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An SRRC elliptically polarizing undulator prototype to examine mechanical design feasibility and magnetic field performance

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In this work, a 1 m long Sasaki-type elliptically polarizing undulator (EPU) prototype with 5.6 cm period length is used to examine the mechanical design feasibility as well as magnetic field performance. The magnetic field characteristics of the EPU5.6 prototype at various phase shifts and gap motion are described. The field errors from mechanical tolerances, magnet block errors, end field effects and phase/gap motion effects are analysed. The procedures related to correcting the field with the block position tuning, iron shimming and the trim blocks at both ends are outlined.

Keywords: elliptically polarizing undulators; magnetic field errors.

1. Introduction

The Synchrotron Radiation Research Center (SRRC) is a low-emittance 1.5 GeV synchrotron-radiation facility located in Hsinchu, Taiwan. A users group is particularly interested in producing elliptically and circularly polarized light in the VUV and soft X-ray region to examine magnetic materials more closely. Several possible planar helical undulators can generate circularly polarized light. Elleaume (1989, and references therein) performed a major step in the construction of a linear and helical undulator at ESRF. The Sasaki-type elliptically polarizing undulator (Sasaki, 1994) can generate a higher magnetic field for a fixed vacuum gap and also covers the widest photon energy range. Another potential design, the SPring-8 elliptical wiggler (Marechal *et al.*, 1995) with six magnet arrays, has vertical and horizontal magnetic fields that are independent, thereby allowing the magnetic field to be easily modified. The Sasaki-type undulator, owing to its flux and polarization characteristics, mechanical complexity as well as the effects on the electron beam, has been selected for development of circularly polarized light at SRRC. A source of 3.9 m period elliptically polarized light with a 5.6 cm magnetic period length has been designed to produce variably polarized light from 80 to 1400 eV (Wang *et al.*, 1996). With respect to the production of the linearly and circularly polarized light, the magnetic structure and drive system are rather complicated. Therefore, in this work, we initially fabricated a 1 m long Sasaki-type undulator to examine the mechanical design and magnetic field performance.

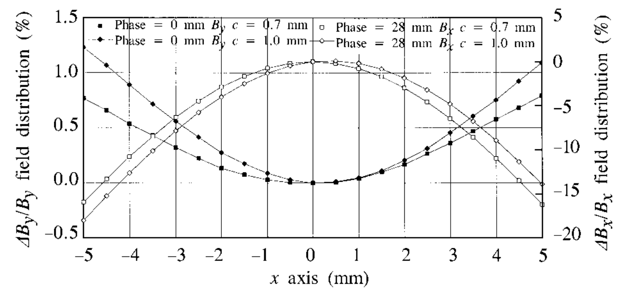

Figure 1
The field uniformity of horizontal (B_x) and vertical (B_y) fields in the transverse direction with magnetic clearance of 1 and 0.7 mm for an 18 mm gap.

2. The magnet's structural features

The magnet structure consists of four permanent magnet arrays. By shifting the relative positions of the arrays with a magnetic period, the EPU undulator can produce a sinusoidal magnetic field in the vertical and the horizontal planes as well as a helical field. The magnetic structure is designed to achieve a vertical peak field of 0.7279 T and a horizontal peak field of 0.4688 T at a minimum gap of 18 mm. Neodymium–iron–boron permanent magnets (ShinEtsu N38H) are used. The 14 mm thick magnet block, having a square cross section of 40 $\times$ 40 mm, is used to satisfy the field requirements and to increase the flexibility in magnet sorting. The sorting algorithm (Fan *et al.*, 1997) attempts to minimize the first integral field and reduce the multipole field. The prototype's magnet arrays are 15 periods long with half-thickness terminators. The magnetic arrays were assembled with a symmetric vertical field and then an anti-symmetric structure introduced for the subsequent horizontal field. Analysis results indicated that clearance between two magnet arrays creates a non-uniform vertical field in the central region. Fig. 1 depicts the field uniformity measured with various clearances between 1 and 0.7 mm. According to this figure, the vertical and horizontal field uniformity in the mid-plane did not markedly improve in the smaller clearance. Therefore, a 1 mm clearance was selected by considering the horizontal magnetic force, the vertical field homogeneity and the mechanical tolerance in the magnet arrays.

3. Mechanical design and fabrication

The magnet holder is designed to attach securely the magnets and to adjust them easily in vertical and transverse positions. Owing

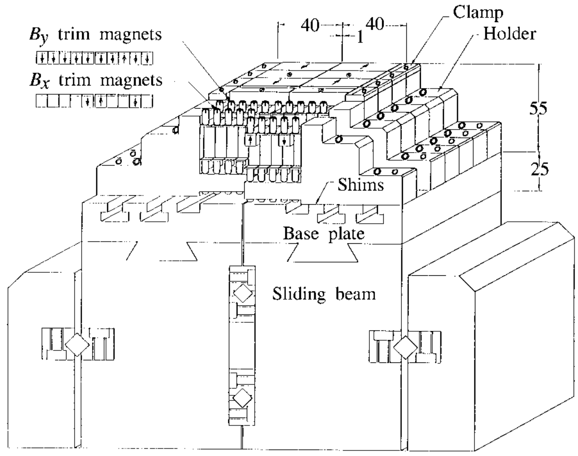

Figure 2
The configuration of mechanical and magnetic features with trim magnetic blocks at the ends.

