

# FIELD CORRECTION OF NSRRC ELLIPTICALLY POLARIZED UNDULATOR 46

Jui-Che Huang, Ching-Shiang Hwang, Jun-Tune Chen, Cheng-Hsiang Chang, Fu-Yuan Lin  
National Synchrotron Radiation Research Center, Hisnchu, Taiwan.

## Abstract

An elliptically polarized undulator (EPU) is a common insertion device in an electron accelerator storage ring to provide synchrotron radiation with varied polarization. Correction of the field is an essential step in construction of an EPU; it can prevent the photon flux decreasing from the ideal case and ensure that the trajectory of the electron beam and the angle of the EPU do not affect the electron orbit. The conventional method to correct the field is tedious and strongly based on experiment. Here we describe the detailed correction of the magnetic field and present practical results from an EPU at NSRRC.

## INTRODUCTION

The elliptically polarized undulator is a device with an "APPLE-II" structure that is extensively used because it has the widest range of tuneable energy and a large rate of circular polarization for a synchrotron light source.

An elliptically polarized undulator of period length 4.6 mm (EPU46) was constructed to be installed in Taiwan Photon Source (TPS) in 2013. The main parameters of EPU46 are shown in table 1; engineering construction can be found in reference [1]. At this time the mechanical inspection of EPU46 has been done; as the subgirder has a deformation at least 0.02 mm in the longitudinal dimension, field correction is required to compensate for mechanical errors. The initial magnetic performance is still outside specification; in particular, the phase error reaches 40°. A procedure to correct the field is thus inevitable to achieve a uniform magnetic field.

A standard operating procedure of EPU field correction is becoming established, which will be beneficial for a future mass-production stage and for training purposes. This paper describes the field corrections processes in NSRRC.

Table 1: Main parameters of EPU46

Type	Elliptically undulator , out of vacuum	Polarized
Magnet	Pure, Nd-Fe-B	
Remanence field Br /T	1.22~1.28	
Coercive force Hc /kOe	25	
Number of periods	83	
Period number/mm	46	
Range of gap / mm	$13 \leq g \leq 22$	
Maximum field strength	$B_y=0.83$ T, $B_x=0.59$ T	
K	$K_{y,max}=3.6$ , $K_{x,max}=2.6$	

## MEASUREMENT SYSTEM

In the initial stage, the field corrections were performed with a Hall-probe system. In Cartesian coordinates the photon propagation is defined as along the z direction; the horizontal axis is the x direction and the vertical axis is the y direction. Two separate Hall-probe sensors are used to measure  $B_x$  and  $B_y$ ; this method can prevent a Hall effect from the Hall-probe sensor. The precision of movement of the Hall probe system is under 10  $\mu\text{m}$ ; the pitch yaw roll angle is under 10 arc-sec for travel along the longitudinal direction.

An APPLE-II EPU has two modes to produce circular polarization. One is a symmetric motion in which A, D and B, C arrays move synchronized, and the other is an antisymmetric mode in which A, C and B, D arrays move together. In NSRRC, EPU46 will operate in a symmetric motion; field correction will hence be performed in a phase mode separately on the A, C and B, D magnet arrays. Once the field of each pair of magnet array is corrected, the four magnet arrays will be assembled for the field correction.

In the first few trials, we used field correction in situ by flipping and swapping magnet blocks [3]; this method is effective for a linear undulator with a short period. EPU46 has a large magnetic attractive force between the magnets and accessing the magnet array from the frame side is difficult, so we decided to shim the magnet position for field correction.

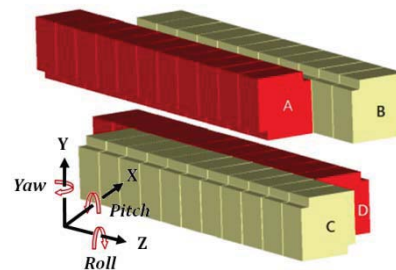


Figure 1: Sketch of an EPU46 magnet array.

## MAGNET ASSEMBLY

The magnet assembly (figure 2) consists of 5, 7 or 9 magnet blocks; each magnet block is attached to the magnet holder, and a sliding wedge can adjust the height of the magnet. Tuning the wedge screw and placing shim pads moves the magnet block toward, or away from, the center line of the magnet array.

