THE MAGNETIC PERFORMANCE OF A DOUBLE ELLIPTICALLY POLARIZED UNDULATOR

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Abstract

A pair of elliptically polarized undulators with APPLE-II type which will be used in a soft X-ray beam line for ARPES and PEEM at SSRF has been built and installed in the storage ring. The undulators can cover the energy range from 20eV to 2000eV of arbitrary polarized light including the horizontal, vertical, elliptical and circular polarization. The quasi-periodic design of the low energy undulator minimizes the contributions of the higher harmonics to be less than 20%. The magnet design and the measured magnetic field performance are presented in this paper.

INTRODUCTION

A soft X-ray beamline for ARPES and PEEM is being built at SSRF. The IDs is a pair of EPUs and can cover the energy range from 20eV to 2000eV of arbitrary polarized light including the horizontal, vertical, elliptical and circular polarization[1]. Two undulators LEID and HEID are used. LEID with the period length of 148mm will produce the low energy photons from 20eV to 200eV and HEID with the period length of 58mm will produce the high energy photons from 200eV to 2000eV with the first and third harmonics. Figure 1 shows the central cone flux spectrum of two undulators with the beam energy 3.5GeV and beam current 300mA. The quasi-periodic design is used for the low energy undulator LEID to minimize the contributions of the higher harmonics.

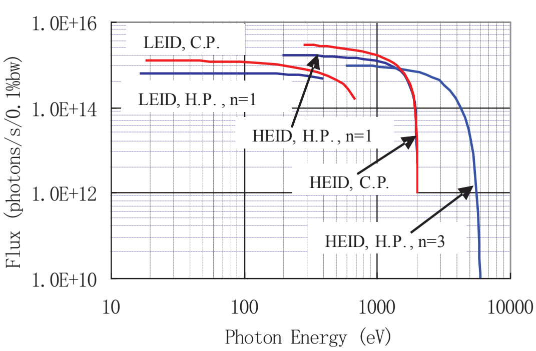


Figure 1: The spectrum of DEPU.

Two undulators have the roughly same magnet array lengths of about 5m and share a common support system with H-type which can move transversely to switch two undulators as shown in Figure 2. 13 motors are used to control the gaps, the phase shifts and the switch of two IDs. The gaps and phase shifts of two IDs are controlled independently.

Figure 2: The photo of DEPU which has been installed in the SSRF storage ring.

MAGNET DESIGN

Both two EPUs are designed with the Apple-II structure which consists of four standard "Halbach-type" permanent magnet arrays with two above and two below the electron orbit[2]. The material of magnet blocks is NdFeB with the grade N38SH and the remanance Br=1.25T. Two arrays at one diagonal can move along the longitudinal direction to provide the various polarization modes including the horizontal linear polarization mode (H.P. mode), the vertical linear polarization mode (V.P. mode) and the circular polarization mode (C.P. mode).

The low energy undulator LEID with the period length of 148mm has 32 periods and each of four magnet arrays consists of 133 magnet blocks including six end blocks. The high energy undulator HEID with the period length of 58mm has 84 periods and each of four magnet arrays consists of 341 magnet blocks. Table 1 lists the design parameters of two EPUs. To fix the magnet on to the holder two cuts of 4×4mm in two corners are designed. The magnet holder can be adjusted within ±0.5mm both in horizontal and vertical positions to perform the phase shimming of the local fields. The clearances between two upper/down arrays improves the uniformities of the vertical fields, decreases the magnetic forces between the arrays and provides the space for the magnet holder adjustment in horizontal direction.

Table 1: The Magnet Parameters of DEPU

Name of Undulator	LEID	HEID
Period Length (mm)	148	58
Number of Periods	32	84
Gap Range (mm)	22 ~ 130	16.5 ~ 120
Dimension of Blocks (mm)	29×22×37	29×29×14.5
Clearance between Arrays (mm)	3	1.5
Magnet Array Length (mm)	4884	4968
Max. Peak Field in H.P. Mode (T)	0.66	0.77
Max. Peak Field in C.P. Mode (T)	0.45	0.43

The low energy undulator LEID is designed with the quasi-periodic magnetic fields to suppress the higher harmonics and it is performed by vertically translating a few H-magnets (blocks magnetized horizontally) by a value d as shown in Figure 3. The choice of the H-magnets to be displaced vertically is made as follows. There are 64 standard H magnets in one array. All H-magnets in one array are numbered from m=1 to 64. The following sequence of z_m is computed for each index m of H-magnets [3]:

$$z_m = m + \left(\frac{1}{\eta} - 1\right)\left\lfloor \frac{m}{\eta+1} + 1 \right\rfloor.$$

Where the bracket [y] denotes the greatest integer less than 1 and η is a dimensionless number also called the inter-lattice ratio. The sequence of z_m is such that z_m - z_{m-1} is equal to either 1 or $1/\eta$. If it is equal to 1 the m-th H-magnet is untouched otherwise if it is equal to $1/\eta$ it is vertically displaced by d. The other three girders are processed symmetrically with respect to the median horizontal plane.

