IN VACUUM UNDULATOR SYSTEM FOR PAL-FEL*

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Abstract

Pohang Accelerator Laboratory (PAL) is planning to develop a 0.1 nm SASE based FEL as a next generation light source. It will be based on the 10 GeV S-band linac with In Vacuum Undulator system. The proposed in vacuum undulator has 22.3 mm magnetic period with 5.0 mm vertical clearance aperture. The magnetic length will be 4014 mm with breaks between undulators for diagnostic and focusing elements. The mechanical and magnetic requirements of the IVU system are very challenging. In this report, the design issues related to the development of the IVU with preliminary magnetic design will be presented.

INTRODUCTION

Pohang Accelerator Laboratory (PAL) is planning to build a X-ray FEL based on SASE (self amplified spontaneous emission) process[1]. The machine will utilize a 10 GeV S-band linac for injector. The SASE FEL offers unprecedented opportunity for X-ray users. SASE XFEL radiation is supposed to be at least ten orders of magnitude brighter than the 3rdgeneration synchrotron light sources. The SASE XFEL is transversely coherent and the pulse length is very short, femto-second level, which also privides users with chances for new scientific research.

On the other hand, the SASE XFE is quite a scientific challenge, as is well known; the generation of an extremely low emittance electron beam through a photo-cathode RF gun, bunch compression to an extremely short length, maintaining the low emittance to the end of the linac, and keeping the beam orbit as straight as possible in the undulator. The PAL-FEL adds a few more scientific difficulties because it is targeting relatively short radiation wavelength (0.1 nm) with lower electron beam energy (10.0 GeV). Therefore, the PAL-FEL requires very short period undulator with minimum possible gap. This implies the use of in Vacuum undulator developed at SPring8 is essential to the project. In this paper, IVU program at PLS and a preliminary the magnetic design PAL-FEL undulator will be described.

IN VACUUM DEVICES AT PLS

In 2000, PAL leased a revolver IVU from SPring8 and installed at PLS. And starting from 2007, PAL is collaborating with ADC to develop a IVU for USAXS (Ultra Small X-ray Scattering Beamline). The 1st in vacuum device is the revolver in vacuum undulator [1] leased from SPring8 in 2000. A number of magnetic arrays with different magnetic period are mounted on the rotary beam. The rotary beam is rotated to select the desired undulator wavelength. The revolver IVU which is developed at SPring8 has 10, 15, 20, 24 mm magnetic period with 1 m magnetic length. The major parameters of the 4 magnetic arrays are listed in Table 1. The minimum usuable magnetic gap is limited by the reduction of the lifetime. With careful control of the electron orbit, operation without reduction of the lifetime at 6 mm gap is possible. The revolver IVU is installed at the 11th straight section of the PLS and successfully used for resonance X-ray scatering for magnetic studies.

Table 1: Major Parameters for Revolver IVU at PLS for 24mm and 20 mm Magnetic Period.

Parameter			Unit
Pole Gap (nominal)	4	4	mm
Period	20	24	mm
Magnetic length	1020	1020	mm
Number of Full Field Periods	42	50	
Effective Peak Field (B_{eff})	1.05	1.11	Tesla
Effective K value (K_{eff})	1.97	2.49	
Fundamental photon energy	2.03	1.45	keV

PAL is also trying to develop more traditional IVU for USAXS (Ultra Small Angle X-ray Scattering) beamline with ADC. It features 2200 mm flange to flange distance with 1800 mm magnetic length. Magnetic structure is consists of NdFeB magnet with low carbon steel. The undulator is scheduled to be installed during 2009 summer break. The major parameters of the device is summarized in Table 2. A part of the schematic 3D drawing is shown in Fig. 1.

