Performance of an Elliptical Polarization Undulator in TPS

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Abstract. The advantages of an APPLE-II elliptically polarized undulator (EPU) are a wide range of tuneable energy and a large polarization rate. National Synchrotron Radiation Research Center (NSRRC) therefore decided to install a 4-m EPU with period length 46 mm at a beamline for soft x-rays in Taiwan Photon Source. Magnetic-field shimming was developed; the final magnetic performances of the phase error, electron trajectory and multipole errors are presented in this paper.

1. Introduction
A 4-m elliptically polarized undulator (EPU46) was chosen to provide great flux at photon energies 0.30~1.5 keV in Taiwan Photon Source (TPS); Huang et al. [1] reported the detailed parameters of EPU46. The spectral bandwidth on axis for an insertion device is affected by variations of the magnetic field; EPU46 with 1320 magnet blocks must therefore be individually adjusted to maximize the spectral flux. At the initial measurement, the worst r.m.s. phase error was 40°; the r.m.s. trajectory was 18 μm in the linear-polarization mode. A large r.m.s. optical phase error deteriorates the spectral flux for high harmonics of the undulator, especially for a storage ring of moderate size such as TPS that uses linear polarization of the third to eleventh harmonics.

2. Procedures to correct the field variations
To correct the field of an EPU, we must first correct the phase error in four polarization modes -- horizontal and vertical linear polarization (HLR/VLR), and left and right circular polarization (LCR/RCR) -- to provide satisfactory flux intensity. Secondly we must decrease the integrated multipoles to allow stable dynamics of the electron beam in the storage ring. A standard operating procedure for shimming an EPU in NSRRC is described in the following section.

2.1 Correction of longitudinal misalignment in the each pair of magnet arrays.
The precision of manufacture of an EPU magnet block is critical. If there is misalignment caused by an accumulated error of magnet block size between the upper and lower magnet arrays, the \( \frac{dI_y}{<I_y>} \) (relative deviation of the first field integral in a half period length of the undulator; \( I_y = \int B_y \, dz \)) distributions in RCR and LCR modes differ[1][2]. Figure 1 shows several misalignment locations, for which the \( \frac{dI_y}{<I_y>} \) distributions differ in the circular-polarization modes; as a result, the corresponding distribution of phase error varies, shown in figure 2. To correct the longitudinal misalignment, we inserted tape spacer (Kapton) between the magnet subsets to compensate the size error.
2.2 Correction by vertical shimming on $dI_x/<I_x>$ and horizontal shimming on $dI_y/<I_y>$

Vertical shimming serves to adjust the vertical position of a magnet block with the vertical field; it alters not only the $dI_x/<I_x>$ field distribution, but also 30 % of $dI_y/<I_y>$ [1]. We must therefore correct the vertical field before the horizontal field. The error storage [3] is an accumulated integral deviation $dI_x/<I_x>$; if the distributions of error storage and phase error are similar, a large value of $dI_x/<I_x>$ must be corrected first. In figure 3, the large $dI_x/<I_x>$ is responsible for a large slope of the gradient of the phase error that must be corrected first.

![Figure 1. Distribution of first integral deviation in three polarizations.](image1)

![Figure 2. Corresponding phase error from three polarizations.](image2)

![Figure 3. Error storage and phase error.](image3)

![Figure 4. Trajectory correction by shimming the kicker value.](image4)

2.3 Vertical and horizontal shimming on the kicker value

A large wandering of the beam trajectory is responsible for a large r.m.s. phase error and a shift of the fundamental photon energy. As a result, we must diminish the trajectory wandering by decreasing the first integral field deviation. The kicker value [3] (kicker_value($n$) = ($I_{x,y,n}$ - (-1)$^n$<I_b><I_b>)/<I_b>, for pole number $n$) explains how the extra first integral differs from the average result in trajectory wander; the correct kicker value is an efficient way to achieve a straight trajectory. Figure 4 shows an example of a trajectory modification after six poles were shimmed. The criterion for the r.m.s. trajectory is 5 μm.

2.4 Iterations between step 2.1 and step 2.3

An automatic procedure to correct 30 poles concurrently was tried, but the results were less satisfactory than we predicted. Several iterations to achieve a convergence results were thus necessary.

2.5 Assembly and correction of four magnet arrays for a transverse misalignment between magnet arrays.

Four magnet arrays were assembled after pairs of magnet arrays were shimmed. Transverse misalignment between neighboring magnet arrays must be corrected with spacer tapes (Kapton), because transverse misalignment results in a difference between $dI_x/<I_x>$ distributions in RCP and LCP.
2.6 Vertical and horizontal fine tuning on $d_{i,j}/<I_{i,j}>$ and kicker value
After assembly of four magnets, the r.m.s. phase error was measured to be $5^\circ$, which proves that, if an EPU uses a symmetric motion to generate polarization, pairs of up-down magnets can be shimmed individually. Fine tuning of the corrections of the vertical and horizontal fields was performed; figure 5 shows the magnetic performance from an array of four magnets assembled to the final condition.

