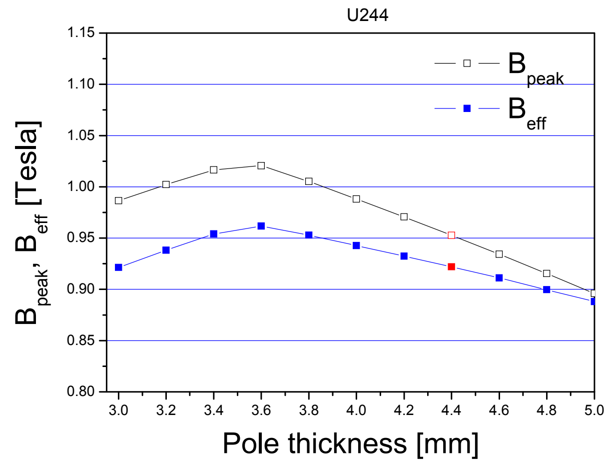

Figure 3: The dependence of the peak field and effective field on the pole thickness.

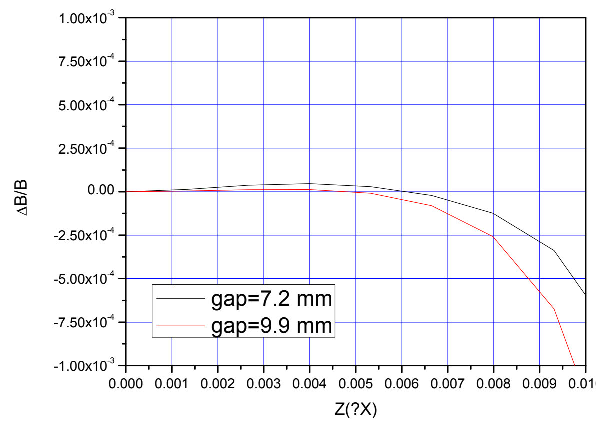

Figure 4: Transverse roll-off at minimum working gap and at maximum working gap.

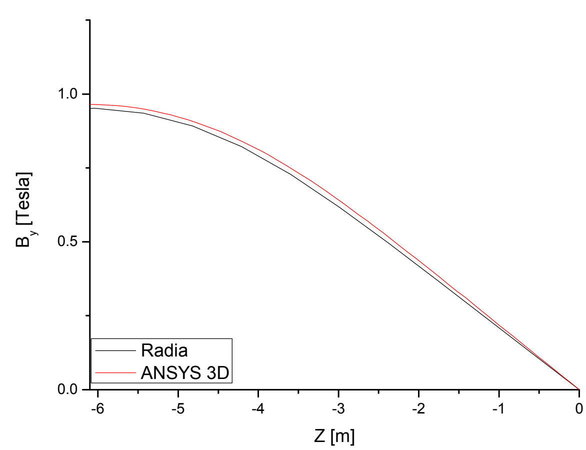

Figure 5: The comparison of the ANSYS calculation and RADIA calculation.

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The shortened Radia model is shown in Fig. 6 and the small end magnet can be seen. The control thickness of the next magnet is from 0.0mm to 0.2 mm which is too thin to be visible. The calculation results are shown in Fig. 7 where orbits are calculated for several depth of the tuning magnets.

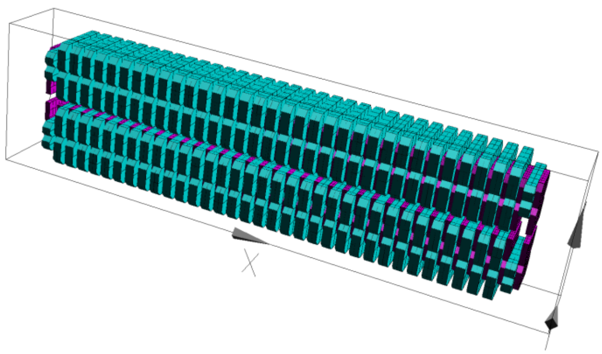

Figure 6: Shortened RADIA model of the undulator.

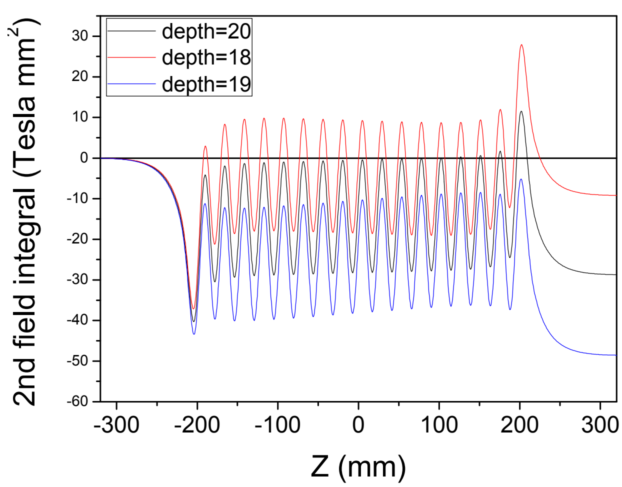

Figure 7: The calculated orbit for 3 different tuning block depth.

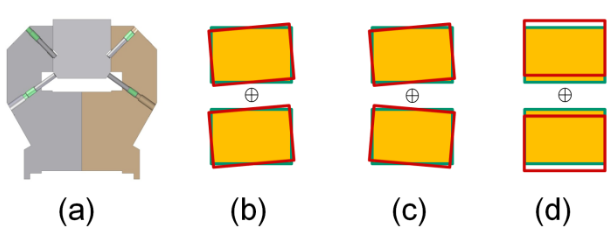

Figure 8: Tuning scheme. (a) shows the tuning studs and locking studs for the pole. (b) shows the correction scheme for skew dipole (c) shows the correction scheme for normal quadrupole (d) shows the correction scheme for dipole or orbit.

Movable tuning magnets at the end regions are shown in Fig. 8 the tuning scheme utilizing the tuning and locking screws is shown. Actually (b) type tuning can correct the skew dipole component and (c) type tuning can correct normal quadrupole component and (d) type tuning can correct the normal dipole or correct the orbit. This kind of tuning scheme is already successfully applied and tested for PLS-II in vacuum undulators using discrete copper shims.

SUMMARY

In this report, the status of the PAL-XFEL undulator system is described. The undulator system is benchmarking EU-XFEL undulator which is successfully manufactured and applied to FLASH and DESY. We need to customize magnetic structures for PAL-XFEL pole gap and magnetic period. The periodic structure and the transition parts are optimized using ANSYS and Radia. The calculated results from ANSYS and Radia showed about maximum 1.0% difference. Also the tuning schemes of the EU-XFEL undulator is summarized which is applied successfully to PLS-II in vacuum undulator system using discrete copper shims.

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