MAGNETIC FIELD ADJUSTMENT OF A POLARIZING UNDULATOR (U#16-2) AT THE PHOTON FACTORY

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Abstract

We have been developing a rapid-polarization-switching source at the B15-16 straight section in the Photon Factory (PF) 2.5-GeV ring. The source consists of two tandem APPLE-II-type elliptically polarizing undulators (EPU), namely U#16-1 and U#16-2, and a fast kicker system. These two EPUs are designed to obtain soft x-rays in the energy region from 200 eV to 1 keV under various polarization states. We constructed U#16-1 and installed it in the PF ring in March 2008. Operation of U#16-1 for user experiments has been ongoing since April 2008. [1]

The construction of the second EPU, U#16-2, is underway, and it will be installed in the PF ring this summer. In this paper, we report the result of the adjustment of the magnetic field of U#16-2.

INTRODUCTION

At the 2.5-GeV Photon Factory (PF) storage ring, we have been developing a rapid-polarization-switching source in the VUV and soft X-ray region to be installed in the straight section between bending magnets B15 and B16 in the PF ring. This is one of the two longest (8.9 m) straight sections in the PF ring since reconstruction to upgrade the straight sections. [2]

We plan to construct a rapid-polarization-switching source consisting of a fast kicker system and two identical elliptically polarizing undulators (EPU), U#16-1 and U#16-2, to be installed in tandem in the B15-B16 straight section. The target energy region of this light source is from 200 eV to 1 keV, with the first harmonic radiation of the EPUs. The frequency for switching of the polarization states is designed to be more than 10 Hz. Figure 1 shows a schematic view of the polarization switching system. We adopted an APPLE-II-type magnetic arrangement for the EPUs to obtain various polarization states-not only circular (left-handed and right-handed), but also linear (horizontal and vertical and/or +/-45deg.). [3,4,5]

As the first step of the project, we constructed U#16-1 and the kicker system in 2007 and installed them in the B15-B16 straight-section in the PF ring in March 2008. U#16-1 became operational for user experiments after commissioning in the PF ring. Experiments using the circular polarization have been made successfully since May 2008. Currently, the available polarization modes are circular polarization (Bx/By = 1), elliptical polarization (Bx/By = 1/2), and linear polarization along the horizontal and vertical directions.

As the next step, we are constructing a second EPU, U#16-2. The magnetic adjustment of U#16-2 has been finish as scheduled, and we will continue magnetic measurements of U#16-2 under the various conditions of all operation modes. After the magnetic measurements, we will install U#16-2 in the PF ring this summer. Figure 2 shows a photograph of U#16-2 during the magnetic adjustment.

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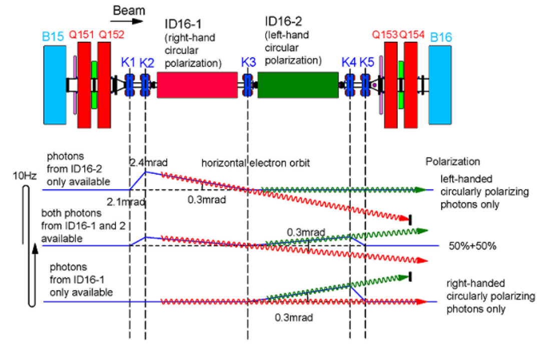

Figure 1: Schematic view of polarization switching system.

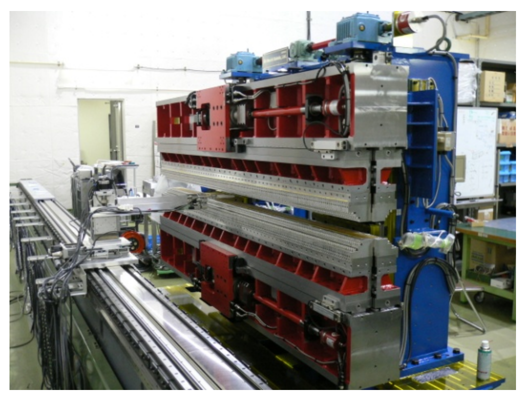

Figure 2: Photograph of U#16-2.

BASIC CHARACTERISTIC OF U#16-2

U#16-2 is identical to U#16-1, and has an APPLE-II-type magnetic arrangement. The period length of the EPU is 56 mm and the number of periodicity is 44. As a magnet material, we employ a Nd-Fe-B alloy with a remanent field of Br=12.5 kG and a coercivity of iHc=25.0 kOe (NEOMAX 38VH manufactured by NEOMAX Co. Ltd.). The target energy region is from 200 eV to 1 keV with the first harmonic in the 2.5-GeV PF ring. Figure 3 shows an example of the calculated spectrum of U#16-2. U#16-2 has four variable rows of magnetic arrays to change the polarization states, and a gap-driving mechanism to change the photon energy.

