MULTIPOLE AND END-FIELD SHIMMING RESULTS OF EPU46 AT THE TPS

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Abstract

Multipole error and the first and second field integrals of EPU46 require shimming to fulfill the tolerance requirements of beam dynamics. In this paper, we describe the field correction, including central-field and end-field shimming procedures, and the results for EPU46 at TPS. End-pole shimming for the first and second field integrals serve to adjust the beam trajectory, and magic fingers to decrease the multipole error. For the active multipole shimming for Apple-II type undulators , a trim-long-coil array is used to compensate for multipole error. This scheme efficiently eliminates a phase-dependent skew quadrupole error.

INTRODUCTION

An elliptical polarizing undulator (EPU) of Apple-II type has been extensively used as a source of polarized soft x-rays because of its widest range of tunable energy and greatest rate of polarization. For these reasons, two EPU with period of length 48 mm and one of 46 mm are under construction and will be installed in Taiwan Photon Source (TPS) in 2014. Two EPU48 are under mechanical manufacture and inspection. For the EPU46, the central-field shimming is complete and end-field shimming will be finished.

Techniques to correct the central field were developed at NSRRC [1,2]. The major concept is to increase the field homogeneity and to decrease the deviation of the first integral at each half period by swapping magnet blocks and adjusting the magnet holders. Regarding the end-field shimming, we use conventional schemes, including end-pole adjustment and magic fingers, to correct the trajectory of the electron beam and multipole error. An Apple-II type EPU is well known to have a strongly non-linear effect on the electron beam because of its small region of effective field. Passive shimming, using L-shaped iron shims [3] and magic fingers [4], can improve this deficiency only for a given phase mode. For the contribution of the first integral between various phase modes, an active shimming scheme using current-carrying strips surrounding a vacuum chamber has been proposed and implemented [5]. Although this scheme has been demonstrated to compensate the multipole scale and to maintain the tuning shift, it limits the minimum gap, especially for a desired strong field. For our EPU46 case, the space between a vacuum chamber and a magnet surface at the minimum gap is less than 1 mm; we must hence adopt other active shimming methods. In this paper, we show the results for the central-field and end-field corrections, especially the active multipole shimming using long coils.

CENTRAL-FIELD SHIMMING

A procedure of central-field shimming has been developed in NSRRC. The first step is to correct the first field integral at each half period measured at a position on the axis. This correction takes into account also the error-storage (ES) function, which is an accumulated integral deviation. This ES function has been shown to be connected to the phase error [6]. The second correction is based on field storage (FS), which explains how the extra first integral from the average results in a trajectory wander. The final results of phase error for various phase modes are less than 4^{o} at the minimum gap, 13.5 mm, as shown in Fig. 1. These results maintain a great spectral intensity, even for the energy at high harmonics. For example, the flux density of the horizontal linear (HL) mode at the thirteenth harmonic energy is greater than 80 % of the ideal value. For the circular-polarization mode (CP), the flux density in the fundamental harmonic attains 91 % of an ideal value, which is large enough to satisfy the users of soft X-rays.

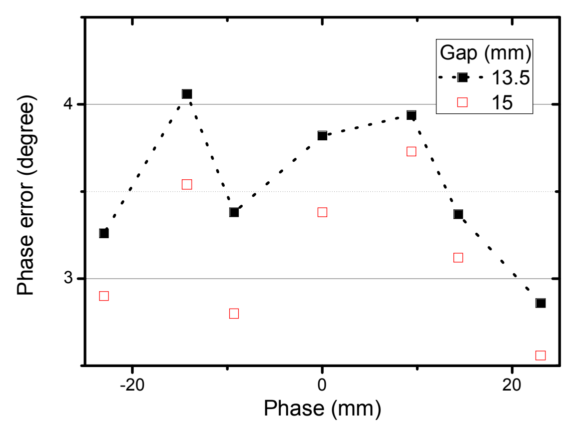

Figure 1: r.m.s. phase error as a function of gap and phase.

END-FIELD CORRECTION

To correct the error of the electron beam trajectory and the multipoles, two processes are used: the first is a conventional passive shimming method, including end-pole adjustment and magic fingers. The second is an active shimming method using a long coil. On adjusting the end pole, the electron trajectory either horizontal or vertical can be corrected to approach an ideal trajectory.

Figure 2 shows that the trajectory of a circular mode has been corrected to approach the ideal trajectory.

