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A QUASI-PERIODICELLIPTICALLY POLARIZED UNDULATOR AT THE NATIONAL SYNCHROTRON LIGHT SOURCE II*

M. Musardo†, T. Tanabe, O. Chubar, Y. Hidaka, D. Harder, J. Rank, P. Cappadoro and T. Corwin,
Energy Sciences Directorate, Brookhaven National Laboratory, 11973 Upton, NY, USA
C. A. Kitegi, Synchrotron SOLEIL, Saint-Aubin, France

Abstract

A 2.8 m long quasi-periodic APPLE II type undulator has been commissioned at the National Synchrotron Light Source II (NSLS-II) for the Electron Spectro-Microscopy (ESM) beamline in the framework of the NEXT (NSLS-II Experimental Tools) project [1]. It provides high brilliance photon beams in circularly and linearly polarized radiation from VUV to soft X-Rays. The mechanical structure implemented to achieve the quasi-periodicity in the magnetic field profile is described together with the optimization techniques utilized to correct the undesirable phase-dependent errors. The final magnetic results are presented as well as the spectral performance of the device. Although this EPU (Elliptically Polarizing Undulator) was procured as a turn-key device, the vendor was only responsible for the mechanical frame and the control system. Sorting and assembly of the magnet modules and the magnetic field tuning - Virtual Shimming and Magic Finger - were performed at the NSLS-II Magnetic Measurement Lab.

MAGNETIC AND MECHANICAL STRUCTURE

The magnetic structure of EPU105 is configured as four Halbach arrays in four adjacent quadrants. The support structure is equipped with four translation units for the polarization control (linear, circular, and elliptical). The period length (λ) is 105 mm and the minimum magnetic gap of the device is 16 mm. The main magnet dimensions are 34 mm (H) x 34 mm (V) x 26.25 mm (L). The remanence of the NdFeB magnets is 1.25 T. The longitudinal air-gap between the magnets is 50 μm and the gap between the magnet arrays is 1 mm. The full length of the magnetic core is 2654.25 mm, excluding girder movement and the trim magnet holders. The device has two different types of terminations, both composed of one vertically magnetized full block, two vertically magnetized half blocks and four horizontally magnetized half blocks. The end section configuration block width and the space between blocks is optimized to minimize trajectory steering and field integrals. A NEG-coated vacuum chamber with current strip corrections used for dynamic field integral correction is employed [2]. ESM EPU105 is a quasi-period undulator (QPU). The Quasi-Periodicity (Q-P) is obtained by modulating the magnetic field amplitude along the length of the device. This is achieved by vertical displacement of B-magnets (blocks magnetized longitudinally) at six specific locations. In order to reduce the magnetic field strength at those locations the standard magnet holders were replaced with special holders that displace the magnets vertically by 13 mm with respect to the mid-plane, as shown in Fig. 1.

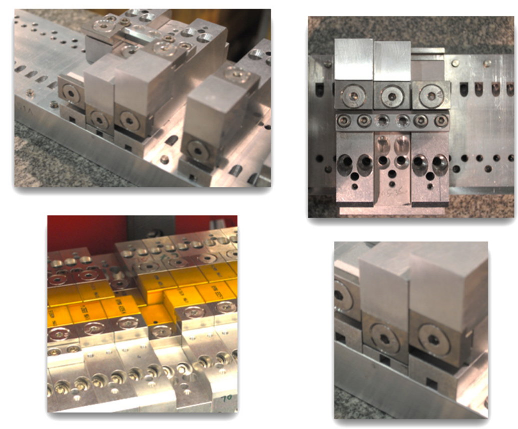

Figure 1: Magnet holders for the Q-P configuration.

During the assembly process only those magnets with longitudinal magnetization are shifted in order to minimize the deleterious effects of the Q-P adjustment on the first and second magnetic field integrals. Figure 2 shows the measured magnetic field on-axis and the 3 GeV electron trajectory in the horizontal plane at the minimum gap and phase 0.

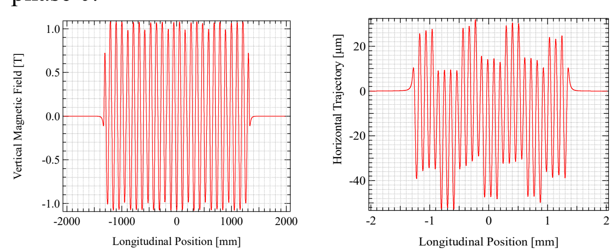

Figure 2: Measured vertical magnetic field on axis (left) and horizontal trajectory (right) in the Q-P configuration.

The quasi-periodicity in the magnetic field profile was introduced in order to modify the properties of the emitted photon beam - a reduction in intensity and shift in energy of the higher harmonics compared to the fundamental. Because of the shift in energy the higher harmonics are no longer proportional to an integer multiple of the fundamental energy, which drastically reduces the amount of unwanted higher harmonic radiation transmitted through the monochromator in the ESM beamline.

Quasi-periodic undulators were originally proposed as a method to reduce contamination from high order spectral harmonics where optical filtering is not possible or convenient [3].