The dovetail of the magnet base assembly mates with the dovetail of the subgirder. The brass keeper backed up with M5 set screws is used to tighten the magnet base and the subgirder; details are shown in Figure 3. The large torque (over 35 kgf-cm) firmly fixed the magnet base and the subgirder, but it caused many troubles on the screw strip. Various smaller torques were tested with assembly repeatability and reproducibility of the magnetic performance; 20 kgf-cm was determined to yield sufficient reproducibility and the set screws have less trouble on the strip.

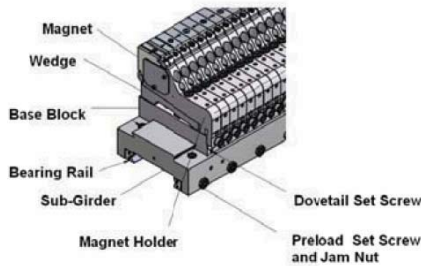


Figure 2: Magnet Assembly [2].

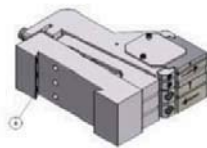


Figure 3: Dovetail of the EPU46 magnet array [2].

### ASSEMBLY REPEATABILITY

The repeatability of the magnetic performance is important; a special tool was therefore used during the assembly to keep the magnet block tightly pressed. The repeatability tests were measured for the most important temperature, which is controlled at 25+0.5 oC. The repeatability of  $dI_{x,y}/I$  was measured to have a maximum deviation 0.2 %.

### ERROR OF MAGNET MANUFACTURE

Errors in the manufacture of the magnets might cause deviations from an ideal field profile; these errors include magnet size, magnetization direction and permeability, but only the size error is readily compensated with mechanical solutions. The manufacturing tolerance of the magnet block was specified as +0.05 mm; measurements of the magnet assembly size show a maximum deviation 0.2 mm from an ideal designed value. To solve this problem, a sorting technique was applied to the magnet assembly arrangement, and aluminium spacers 0.1~0.2 mm thick were placed between magnets to diminish the misalignment error between the A,C and B,D magnet arrays. The results of variation of  $dI/I$  in various phase modes are shown in figure 4. Without the spacer correction,  $dI/I$  varies with the phase mode. After the correction, only a few poles have local misalignment

problems, but increasing the spacing between magnets longitudinally does not alter  $dI/I$  characteristics for phase mode equal to 0. The  $B_x$  field is less sensitive to misalignment errors of the magnet array.

### FIELD CORRECTION

The designed space between magnet arrays A,B and C,D is 0.7 mm; a large space deteriorates the region of effective field of the transverse magnetic field. A small gap results in a large attractive force. For these reasons and consideration of the size of the vacuum chamber, there is only 0.15 mm in vertical and horizontal directions for shimming. In the case of EPU46, if  $dB_{x,y}/B$  is over 2 %, the space is insufficient for shimming and this magnet block must be replaced.

The deviation of the half period integral at each pole was measured at an on-axis position; the half period integral  $\lambda u/2 \leq z \leq z+\lambda u/2$  is calculated with equation 1.

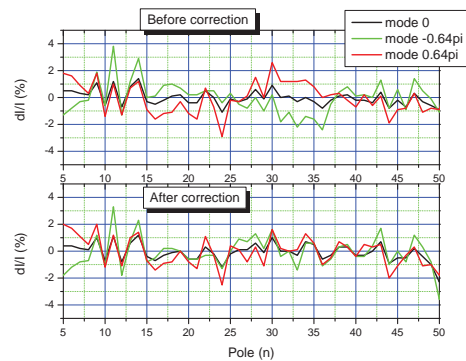


Figure 4: Correction for magnet array misalignment.

$$ES(n) = \sum_{m=1}^n \left( \frac{|I_n| - \langle I \rangle}{\langle I \rangle} \right) \quad (1)$$

$$\text{Where } I_{n(x,y)} = \int_z^{z+\frac{\lambda u}{2}} B_{x,y} dz$$

in which n indicates the n'th pole.

The phase error is calculated with equation 2 [4]; a large phase error results in a flux spectrum intensity smaller than the ideal case, especially in the high harmonics. The phase error shall therefore be kept as small as possible.

$$\Delta\phi = \frac{2\pi}{\beta} \frac{\delta s}{\lambda_r} \quad (2)$$

in which  $\beta$  is the ratio of velocities of the electron and light,  $\lambda_r$  is the radiation wavelength and  $\delta s$  is the standard deviation of the trajectory length in a half period.