Typical operation modes consist of a symmetric and an antisymmetric mode. In the symmetric mode, we displace one pair of rows opposing diagonally another diagonal pair. The symmetric mode plays a major role in obtaining various polarization states, which are obtained by: (1) rotating the polarization angle from the horizontal to the vertical direction in the case of linear polarization; and, (2) left or right rotation in the case of circular or the elliptical polarizations.

By moving the four rows of magnetic arrays individually, we can use U#16-2 as both the usual APPLE-II type EPU and the adjustable phase undulator (APU). [6,7] In APU, we move the top pair of the magnetic rows longitudinally with respect to the bottom pair; however, the gap is fixed to change the photon energy.

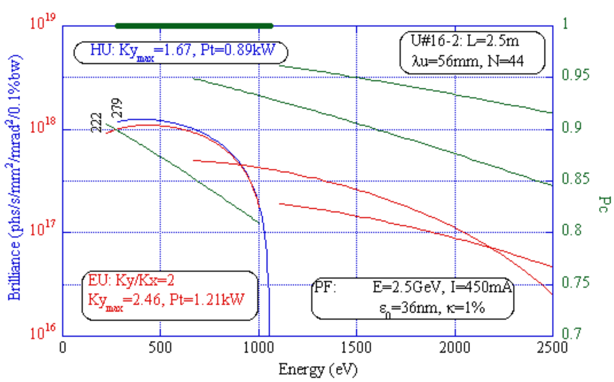

Figure 3: Spectral properties of U#16-2 in symmetric mode.

OPTIMIZATION OF THE MAGNETIC ARRANGEMENT OF U#16-2

We developed an optimization procedure for the arrangement of magnetic arrays of U#16-2 as described below. By adopting a pure Halbach magnet arrangement, we can estimate the property of the total magnetic field distribution of the EPU by the superposition of individual fields of each of the magnets that make up the EPU. First, we measured the magnetic field distribution of each magnet block. Second, we determined the suitable arrangement of the magnetic arrays by a simulated annealing method using the measured filed data of the magnets. Finally, we analyzed the result of the superposed magnetic field distribution at the calculated arrangement of the magnets in a planar undulator mode.

Magnetic Measurements of Each Magnet Block

We measured the magnetic field distribution of all the magnets along the beam axis. The total number of magnet blocks, including spares, is 740.

Figure 4 shows a photograph of the setup used for the measurement. The magnetic measurement system was developed for U#16-1. We used two moving Hall probes to measure the horizontal and vertical magnetic field individually. The sampling ratio of data acquisition was 50 kS/sec and the speed of movement of the Hall probes was 5 mm/sec. We have obtained the magnetic field data at 0.1 mm steps after an averaging process for noise reduction. The height of the probe above the surface of a magnet is 10.5 mm, corresponding to a minimum gap of 21 mm.

Figure 5 shows an example of the measured magnetic field distribution of a single magnet block for a vertically and a horizontally magnetized magnet, respectively. As a result of measurements, we found the center of the magnetic field distribution does not correspond with the center of the magnet block for every vertically magnetized magnet with a value of 0.3 mm. It follows that we have two possible off-center directions when we arrange these vertically magnetized magnets on the magnet-mounting beams of the EPU. A lack of uniformity in these off-center directions causes a phase error in the magnetic field of the EPU. Thus, it is an important procedure to make the off-center directions uniform for all magnet blocks to suppress phase error.

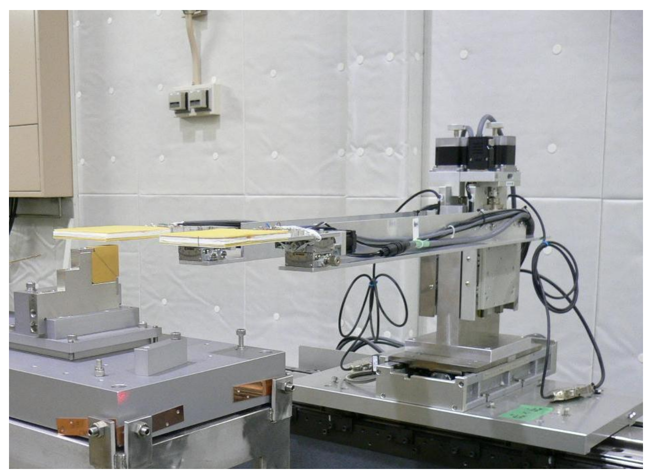

Figure 4: Photograph of magnetic measurement system used for individual magnet blocks.