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† musardo@bnl.gov

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MAGNETIC FIELD OPTIMIZATION

The magnetic module assembly of ESM EPU105 has been carried out using a sorting scheme which progressively optimizes the magnetic field quality of the device to improve the electron trajectory straightness. After assembly, a virtual shimming process was performed to further reduce the radiation phase error and the integrated multipole variation at different phases. Fine tuning of the device using multiple trim magnets - Magic Finger (MF) - has been implemented to correct the field integral imperfections and to compensate the residual multipole effects. These optimizations were implemented using IDBuilder, a genetic algorithm-based computer code for magnetic tuning of undulators [4].

Sorting Method and Results

The sorting technique is an accurate and efficient method of field optimization. This method was first developed at ESRF [5] and then successfully used by other laboratories and industries [6]. The magnetic structure of the device is modularized. The magnets are grouped in small compensated modules. They are clamped on individual holders and arranged in modules containing either three (M3) or five (M5) magnets by means of small aluminum bars as shown in the Fig. 3.

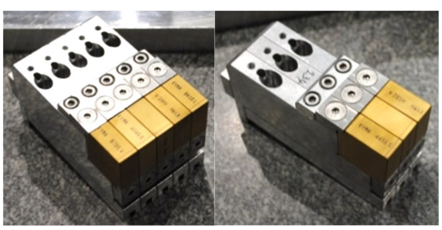

Figure 3: M5 (left) and M3 (right) modules for EPU105.

Symmetry in the design allows placement of the modules in any of the four quadrants of the EPU structure. The M5 and M3 modules form a double period that is repeated 24 times through the central region of all four magnetic arrays. These compensated modules are accurately characterized by measuring their field integral. The average of the magnetic field integral measurements of all M3 and all M5 modules are shown in Fig. 4.

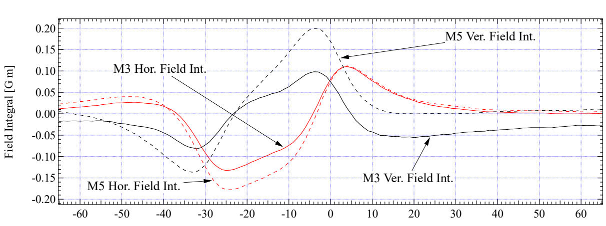

Figure 4: Horizontal (red) and vertical (black) average field integral of M3 (continuous line) and M5 (dashed line) module populations.

These measurements are used to optimize the arrangement of the modules within the undulator in order to minimize the unwanted field integrals and multipole errors, and to ensure a straight electron beam trajectory through the device. The optimization is iterative and provides a good control of the field integral errors, reducing the post-assembly field correction effort. The assembly process consists of successive and repetitive installation of M3 and M5 magnet modules onto the mechanical frame in order to build up the 24 periods of the EPU. Because the phase dependent errors cannot be corrected by sorting, the undulator was set to zero phase mode (purely vertical field) during all of the measurements. The sorting process can be briefly summarized as follows: assembly of two period of the device, i.e. one M3 and one M5 magnet module on each array of the mechanic frame and measurement of the magnetic field integral of all assembled modules. The measured data of the current configuration and the previously measured field integrals of each module are used as inputs to IDBuilder. The software then optimizes the selection of the next two sets of M3/M5 modules to be installed. Following that process for each successive installation of two magnet modules, permits IDBuilder to minimize the first and second field integral for the fully assembled EPU. The first field integrals at a gap of 16 mm and five phases (±λ/2, ±λ/4 and 0) are shown in Fig. 5. A maximum variation in phase of the horizontal field integral on-axis of about 1 G m occurs at ± λ/4. These results demonstrate that the assembly/sorting process has been very effective: the peak to peak field integral of the fully assembled device (consisting of 48 M3 and 48 M5 magnet modules) is comparable to the field integral of the individual modules.

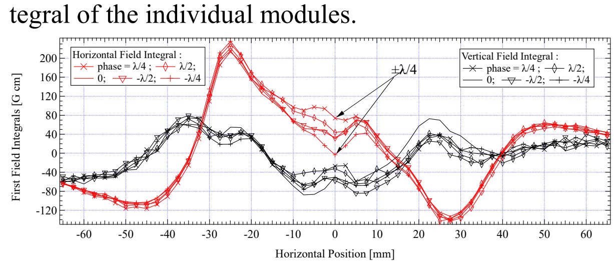

Figure 5: Horizontal (red line) and vertical (black line) field integral at minimum gap and at different phases.

In order to meet the requirements for installation in the NSLS-II storage ring a virtual shimming of the device followed by Magic Finger correction has been performed after assembly to further reduce the field integral distribution and to minimize the multipole variation in phase.