In our design, $\eta = \sqrt{5}$ and d=16mm are selected and the third and the 5th harmonics are suppressed effectively.

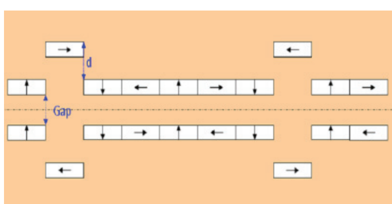
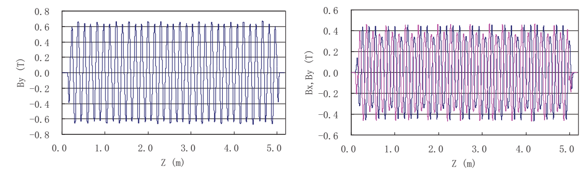


Figure 3: The quasi-periodic design of LEID is performed by vertically translating a few H-magnets by a value d.

MAGNETIC FIELD MEASUREMENT AND SPECTRUM SIMULATION

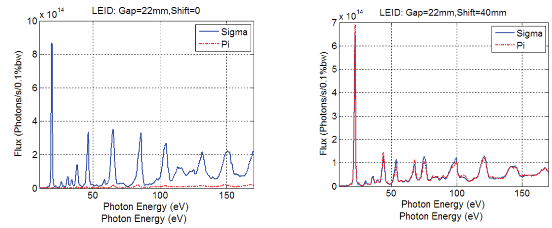
The field distributions on axis at deferent gaps in various polarization modes of both undulators were measured by using a hall sensor with three hall probes which can measure the three components of the magnetic fields. Figure 4 shows the measured quasi-periodic magnetic fields on axis of LEID at the minimum gap of 22mm in H.P. mode and C.P. mode. The peak fields in two polarization modes are about 0.66T and 0.45T respectively.

The spectral flux distributions are also be simulated by using the measured on-axis fields. Figure 5 shows the flux spectrum of LEID in the window $0.36 \times 0.36\text{mrad}^2$ at the minimum gap in two polarization modes with the beam energy 3.5GeV and beam current 300mA. The fundamental photon energies in two polarization modes are 19.1eV and 22.4eV respectively. Table 2 lists the simulated fluxes of the high harmonics as well as the design results. The contribution of the higher harmonics is less than 20%.



(a) (b)

Figure 4: The quasi-periodic magnetic fields on axis of LEID at minimum gap of 22mm in (a) H.P. Mode and (b) C.P. Mode.



(a) (b)

Figure 5: The simulated flux spectrum of LEID in the window $0.36 \times 0.36\text{mrad}^2$ at min. gap in (a) H.P. Mode and (b) C.P. Mode.

Table 2: Comparison of the Spectral Fluxes between Design results and Simulated Results for LEID

	Design Results			Simulated Result		
n	En(eV)	Flux(ph/s/0.1%bw)		En(eV)	Flux(ph/s/0.1%bw)	
1	18.8	9.23×10^{14}	1	19.3	8.93×10^{14}	1
3	56.4	0.48×10^{14}	5.2%	57.9	0.35×10^{14}	4.0%
5	94.0	0.59×10^{14}	6.3%	96.5	0.43×10^{14}	4.8%
7	131.6	0.70×10^{14}	7.6%	135.1	0.94×10^{14}	10.5%

The on-axis fields of HEID were optimized by magnetic shimming to obtain the minimum R.M.S. phase errors according to the magnetic field measurement results at the gap 16.5mm in three linear polarization modes: one H.P. mode (shift=0) and two V.P. modes (shift=±29mm). As the shimming results, the R.M.S. phase errors in three linear polarization modes are 4.3º (shift=0), 6.3º (shift=29mm) and 8.3º (shift=-29mm) respectively. Figure 6 shows the phase error distribution of HEID at the minimum gap of 16.5mm in H.P. mode. The magnetic field measurements show that the peak fields in H.P. mode and in V.P. mode are about 0.77T and 0.51T respectively and the peak field in C.P. mode is about 0.43T.

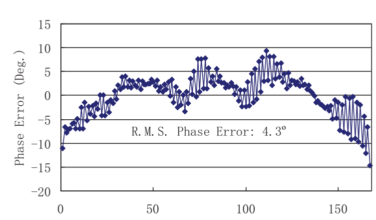


Figure 6: The phase error distribution of HEID at gap 16.5mm in H.P. Mode.

