OBSERVATION AND CORRECTION OF EFFECTS OF VARIABLY POLARIZED UNDULATOR ON ELECTRON BEAM AT SAGA-LS

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Abstract

An APPLE-II type variably polarizing undulator was installed in the SAGA-LS storage ring in 2008. We investigated the influence of the undulator on the electron beam. Based on the beam test results, we developed a feedforward correction system that minimizes the effects of the undulator. This correction system successfully compensates for closed orbit distortion, betatron tune shift, and variation in betatron coupling when the pole gap and phase are changed.

INTRODUCTION

The SAGA Light Source [1, 2] (SAGA-LS) is a synchrotron radiation facility consisting of a 255-MeV injector linac and a 1.4-GeV storage ring with a circumference of 75.6 m. The SAGA-LS storage ring has eight 2.5-m-long straight sections, six of which are available for insertion devices. Three insertion devices are currently installed in the storage ring: an APPLE-II type [3] variably polarizing undulator, a planar undulator, (Saga Univ.) and a 4-T superconducting wiggler [4].

The APPLE-II undulator was installed to meet user requirements to vary the polarization of soft x-ray radiation. Table 1 lists the main parameters of the APPLE-II undulator. The APPLE-II device consists of four magnet arrays, each having 28 periods with a period length of 72 mm. The polarization of the undulator radiation is controlled by longitudinally translating two diagonally opposing magnet arrays. In the APPLE-II undulator, not only the gap change but also this phasing (longitudinal movement) of the magnet arrays perturbs the beam orbit, betatron tune and betatron coupling [5, 6, 7]. Hence, it was necessary to compensate the gap- and phase-dependent undulator effects to enable beamline users to fully control the photon energy and the polarization during user operation.

Following the installation of the APPLE-II undulator, we investigated its effects on the stored 1.4-GeV electron beam. Based on the beam tests, we developed a correction system for minimizing undulator effects. Since the gap- and phase-dependent undulator effect is reproducible, we employed a feedforward scheme in the correction system in which feedforward tables are applied at a rate of 10 Hz. This paper describes an experimental investigation of the undulator effect and the effectiveness of the feedforward correction.

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Table 1: Main Parameters of the APPLE-II Undulator

Magnet Material	NdFeB
Number of Periods	28
Period Length λ_u [mm]	72
Pole Gap [mm]	30 – 200
Phase ΔZ (Longitudinal Movement) [mm]	-36 – +36

BEAM TEST PROCEDURE

The following procedure was used to experimentally investigate the effect of the APPLE-II undulator and development of the correction system. Firstly, the variation of the closed orbit distortion (COD) with respect to the reference orbit was measured as functions of the pole gap and the phase using 24 beam position monitors. The COD variation was minimized using the steering magnets located on both sides of the undulator. Secondly, the betatron tune shift was measured and corrected using quadrupole doublets on both sides of the undulator. Finally, the effect of the undulator on betatron coupling was investigated using a beam size monitor. A wire skew quadrupole magnet was added to the undulator duct for coupling correction.

RESULTS

Closed Orbit Distortion

The residual field integral of the APPLE-II undulator was evaluated to be of the order of 10 G-cm in magnetic field measurements using a flipping coil. The field integrals derived from the beam measurement are in approximate agreement with those evaluated in the magnetic field measurements. We developed a feedforward correction system to compensate for the orbit distortion due to the residual field [8]. Two-dimensional feedforward tables for the steering coils were determined from the beam measurement by the singular-value decomposition method. By applying the feedforward correction, the standard deviation of the orbit displacement relative to the reference orbit was suppressed to less than 4 μm when the gap and phase were varied.

Betatron Tune Shift

The betatron tune shift was measured as a function of the gap as the phase was varied from -36 to +36 mm in 9 mm intervals. Figure 1 shows the betatron tune shift measured in horizontal linear, circular, and vertical linear polarization modes where the undulator phase ΔZ was set to 0, +27

(+3λ_u/8) and +36 (+4λ_u/8) mm, respectively. A noticeable change in the betatron tune was observed when the gap was closed. Although the tune shift is of the order of 0.001, tune correction is essential for coupling correction (as discussed in the next section).