![Figure 5. Magnetic field performance before and after fine tuning.](image)

2.7 Adjustment of the end-pole magnet and correction of integrated multipoles
The adjustment of the upstream end pole magnet serves to adjust the condition of the trajectory injection at the entrance of an EPU; adjustment of the end pole position hence corrects the injection and exit angle of the trajectory. Integrated multipoles that arise from small errors of the field integral caused by errors of the permanent magnet block are additive. Magnet chips in a series with magnetic-field component of the opposite strength are thus placed in the integral path to nullify that EPU46 field integral. The longitudinally traversing field is measured with a stretched-wire system. A simulator, figure 6, predicts the field integral added from the magnet chips (magic finger) and the undulator.

![Figure 6. Simulator for correction of the transverse first integral.](image)

3. Performance of EPU46
3.1 R.m.s. phase error and r.m.s. trajectory
The results of the field correction measured without correctors at the end of the undulator appear in Table 1 below. The measurement on axis was recorded at the minimum gap 15 mm. The requirement are a r.m.s. phase error less than $3^\circ$ in all phase modes, r.m.s. $dB/B$ less than 0.5 %, and the r.m.s. trajectory for 3 GeV less than 5 $\mu$m. The r.m.s. phase mode and r.m.s. trajectory measured for varied gap and polarization are shown in figures 7 and 8 respectively. These results satisfy the requirements.

| Polarization Mode | r.m.s. trajectory ($\mu$m) | r.m.s. phase error (degree) | r.m.s. $dB/B$ (%) |
|-------------------|---------------------------|-----------------------------|------------------|
| HLP               | $B_z$: 3.52               | 3.01                        | $B_z$: 0.20      |
| VLP               | $B_z$: 2.88               | 2.51                        | $B_z$: 0.24      |
| RCP               | $B_z$: 2.52               | 1.78                        | $B_z$: 0.29      |
| LCP               | $B_z$: 2.41               | 1.78                        | $B_z$: 0.48      |
|                   | $B_z$: 2.34               | 2.40                        | $B_z$: 0.34      |
|                   | $B_z$: 3.67               | 2.40                        | $B_z$: 0.40      |

3.2 Integrated multipoles
The integrated multipoles were measured in a range $\pm$ 15 mm and fitted with a polynomial of fifth order. The results appear in table 2. The variations of the $B_z$ integrated multipoles in various phase modes are small, and the magnet chip correction can nullify the transverse first integral, but the integrated multipoles in $B_z$ varied with the phase mode, especially in LHP; a method of actively shimming the current strip used for Bahrdt J et. al.[4] must be implemented to correct the dynamic integral multipoles.
Table 2. Integrated multipoles measured in EPU46.

| Phase mode | Dipole (G cm) | Quadrupole (G) | Sextupole (G cm\(^{-1}\)) | Octupole (G cm\(^{-2}\)) |
|------------|---------------|----------------|---------------------------|--------------------------|
| B\_y B\_x  | B\_y B\_x  | B\_y B\_x  | B\_y B\_x  | B\_y B\_x  |
| VLP        | -40 15       | 0.7 3       | 36 -95       | 70 19        |
| LCP        | -46 38       | 17 92      | 65 -112\(^a\) | 56 -60       |
| HLP        | -42 -4       | 55 240\(^a\) | 51 -49       | 35 -173\(^a\) |
| RCP        | -30 43       | 44 25      | 31 -79       | 28 -6        |

\(^a\) the component is out of specification.

Figure 7. r.m.s. phase error as function of gap and phase mode.

Figure 8. r.m.s. trajectory as a function of gap and phase mode.

3.3 Energy Spectrum

As the EPU provides an enhanced flux in the range 0.3~1.5 keV of photon energy, the output of synchrotron radiation was calculated with SPECTRA 9.0 [5] based on the measured magnetic field. The photon flux density was compared with an ideal case; for VLP and HLP modes (figure 9), the ratio between measured and ideal values is greater than 83 % up to the 13th harmonic; for LCP and RCP modes (figure 10), the flux density in the fundamental harmonic attains 93 % of an ideal case.

Figure 9. Flux density spectra in linear polarization.

Figure 10. Flux density spectra in circular polarization.

References

[1] Huang JC, Hwang CS, Lin FY, Chen JT, Chang CS 2012 Trans. Appl. Super. 22 4100705
[2] Hwang CS, Chang CH, Lin FY, Chen HH and Fan TC 2002 Rev. Sci. Instrum., 73, 1436
[3] Tanaka T, Seki T and Kitamura H 2001 Nucl. Instrum. Method Phys. Res., Sec. A 465 600
[4] Bahrdt J, Frentrup W, Gaupp A, Schen M and Westefeld G 2008 Proc. EPAC08 (Genoa, Italy) p 2234
[5] Tanaka T and Kitamura H 2001 J. Synchrotron Rad. 8 1221