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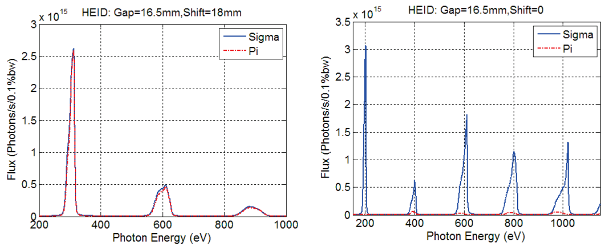
The spectral flux distributions are also be simulated by using the measured on-axis fields. Figure 7 shows the flux spectrum of HEID in the window $0.14 \times 0.22\text{mrad}^2$ at the minimum gap in two polarization modes with the beam energy 3.5GeV and beam current 300mA. The fundamental photon energies in two H.P. mode and in C.P. mode are 202eV and 313eV and the fluxes are 3.07×10^{15} photons/s/0.1%bw and 5.21×10^{15} photons/s/0.1%bw respectively.



(a) (b)

Figure 7: The simulated flux spectrum of HEID in the window $0.14 \times 0.22\text{mrad}^2$ at gap 16.5mm in (a) H.P. Mode and (b) C.P. Mode.

FOCUSING EFFECT ON THE BEAM

The long period length of LEID will introduce a large focusing effect on the electron beam due to the roll-off of the peak field caused by the clearances between two upper/down magnet arrays. For the ID with the sinusoidal magnetic field of period λ_0, the focal lengths in the horizontal/vertical planes can be written as[4]:

$$\frac{1}{F_x} = -5.7\times10^{-4}\left(\frac{\lambda_0}{E}\right)^2 L\frac{\partial^2(B_{xm}^2+B_{ym}^2)}{\partial^2 x},$$
$$\frac{1}{F_y} = -5.7\times10^{-4}\left(\frac{\lambda_0}{E}\right)^2 L\frac{\partial^2(B_{xm}^2+B_{ym}^2)}{\partial^2 y}. \quad (1)$$

Where E is the beam energy, L is the length of ID, $B_{xm,ym}$ are the peak fields and vary with the magnet array shift. For the non-ideal magnetic field of an undulator, the focal length can be written as:

$$\frac{1}{F_x} = -\frac{\alpha^2}{2}\int_{-\infty}^{\infty}\frac{\partial^2}{\partial x^2}\Phi(x,y,z)dz,$$
$$\frac{1}{F_y} = -\frac{\alpha^2}{2}\int_{-\infty}^{\infty}\frac{\partial^2}{\partial y^2}\Phi(x,y,z)dz. \quad (2)$$

Where $\alpha = \frac{ec}{E}$, e is the electron charge, c is the light velocity, and

$$\Phi(x,y,z) = \left(\int_{-\infty}^{z} B_x dz\right)^2 + \left(\int_{-\infty}^{z} B_y dz\right)^2. \quad (3)$$

The focusing effect will produce a tune shift:

$$\Delta\nu_{x,y} = \frac{\bar{\beta}_{x,y}}{4\pi F_{x,y}}, \quad (4)$$

Where $\bar{\beta}_{x,y}$ is the average beta function along the undulator length.

To compensate the tune shift, an additional quadrupole field $(GL)_{add.}$ was added in LEID by putting the L-shaped shims at the positions where the beta function is equal to β_m:

$$(GL)_{add.} = -\frac{\bar{\beta}}{\beta_m}\cdot(GL)_{\text{int.}} = \frac{\alpha\cdot\bar{\beta}}{2\beta_m}\int_{-\infty}^{\infty}\frac{\partial^2}{\partial x^2}\Phi(x,y,z)dz. \quad (5)$$

Figure 8 shows the intrinsic quadrupoles calculated from formula (5) and the additional quadrupoles measured by using the flipping coil.

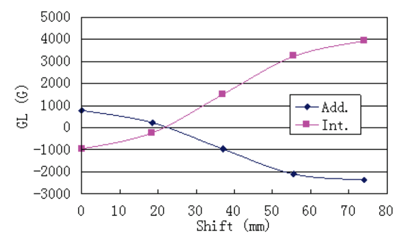


Figure 8: The intrinsic/additional quadrupoles of LEID vs. magnet array shift.

CONCLUSION

A pair of EPUs which covers the energy range from 20eV to 2000eV with arbitrary polarized light has been built and installed in the SSRF storage ring. The magnetic fields measurement results show that the R.M.S. phase error of HEID at the minimus gap is about 4.3º and with the quasi-periodic undulator of LEID the contribution of higher orders for the low energy photons can be reduced to less than 20%. The additional quadrupoles were added by putting the L-shims to compensate the intrinsic focusing effect on the electron beam.

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