The accumulated integral deviation is calculated in equation 2 of Tanaka et al [3] that describes the accumulation of the integral deviation as an error storage,

and it has a correction of the phase error. As the accumulated results reflect a positive or negative trend of the first field integral, one can readily determine whether the positive or negative first field integral has to be corrected. The first function is effective for a large decrease of phase error. We can readily decrease the phase error from 50o to 20o by correcting the large deviation of the first field integral.

Only the poles (magnets with vertical fields) are generally shimmed; shimming the poles (magnets with horizontal fields) contributes a third of the value of altering dI/I of the two neighbouring magnet blocks.

Horizontal shimming has a main influence on the By field, but the Bx field becomes slightly altered. According to our strategy, vertical shimming is undertaken before horizontal shimming; after a few iterations we expect both dIx/I and dIy/I variations to be within 1 %. The final condition of the deviation of the first field integral should be controlled within 0.5 %.

The trajectory of the electron beam becomes a dominant parameter when the phase error becomes small. The function of the kicker is defined in equation 3; the kicker value explains how the extra first integral from the average results in trajectory wander.

$$FS(n) = \frac{\sum_{m=1}^n I_n - (-1)^n \langle I \rangle}{\langle I \rangle} \quad (3)$$

In EPU46, the maximum fields at odd poles are positive. The summation of the kicker values shows the accumulation of the error deflection; from this we can estimate the electron trajectory. It is important to test the kicker value during the correction, because a strong kicker value reflects the turning points of the trajectory.

Some typical results (figure 5) show the field correction based on the kicker value and the trajectory. There are strong kickers among poles 110-120, so by decreasing the positive kicker the variation of trajectory wander decreases and the phase error greatly diminishes from 10o to 3o. The results show that this method is efficient for field correction: by tuning the group of poles with a positive or negative kicker, the electron trajectory becomes straighter and the phase error decreases.

### THE FIELD CORRECTION

The procedures for field correction without a correction of the end pole and multipole components are proposed in NSRRC; the first step is to correct the longitudinal misalignment, followed by replacement of a poor magnet, a large first integral deviation correction in vertical shimming and then horizontal shimming. Trajectory corrections suppress the phase error. Several iterations decrease both the phase error and the trajectory deviation.

In practice, we devoted most time to correction of the longitudinal misalignment. For the shimming correction of one pair of 3.8-m magnet arrays, less than two weeks was required to achieve a phase error less than 5o and a trajectory RMS less than 5 μm.

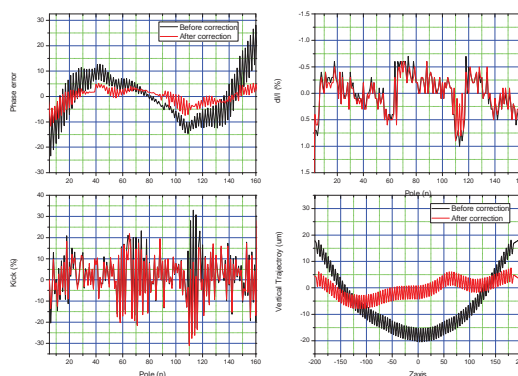


Figure 5: Field corrections on trajectory.

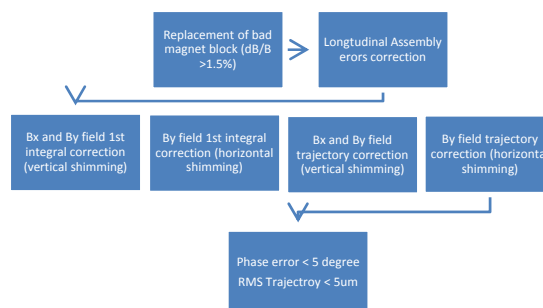


Figure 6: Field correction procedures in NSRRC.

### SUMMARY

An elliptically polarized undulator (EPU) is under field correction. The initial phase error for A,C and B,D were measured at 40° and 28° respectively. Misalignment between the upper and lower magnet arrays causes the first field integral variations in various phase modes. After shimming, the phase error for the Bx and By fields in separate pair arrays was measured to be under 5o and the RMS electron trajectory is under 5 μm. Assembly and field correction of the four magnet arrays is in progress. Finally, multipole correction will be performed during the wire measurement, and magic fingers with small magnet chips inside will be used for multipole error correction.

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