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Table 2: Major Parameters of the USAXS IVU

Parameter		Unit
Pole Gap (nominal)	5	mm
Period	20	mm
Magnetic length	1800	mm
Number of Full Field Periods	88	
Effective Peak Field (B_{eff})	1.05	Tesla
Effective K value (K_{eff})	1.96	
Flange to Flange distance	2200	mm

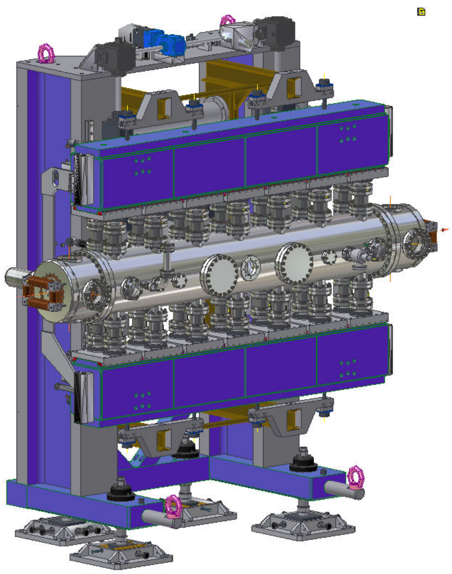

Figure 1: Schematic drawing of the USAXS IVU.

PAL is planning to build a X-ray FEL based on SASE (self amplified spontaneous emission) process. The machine based on the 10 GeV linac for 0.1 nm FEL radiation. The SASE FEL will offer unprecedented opportunity for X-ray users. SASE FEL radiation is supposed to be at least ten orders of magnitude brighter than the 3rd generation synchrotron light sources. The SASE XFEL is transversely coherent and the pulse length is very short, femto-second level, which also privides users with chances for new scientific research.

The PAL-FEL adds a few more scientific difficulties because it is targeting relatively short radiation wavelength (0.1 nm) with lower electron beam energy (10.0 GeV). Therefore, the PAL-FEL assumes short period undulator with small gap. This implies the use of in Vacuum undulator developed at SPring8 is essential to the project. In this paper, the magnetic design of the periodic part, the magnetic design of the end part and other physics requirement of the PAL-FEL undulator will be described. The major design parameters of the PAL-XFEL are summarized in Table 1.

Table 3: Major Design Parameters of PAL-FEL

Beam Parameters	**Value**	**Unit**
Electron energy	10.0	GeV
Peak current	3.4	kA
Normalized slice emittance	1.1	mm mrad
RMS slice energy spread	0.014	%
Full bunch duration	293	Fs
SASE FEL Parameters		
Radiation wavelength	1	Å
FEL parameter ρ	3.64×10^{-4}	
Peak brightness	1.14×10^{32}	Pts/sec/m m^2/mrad^2/ 0.1%BW
Pulses repetition rate (Max.)	120	Hz
3-D gain length	5.14	m
Saturation length, L_{sat}	93.9	m

MAGNETIC FIELD REQUIREMENTS

The basic magnetic structure of the undulator will be a Halbach type hybrid structure that use strong rare earth high performance magnets and ferromagnetic poles. This type can produce higher flux density and the field is mostly dominated by the mechanical manufacturing accuracy instead of less controllable material property of the magnets. Due to these advantages, the ambitious TESLA-FEL at DESY and SLAC LCLS (Linac Coherent Light Source), SCSS at Spring8 are planning to use the Halbach hybrid type undulator.

Vanadium permendur is popular material for ferromagnetic pole due to its higher saturation. For rare earth magnetic material, higher remanence and higher coercivity is required. Higher remanence is important for higher undulator field. Higher coercivity is preferable for stronger resistance to the radiation damage. Experimental studies show that higher coercivity is very helpful for less degradation in magnetic performance after radiation damages[2]. A good compromise would be Neomax35VH class permanent magnets. It features operating temperature of 160 ^{o}C with remanence of 1.17 T to 1.26 T and coercivity of 11.0 kOe to 12.0 kOe. The intrinsic coercivity reaches up to 25 kOe meaning high resistance to demagnetization. The Neomax 35VH is well verified in SPring8 IVU undulators.