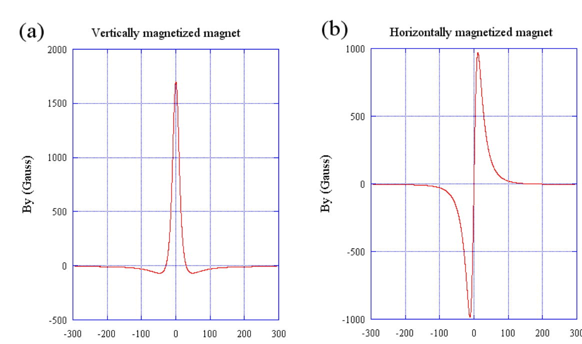

Figure 5: Example of measured field distribution.

Result of Simulation

The arrangement of the magnet blocks was determined by a simulated annealing method to minimize the variance in the first field integrals at individual magnetic poles. We compared the properties of superposed magnetic field distributions at the calculated arrangement of magnets and the case of the initial state. As the initial state, we set magnet blocks randomly. The result of the simulation is summarized in Fig. 6 (a) and Fig. 6 (b). Figure 6 (a) shows the distribution of the first integrals of the magnetic field at individual magnetic poles, and Fig. 6 (b) shows the distribution of the phase errors. The simulated standard deviation of the phase errors is decreased from 3.5 degree to 1.0 degree.

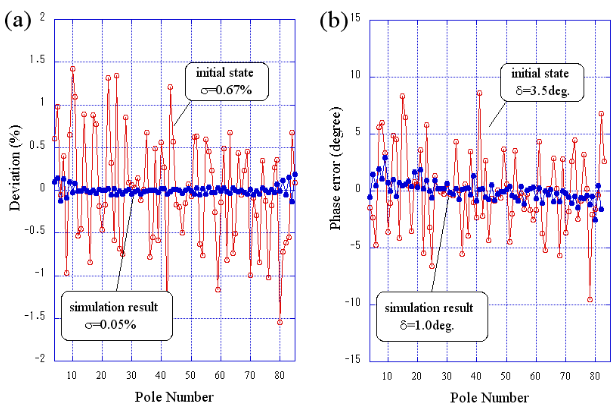

Figure 6: Result of simulation.

MAGNETIC ADJUSTMENT OF U#16-2

After we assembled the magnet blocks using the simulated arrangement, we measured the magnetic field distribution of U#16-2 in the planar undulator mode with the original position of the four rows at a minimum gap of 21 mm. The standard deviation of the phase errors was only 1.5 degree at the first measurement without any adjustment. This shows that the method we used to determine the magnetic arrangement works well, and all the magnet blocks were arranged precisely on the magnet-mounting beams of the EPU.

For the distribution of the first integrals of the magnetic field at individual magnetic poles, we adjusted the horizontal position of the magnetic blocks using shims. The results of the magnetic field adjustment of U#16-2 are summarized in Fig. 7 and Fig. 8. Figure 7 shows the electron orbits at the several typical gaps, which are calculated on the basis of the measured data in the planar undulator mode.

The measured distributions of the first integrals of the magnetic field at individual magnetic poles after adjustment are compared with that of before adjustment in Fig. 8 (a). Figure 8 (b) shows the results of the measured phase error distributions before and after adjustment of the calculated electron orbit. We confirmed that the root-mean-square phase error did not change for a value of 1.5 degree after the adjustment.

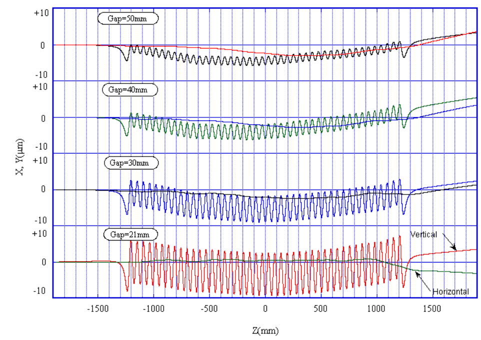

Figure 7: Electron orbits at several typical gaps.

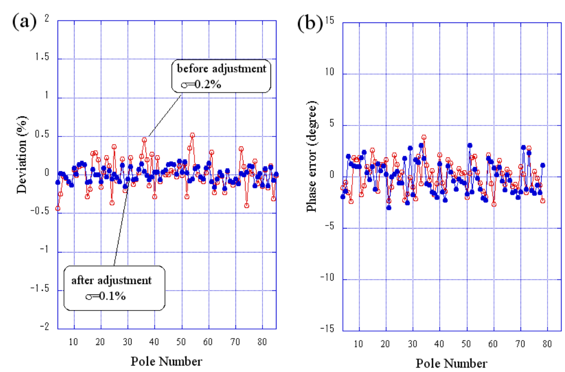

Figure 8: (a) Measured distribution of first integrals of magnetic field at individual magnetic poles.
(b) Distribution of measured phase errors.

SUMMARY

The magnetic adjustment of U#16-2 was concluded satisfactory. After the magnetic measurements, we will install U#16-2 in the PF ring this summer.

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