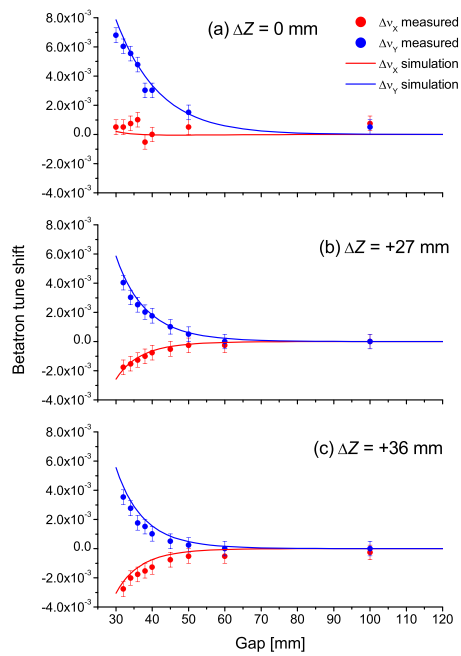

Figure 1: Betatron tune shift measured in (a) horizontal linear, (b) circular, and (c) vertical linear polarization modes.

Based on the betatron tune shift measurements, we determined two-dimensional tables for correction coil currents of the quadrupole magnets. The correction coil current can be determined for any gap and any phase setting by linearly interpolating between values in the data tables. When feedforward correction is applied, the betatron tune shift is suppressed to less than 0.001.

The gap- and phase-dependent betatron tune shift is interpreted in terms of the second-order focusing effect induced by the undulator [9]. The horizontal and vertical focal lengths, F_x and F_y, respectively, of an insertion device are given by

$$\frac{1}{F_{x(y)}} = -\frac{1}{2}\left(\frac{1}{B\rho}\right)^2 \int_0^L \frac{\partial^2 \Phi}{\partial x(y)^2} ds, \qquad (1)$$

where $B\rho$ is the magnet rigidity and L is the undulator length. The function Φ is defined by

$$\Phi = \left(\int_0^s B_x ds'\right)^2 + \left(\int_0^s B_y ds'\right)^2, \qquad (2)$$

where B_x and B_y are the horizontal and vertical components of the magnetic field, respectively. The focal length of the APPLE-II undulator is numerically evaluated using the RADIA code [10]. From the focal length calculation, the betatron tune shift is derived by

$$\Delta\nu_{x(y)} = \frac{1}{4\pi}\frac{\overline{\beta}_{x(y)}}{F_{x(y)}}, \qquad (3)$$

where $\overline{\beta}_{x(y)}$ is the average beta function in the undulator section. The simulated tune shifts are plotted in Fig. 1. The simulation results are almost identical to the observed tune shifts, which indicates that the betatron tune shift is mainly generated by the second-order focusing effect.

Betatron Coupling

To study undulator effects on the betatron coupling in detail, we measured the vertical beam size as functions of the gap and the phase. The vertical beam size was measured at a diagnostic beamline of BL20 [11] where a beam size monitor that uses a synchrotron radiation interferometer [12] is installed.

Since the working point of the SAGA-LS storage ring is close to a difference resonance, the betatron coupling is rather sensitive to a skew quadrupole error field. The integrated skew gradient of the APPLE-II was estimated to be in the order of 10 G in the field integral measurement. For local correction of the skew error field, we used a wire skew magnet [13], which is similar to the flat wires used in BESSY-II for multipole compensation [14]. The wire skew magnet was mounted on the undulator duct.

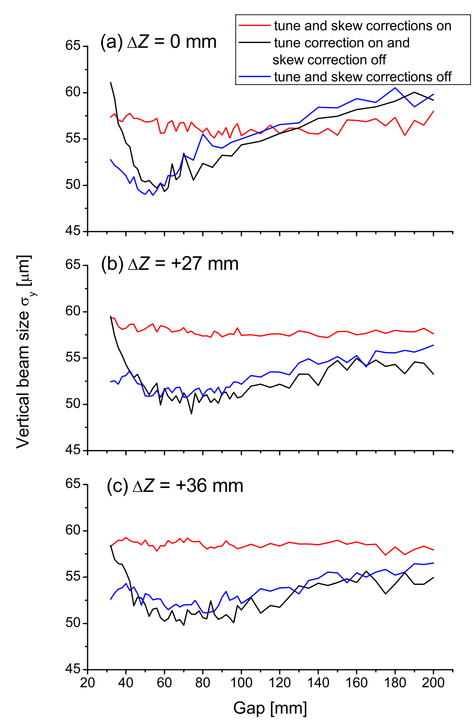

Figure 2: Vertical beam size measured in (a) horizontal linear, (b) circular, and (c) vertical linear polarization modes.

