DEVELOPMENT OF IVUN AT POHANG ACCELERATOR LABORATORY*

D.E.Kim#, K.H.Park, H.G.Lee, H.S.Han, Y.G.Jung, H.S.Suh, C.G.Kim, C.D.Park and S.H.Nam
PAL, POSTECH, Korea.

Abstract

Pohang Accelerator Laboratory (PAL) is developing In Vacuum Undulator (IVU). With operating experience of in vacuum revolver undulator from SPring8 and conventional IVU from ADC, the first IVU with 22.3 mm magnetic period will be developed which has 1.8 m magnetic length and 2.2 m flange to flange length which will be installed in the PLS storage ring. The IVU will be equipped with online built-in magnetic measurement for the end regions to assess the accuracy of the assembly, any degradation coming from the radiation damage or high temperature. In this report, the design issues related to the vacuum system, measurement system, and other engineering problems of the IVU will be discussed.

INTRODUCTION

Since the advent of in vacuum undulator (IVU) in 1990 at KEK which was installed at TRISTAN for hard x-ray production, IVU technology became mature at SPring8 in 1997[1]. Nowadays, the IVUs are not regarded risky any more and many laboratories including Swiss Light Sourc (SLS), Pohang Light Source (PLS), Shanghai Synchrotron Radiation Facility (SSRF), Advance Light Source (ALS) are adopting IVUs as their insertion devices. Newer generation light sources with medium electron energy (~3 GeV) are planning to adopt IVUs to utilize 1 Å undulator radiation in their ring. IVUs became very standard device and there are a few commercial supplier that can supply IVUs to customers. 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). PAL is also persuing a X-ray SASE FEL to generate sub picosend pulse width, GW power Xray laser light. To minimize the saturation length, IVU type device is seriouly considered for undulator system. In this report, the IVU devices at PLS is briefly summarized and the preliminary physical design for PAL-FEL undulator will be described.

IN VACUUM DEVICES AT PLS

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 witout reduction of the lifetime at 6mm 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.

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

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#dekim@postech.ac.kr

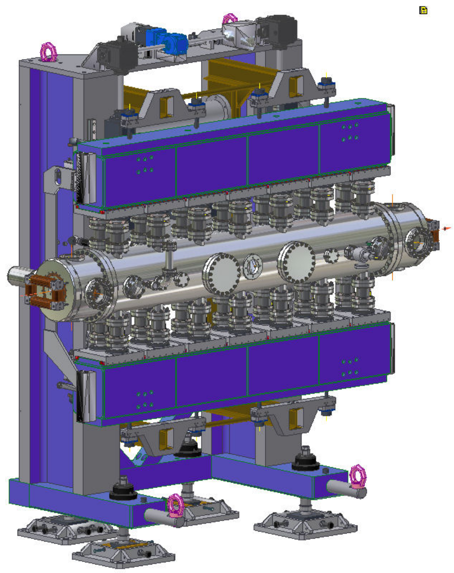

Figure 1: Schematic Drawing of the USAXS IVU

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 PAL-FEL challenging 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 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-FEL are summarized in Table 3.

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/mm^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 °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 IVUN undulators.

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 type.

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 $\Delta B_z / B_z(x=0) \leq \rho$ 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 7 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 $\Delta B / B_0 < 1.0 \times 10^{-4}$ 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 4.

Table 4: Major parameters of SASE-XFEL Undulator.

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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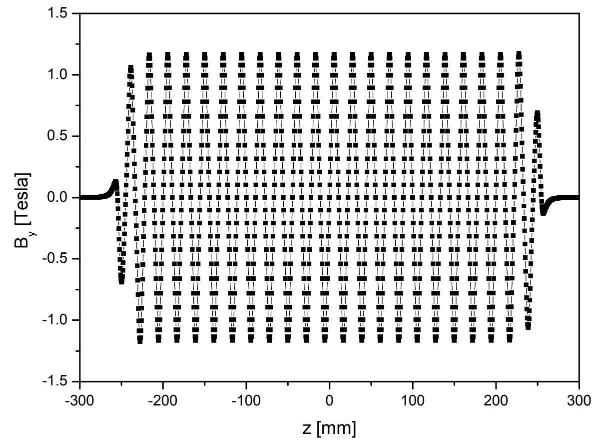

Figure 2: The calculated field profile.