Virtual Shimming and Magic Finger Correction

Virtual Shimming is a well-established magnetic optimization technique for post-assembly tuning of an insertion device. Virtual shimming is accomplished by making small horizontal and vertical displacements of a limited number of magnets. The horizontal and vertical displacement of magnets is an efficient way to compensate the magnetic field errors of the device and thus reduce the phase error of the emitted radiation. The shimming procedure is performed based on magnetic measurement data and pre-calculated shim signatures. The shim signatures are defined as the variations of given components of the magnetic field and/or the field integral with displacements of specific

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types of magnets along a given direction and at a given gap and phase. Figure 6 shows a comparison between the measured and computed vertical and horizontal field integral variation due to a horizontal displacement of 50 µm (shim thickness) of magnet #1 (A+) with the gap set at 16 mm. The magnetic interaction effects of the longitudinal shift of the magnet arrays are taken into account.

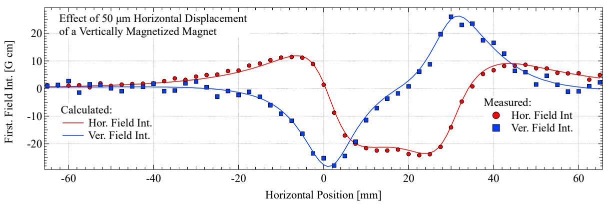

Figure 6: Shim Signatures. Predictions vs. Measurements.

Four successive iterations of virtual shimming were performed in the Q-P configuration and seven Magic Finger iterations were necessary to achieve the NSLS-II specification. MF is another corrective technique used for magnetic tuning of undulators. The MF optimization was carried out using cylindrical permanent magnets inserted into appropriate holders located at both ends of the upper and lower magnetic arrays. An optimal arrangement of these small cylindrical magnets further reduces the residual field integral and the multipole variations. After five successive MF iterations the magnetic field errors were significantly reduced. Figure 7 shows an envelope of the first and second field integral for all gaps and phases of the device.

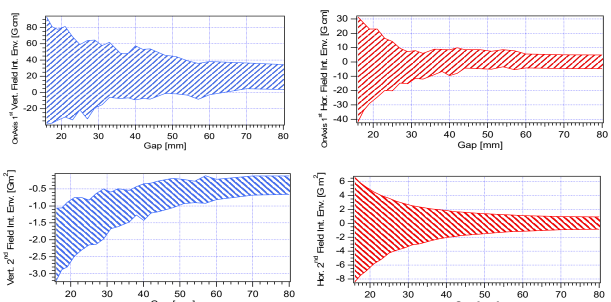

Figure 7: On-axis first (upper) and second (lower) vertical (blue) and horizontal (red) field integral variation for all gaps and phases.

The final normal and skew multipole components are shown in Fig. 8. Both field integrals and integrated quadrupoles are kept well within the tolerances over a large horizontal range. The vertical and horizontal field integral variation with respect to the phase is about ±20 G cm over the measurement range of ±65 mm.

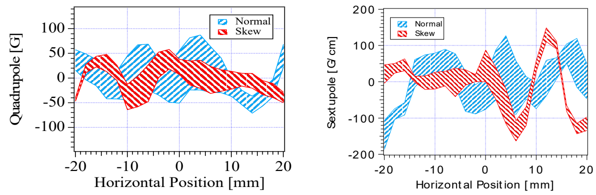

Figure 8: Envelope of the Normal (blue) and Skew (red) Quadrupole (left) and Sextupole (right) variation as function of the horizontal position for all gaps and phases.

Spectral Performance Results

The spectral flux measured at the ESM beamline reveals the quasi-periodic performance of the device [7]. The two Q-P effects, reduction in intensity and a shift in energy of the higher harmonics with respect to multiples of the fundamental (red lines), are clearly visible in the spectrum shown on Fig. 9. The spectral flux was measured with a ring current of 2 mA at a gap of 65 mm. This result is in a good agreement with the flux calculation based on the measured magnetic field as shown in Fig 10.

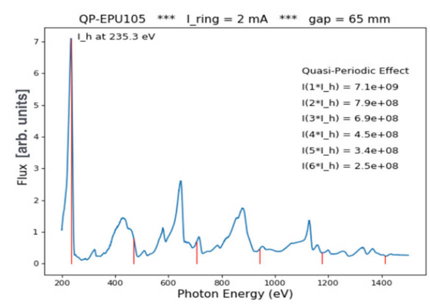

Figure 9: Spectral Flux measured at ESM beamline.

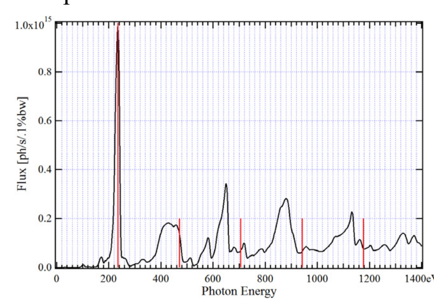

Figure 10: Spectral flux calculation based on the measured magnetic field.

CONCLUSION

Introduction of the Q-P in the device resulted in a large variation of the second field integral as a function of phase. This unwanted variation cannot be corrected using MF, but rather requires additional virtual shimming or, most efficiently, the use of external correction coils. The coils were installed and energized to quantify their correction. The maximum variation was successfully corrected by setting a current of 6.6 A.

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