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to the extremely strong magnetic force between the two magnetic blocks, the magnet is glued by epoxy and also fixed *via* clamps. For magnetic field tuning, each magnet can be adjusted transversely by 0.25 mm from its nominal position as well as vertically by using shims between the holder and the base plate. Each standard module contains seven magnets to operate the array assembly successfully under a strong attractive magnetic force. Fig. 2 illustrates the mechanical and magnet structural features with trim blocks. To maintain the tight tolerance of 1 mm clearance and the gap width in the magnet assembly, the module's flatness and straightness are measured and shimmed within 20 µm. The modules are then attached on the sling-back beam by using a dovetail connection which properly aligns the modules and also prevents contact between the two magnet arrays.

Four magnet arrays that can move independently are utilized in the prototype to allow for more complex use while producing the various linearly and circularly polarized light. The repulsive and attractive magnetic forces strongly interact among the magnet arrays during the gap change and phase shift. The maximum left- and right-handed circular polarization switching rates are 0.1 Hz.

4. Magnetic field tuning method

The magnetic structure consists of two pairs of longitudinally movable magnetic arrays. The upper-front/lower-back and upper-back/lower-front magnet arrays can be shifted simultaneously with a magnetic period. The concept of the elliptically polarizing undulator basically rests on the notion that horizontal and vertical fields can be produced from a diagonal pair of magnet arrays. The on-axis average field errors of two diagonal magnet arrays are extremely sensitive to the mechanical tolerance of clearance, the alignment of the center line and the gap width of the magnet structure. Therefore, in this study, the first step in tuning the magnetic field is performed in each diagonal pair of the magnet array. Despite an appropriate sorting method and maintenance of the magnet flatness within 50 µm to improve the field quality as much as possible, the field homogeneity and integrals still cannot fulfil the electron trajectory and photon spectral requirements. The optimized field process is performed by precisely characterizing the individual magnet blocks. The vertical positions of the *V*- and *H*-type (identified by main field orientation) magnetic blocks can be adjusted with various thicknesses of shims; in addition, the horizontal positions can be easily tuned using a bolt. According to a variation of on-axis peak field and half-period field integrals of B_x and B_y fields, the individual horizontal and vertical field errors can be eliminated by adjusting the position of the *V*- and *H*-type magnet blocks. The fact that the B_x and B_y fields are coupled together in the magnetic structure accounts for the fact that any magnet block that is tuned introduces small localized field perturbations in both B_x and B_y fields. For deriving the optimum block position, the field error's sensitivity is measured and analysed using the slight shift in the block position with a 10 µm step in transverse and vertical positions. The 0.1% variation in the vertical field strength is derived by tuning the position by 10 µm. For compensating the off-axis x = 10 mm transverse field distribution, an additional shimming technique is also employed on the magnet's surface. After many iterative tuning processes, the r.m.s. deviation of on-axis peak field and the half-period field of B_x and B_y fields can be successfully managed within 0.3 and 0.5%, respectively, in the full field-strength pole region.

The magnet block's half-thickness is used in the end pole to compensate for the first field integral. The end block is designed to change the block volume, adjust the gap width and shift the position in the longitudinal axis for tuning the first vertical integral field. Herein, different volumes and positions of the end block are tested and estimated for optimizing the vertical field integral and minimizing the integrated field variations during the phase shift. Moreover, for correcting the integrated multipole component, the vertical positions of trim magnet arrays with a cubic block of 7 mm at both ends can be adjusted to compensate for the vertical field integral in a transverse position. Other trim magnets with cubic block of 7 mm are arranged to generate the horizontal field for modifying the horizontal dipole and multipole integral field.

5. Field measurement results

The stringent magnet field quality is a necessary prerequisite for reducing the electron orbit deviation and satisfying the photon spectrum requirements during the phase shift and gap change. In this study, the magnetic field is measured by a three-dimensional Hall probe and a long loop coil measurement system (Hwang *et al.*, 1997). The field maps are taken in the mid-plane within x = 5 cm at an 18 mm gap. The relative position of the magnet array at a period of 0.29 provides the circular polarization condition for a gap of 18 mm. After the adjustment of end blocks and trim magnets, the first vertical and horizontal magnetic field integrals by Hall probe and long loop coil scans reveal that the integrated dipole varies within 100 G cm for $-1 < x < 1$ cm at 18 mm gap width, as indicated in Fig. 3. Next, by shifting the phase by 56 mm, approximate 50 and 250 G cm of on-axis vertical and horizontal field integrals were varied during the phase shift. This difference of 230 G cm in the horizontal field integral was compared with and without using trim magnets. This difference is due to the fringe field effects of the trim magnets at the ends. The positions of the trim magnet in the diagonal pair of magnet arrays are adjusted longitudinally by 7 mm and 14 mm shifts for reducing the variation of the horizontal field integral. Consequently, the horizontal field integral is optimized to achieve approximately 175 G cm with a 7 mm shift. The r.m.s. deviations of on-axis peak field and half-period field of B_x and B_y fields also slightly change by up to 0.5 and 0.7% in the phase shift. The variations in the horizontal and vertical field integrals are also