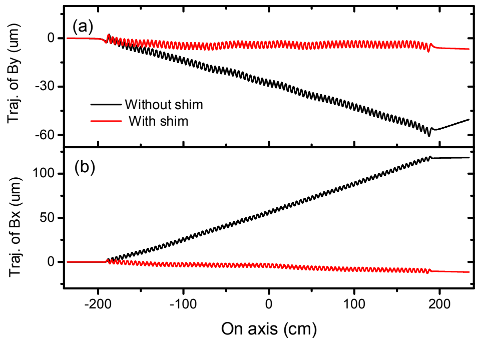

Figure 2: Trajectory of the electron beam on axis at a circular polarization mode. (a) Trajectory of B_y. (b) Trajectory of B_x.

To correct the multipole error, we use magic fingers to flatten the first integral of the horizontal (I_x) and vertical fields (I_y). Figure 3(a) shows the structure of a magic finger, which is an array of magnet chips placed at the ends of the EPU. In the case of EPU46, each row has two magic fingers, upstream and downstream.

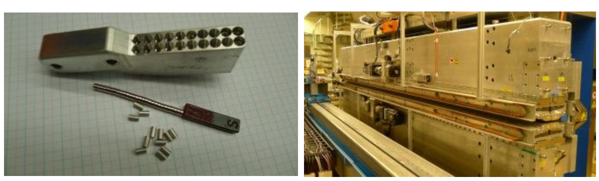

Figure 3: Two methods to correct multipole error. (a) A magic finger structure, magnet chips and aluminium spacers. (b) A long coil loop.

Based on this scheme, I_x and I_y are flattened within ±50 G cm. Figure 4 shows the result for the circular polarization mode. Because the contribution of the magic fingers is only the superposition of each magnet chip, this scheme can efficiently simulate and manipulate the distribution of I_x and I_y, so to improve greatly the multipoles for a given phase mode.

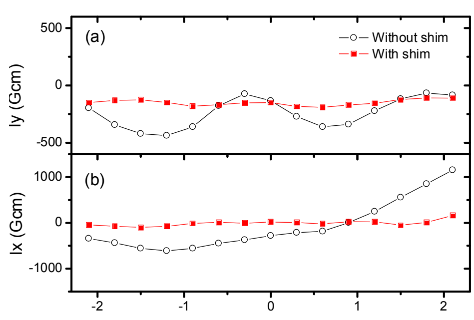

Figure 4: Distribution of the first integral of horizontal (I_x) and vertical field (I_y) for the circular polarization mode.

The advantage of the EPU is to provide radiation with various polarizations via variation of the position of four row magnets, which means that each mode must decrease the influence of the beam dynamics. The main issue of an EPU is the phase- dependent skew quadrupole. ALS attempted to find the reason for this effect using magnetic or mechanical measurements as well as simulations, but they were unsuccessful [7].

In the case of EPU46, the multipole error of normal terms, contributed from the transverse dependence of I_y, has a similar behavior for each mode, but the skew terms, contributed from I_x, exhibit an inconsistency between each mode. This phase- dependent skew quadrupole effect is observed also in our case. The reason is a discrepancy about 160 G cm between the HL and +VL modes. Before the use of magic fingers, this discrepancy can be observed at x = -0.5 cm, as seen in Fig. 5(a). After the use of magic fingers to flatten the distribution of the first integral, this discrepancy remains, as seen in Fig. 5(b), which causes the skew quadrupole term to exceed the specification for each phase mode. The multipole error of each mode is summarized in Table 1. The skew quadrupole specification must be less than 50 G to diminish the influence of a dynamic aperture. The -VL mode is beyond specification up to 91 G.

We attempted to investigate this effect using simulation with software (TOSCA). There is no evidence to explain how this effect comes from magnetic errors or magnet interactions. We observe only the phase-dependent dipole effect due to the non-unit effect [8].

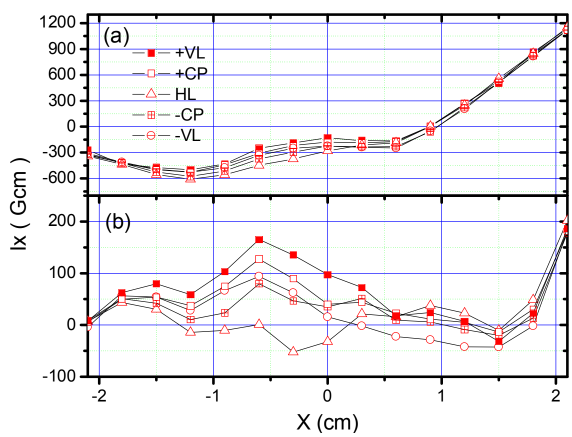

Figure 5: First integral of horizontal field (I_x) along the longitudinal direction (a) without, and (b) with, the magic finger correction.