Figure 2 shows the variations in the vertical beam size in horizontal linear, circular, and vertical linear polarization modes. The vertical beam size varies drastically when the gap is changed without skew correction. For feedforward correction, a two-dimensional table for the skew coil currents was experimentally determined by performing the beam size measurements. As Fig. 3 shows, the skew field strength required for coupling correction is consistent with those predicted by the field integral measurements. In a similar manner to tune correction, linear interpolation is utilized to determine the skew coil current at any gap and any phase.

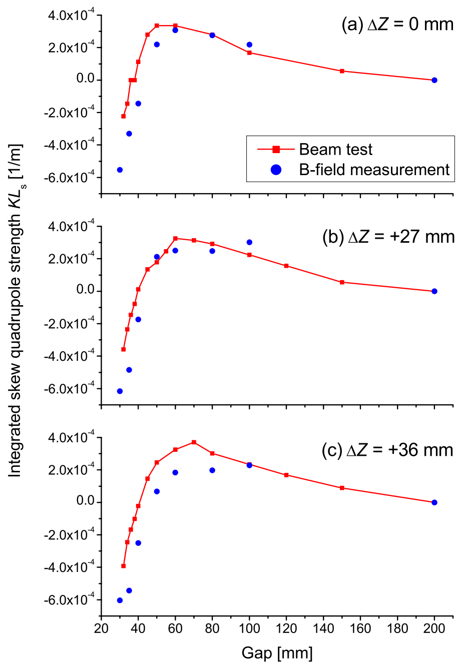

Figure 3: Integrated skew quadrupole strength for (a) horizontal linear, (b) circular, and (c) vertical linear polarization modes.

In addition to the skew quadrupole field, the betatron tune shift also influences the betatron coupling at small gap. A clear difference between the tune corrected and uncorrected beam sizes is observed for the gaps smaller than 40 mm when the skew correction coil is off. This difference is due to the contribution of the betatron tune shift to coupling. Thus, both the skew quadrupole and tune corrections are required to compensate for betatron coupling. Figures 4(a) and (b) show the vertical beam size measured as functions of the gap and the phase with coupling correction off and on, respectively. The feedforward correction significantly reduces the beam size variation at any gap and any phase. After the correction, the relative change in the vertical beam size is suppressed to less than 2% (rms) when the gap is varied at a fixed phase. This result confirms the effectiveness of the feedforward correction scheme.

SUMMARY

We investigated the effect of the APPLE-II undulator on the stored 1.4-GeV electron beam. Changes in the pole gap and the phase cause mainly variation of the COD, betatron tune shift, and change of the betatron coupling. The COD variation can be explained in terms of the residual field integral estimated by the magnetic field measurement. The betatron tune shift is mainly generated by the second-order focusing effect, whereas the variation in betatron coupling

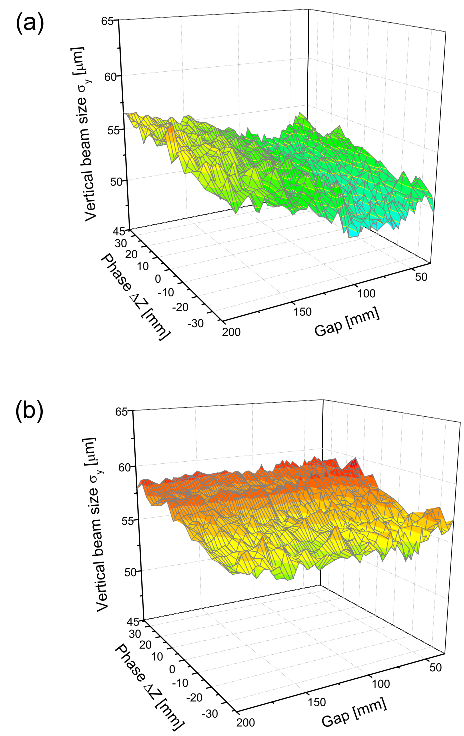

Figure 4: Vertical beam size measured with (a) tune and skew corrections off and (b) tune and skew corrections on.

is due to the skew error field and the betatron tune shift at small gaps. To compensate for these effects we developed a feedforward correction system that employs two-dimensional tables determined from the beam tests. The system sufficiently compensates for undulator effects. It has already been applied to user operation.

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