PERIODIC MAGNETIC STRUCTURE

The key features of PAL SASE-FEL can be summarized as achieving most promising 0.1 nm wavelength FEL radiation with shorter saturation length. PAL-FEL undulator system will be IVU which is actively developed and used by SPring8 ID team. Since the advent of SPring8's success in implementing IVU in their storage ring, the adoption of IVU in synchrotron radiation sources have been becoming popular in all major synchrotron radiation laboratories.

To estimate the minimum undulator pole width, we need to know the required transverse roll-off. Pierce parameter is a key parameter in FEL theory and it determines the gain length and the spectral bandwidth. And it naturally gives requirements for undulator field accuracy. For 0.1 nm PLS SASE-FEL case, the undulator period is 22.3 mm and $\rho \sim 3.64 \times 10^{-4}$.

The transverse uniformity of the field should satisfy $\Delta B_z / B_z(x=0) \le \rho$ for sufficient wide range. Although the rms e-beam radius is about r~22μm, we require good field region of ±1 mm for expected operating magnetic gap of 5 mm~7 mm. This redundancy will alleviate alignment requirements and other tolerances with small increase in pole width. The maximum gap is set to 6 mm arbitrarily as the upper limit of the operation since the field will be small for gap larger than 7 mm and there will be no chance of saturated SASE-FEL lasing.

To estimate the required pole width, the transverse roll-off is calculated using ANSYS[3] while varying the pole width with 22.3 mm period and 7 mm maximum operating gap. From the calculation, it is seen that we can safely achieve required tolerance of $\Delta B / B_0 < 1.0\times10^{-4}$ for ±4 mm at pole width of 40 mm. The pole width 40mm is good enough allowing wide good field region. The pole thickness is determined o optimize the effective peak field. The final geometry with major undulator parameters are shown in Table 3.

Table 2: Major Parameters of SASE-XFEL Undulator. The Effective Peak Field at 4 mm is Slightly Higher than the Target Field (B_0=1.0573, K_{eff}=1.4812). This Difference can be used as a Engineering Margin.

Parameter	Value
Pole Gap (nominal)	5 mm
Period	22.3 mm
Pole Dimension (W × H × T)	40 × 20 × 3.30 mm^3
Magnet Dimensions (W × H × T)	50 × 25 × 7.85 mm^3
Effective Peak Field (B_{eff})	1.116 Tesla
Undulator Magnetic Length (L_{und})	4010 mm
Effective K value (K_{eff})	2.314
Fundamental photon energy	12.4 keV
Fundamental photon wavelength	0.10 nm

The transition parts are calculated using RADIA[4,5]. APS[6] and LCLS undulator uses a pole recess and partial strength magnet for the last magnet. In our case, we modify APS scheme and try to use a recess in the last pole and thinner last magnet. Also more traditional ±1/4, ±3/4, ±1 .. scheme is also designed. Simulating the whole undulator is unpractical due to the limited computer resources. As a compromise, only 20 periods are calculated. The typical calculated field profile is shown in Fig 2 for ±1/4, ±3/4 configuration.

SUMMARY

In this report, the IVU program at PAL is briefly summarized. PAL is planning SASE based X-ray FEL and IVU is assumed for its undulator system. A preliminary physical design of the undulator is summarized.

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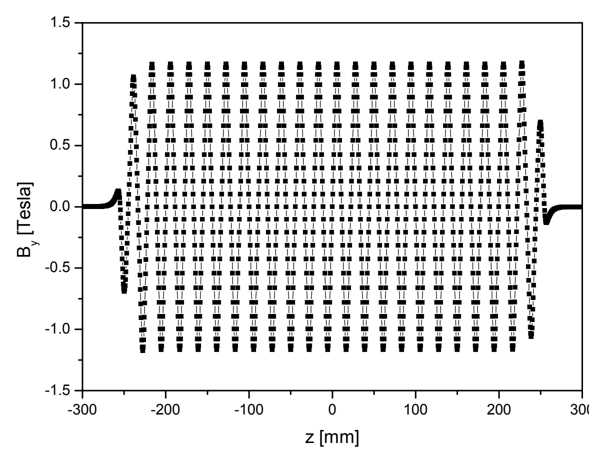

Figure 2: The calculated field profile.