To diminish this discrepancy between each mode, four long loops are built to generate a quadrupole field. Figure 3(b) illustrates this structure. Unlike the structure of BESSY, which is an array of wires attached to a vacuum chamber, our long coils are hung on the outside of the magnet array, which does not occupy the space of the gap. This structure can provide the three first-harmonic fields with an appropriate current supply. Each loop has twelve turns, of length 3.74 m, and is separated by 30 cm. The magnetic field in the center of the coils is about 15 G. The first integral on the axis of length 3.74 m is large enough to influence the beam dynamics. Figure 6 shows the

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experimental data and the results of simulation. At a current supply with 120 A T, the skew quadrupole term is corrected up to 50 G; this amount provides a solution to the skew quadrupole effect. The experimental data consist also of the simulated value, indicated with the solid line in Fig. 6. The normal quadrupole term can also be corrected up to this value, but alters the polarity of current into the loops. Based on this scheme, multipoles of each phase mode are corrected within specification, as Table 1 shows. This scheme decreases the significant impact of the EPU-related variation of the vertical beam size.

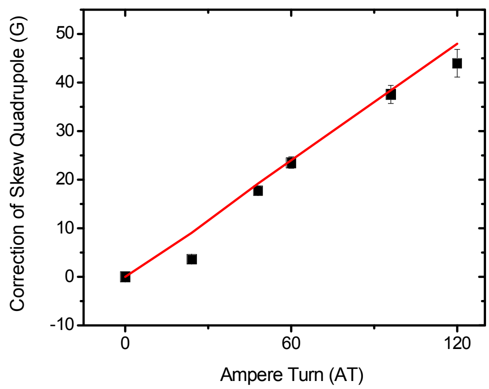

Figure 6: Correction of the skew quadrupole term using long coils. Squares mark the experimental data; the solid line is from the simulation.

Table 1: Multipole Analysis of EPU46 for each Phase Mode at Gap 15 mm

Phase mode	w/o correction			
	Di.	Quad.	Sext.	Octu.
+VL	76	-89	-5	28
+CP	46	-68	3	23
HL	-18	-8	23	9
-CP	22	-48	8	18
-VL	11	-91	10	29

Phase mode	with correction			
	Di.	Quad.	Sext.	Octu.
+VL	74	-35	-6	23
+CP	46	-17	2	23
HL	-18	-8	23	9
-CP	22	-48	8	18
-VL	12	-40	10	28

To verify the reliability of the long coils regarding the temperature issue, temperature sensors are attached to magnets and embedded into the coil to sense the temperature increase of the magnet and the maximum temperature. For the largest current (120 AT), the magnets have no temperature increase. The temperature of coil increases up to 42^{o} during 8 h, as seen in Fig. 7.

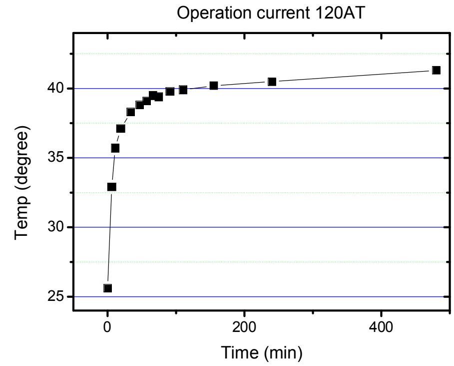

Figure 7: Temperature variation of long coils operating at 120 AT.

CONCULSION

An elliptically polarized undulator is subject to field correction. A procedure of central-field shimming has been developed that efficiently decreases the RMS phase error from 40^{o} to less than 4^{o} for each phase mode. It promises to provide highly intense radiation. For the end-field correction, magic fingers provide a suitable method to decrease greatly the multipole error, but only for a given phase mode; there is a discrepancy between each mode, causing the phase-dependent skew quadrupole effect. Long coils served to decrease this impact. At 120 AT, the skew quadrupole term can be corrected up to 50 G. This scheme provides an appropriate method to correct the multipole error and to increase the stability of the electron beam.

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