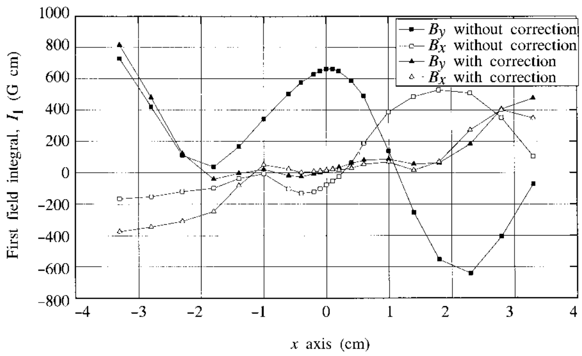

Figure 3
The field distribution of the first horizontal and vertical field integrals in the transverse direction with and without end-block and trim-magnet-block correction at 18 mm gap.

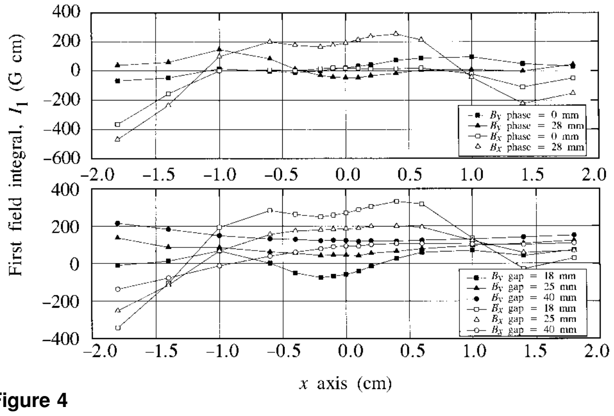

Figure 4
The variations of the first horizontal (I_{1B_x}) and vertical (I_{1B_y}) field integrals in the transverse direction during the phase shift for an 18 mm gap and a gap change with a phase shift of 17 mm.

measured within 200 G cm during the gap change from 18 to 40 mm. Fig. 4 shows the variations of the field integral with phase shift and gap change. The electron trajectories are calculated from Hall-probe measured data. Fig. 5 displays the on-axis trajectories with a deviation of around 20 µm in the circularly polarized phase.

6. Conclusions

This work presents the EPU5.6 undulator prototype to assess the mechanical design feasibility and magnetic field performance. The mechanical assembly errors are 5 µm for clearance, gap width and center-line alignment between two magnet arrays under the strong attractive magnetic loads. Each magnet block can be adjusted in vertical and horizontal positions for tuning the magnetic field. The optimizing field tuning process is performed *via* a diagonal pair of magnetic structures. Final electron trajectories with a deviation of around 20 µm are also presented. Cumulatively, 200 G cm of horizontal and vertical field integral variations are also measured during the phase shift and the gap change.

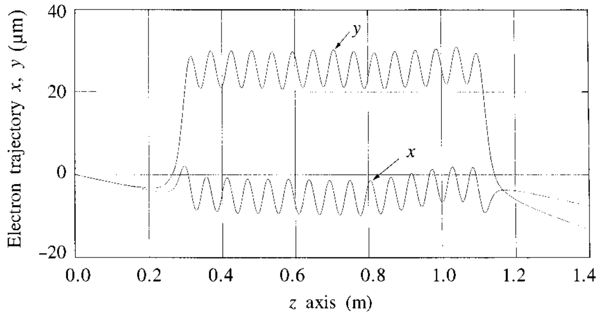

Figure 5
The on-axis electron trajectory along the longitudinal direction of a phase shift for an 18 mm gap.

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References

Elleaume, P. (1989). *Rev. Sci. Instrum.* **60**, 1830–1833.

Fan, T. C., Hwang, C. S., Chang, C. H. & Wang, Ch. (1997). *1997 IEEE Particle Accelerator Conference*, Vancouver, Canada.

Hwang, C. S., Fan, T. C., Lin, F. Y., Yeh, S., Chang, C. H., Chen, H. H. & Tseng, P. K. (1997). *J. Synchrotron Rad.* **5**, 471–474.

Marechal, X. M., Tanaka, T. & Kitamura, H. (1995). *Rev. Sci. Instrum.* **66**, 1937–1939.

Sasaki, S. (1994). *Nucl. Instrum. Methods*, A**347**, 83–86.

Wang, Ch., Chang, L. H., Chang, C. H., Chen, H. H., Fan, T. C., Hsu, K.T., Hsu, J. Y., Hwang, C. S., Lin, M. C. & Pan, K. T. (1996). *Proc. 5th European Particle Accelerator Conference*, Barcelona, Spain, pp. 2567–2569.