RECENT MAGNETIC MEASUREMENT ACTIVITIES AT NSLS-II INSERTION DEVICE LABORATORY*

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Abstract

National Synchrotron Light Source II (NSLS-II) at Brookhaven National Laboratory (BNL) is a new 3 GeV third generation electron storage ring designated to provide extremely intense beams of X-ray, ultraviolet, and infrared light for basic and applied research.

Insertion devices (IDs) play a significant role in achieving the high performance demands of NSLS-II. An accurate magnetic characterization and proper corrections of these devices are essential activities in the development of a state-of-the-art light source facility.

This paper describes the results of the latest magnetic measurement activities at the NSLS-II ID laboratory.

INTRUDUCTION

The National Synchrotron Light Source II was designed and constructed to achieve a spectral brightness of 10^{22} ph/s/mm^2/mrad^2/0.1%bw, a very high-current electron beam of 500 mA and an ultra-small horizontal emittance of 0.9 nm.rad. At this time NSLS-II has reached its design performance, except for the maximum current intensity which is so far of 400 mA [1].

NSLS-II is officially in operation since February 2014. To support the aggressive schedule of the NSLS-II project and for risk mitigation, the IDs were procured as turnkey devices. In practice, the involvement of the ID group during the procurement was significant and this collaboration with vendors led to original developments such as the double mechanical frame for the CSX EPUs and the adoption of technology not commonly used in IDs such as an aluminum wire vacuum seal [2,3].

Measurement of the ID magnetic field upon delivery at BNL is another very important mission of the ID group. The magnetic measurements conducted at BNL were used to confirm the vendor's measurements, validate the specification requirements, and for the final survey of the IDs prior to their installation in the ring. In a few cases, retuning of the field was necessary in order to improve the magnetic performance of the IDs [4]. It was then the responsibility of the vendor to retune the device at BNL, in the NSLS-II ID laboratory. Since the completion of the NSLS-II baseline project, the responsibility of some of these activities was transferred to the NSLS-II ID group.

This paper reports the principal activities performed by the NSLS II ID group hereafter.

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MAGNETIC MEASUREMENT ACTIVITIES

Measurement of Turnkey Devices

The 17 turnkey devices previously ordered and the vendor's magnetic characterization have provided a cross check for the magnetic measurement system at the NSLS-II ID laboratory. This has contributed significantly to improving the reliability and accuracy of the Hall-Probe and Flip-Coil bench, utilized respectively for field mapping and field integral measurements [3]. In most cases they provide confidence in vendor magnetic measurement capabilities.

Recently a 1.4 m long elliptically polarizing undulator EPU-57 (see Fig. 1) has been delivered for the Electron Spectro-Microscopy beamline (ESM).

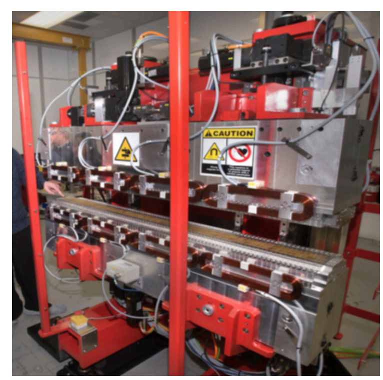

Figure 1: EPU57 at BNL ID Laboratory.

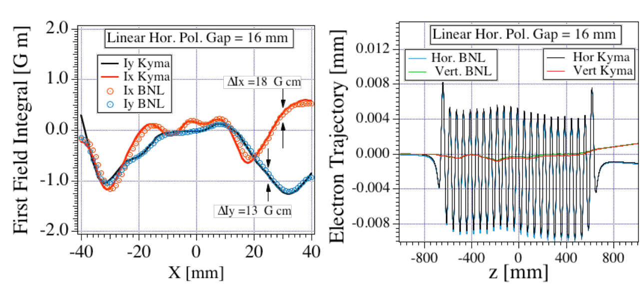

Figure 2: (Left) Comparison of the first field integrals between Kyma (solid lines) and BNL (dotted lines) at 16 mm gap and phase 0. (Right) Comparison of the 3 GeV electron trajectory using the measured magnetic field.

This device has a 57 mm period and a minimum gap of 16 mm. It will provide synchrotron radiation from 165 eV in horizontal polarization mode and 275 eV in circular and vertical polarization. The confidence in the vendor

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capability during a previous project allowed us to perform magnetic measurements at only a selection of a few gaps and phases, shortening significantly the required measurement time in the ID NSLS-II laboratory. Peak field distribution, electron trajectory, first integrals and phase errors are in good agreement with the vendor's results. Figure 2 compares the magnetic measurements between the manufacturer and BNL at minimum gap in linear horizontal polarization. These results indicate an excellent correspondence between two independent measurement systems.

Three Pole Wiggler

When necessary the NSLS-II ID group has performed magnetic optimizations since the early days of the NSLS-II project. These optimizations were performed in collaboration with the ID manufacturers. For several new projects, the magnetic measurement and tuning are the sole responsibility of the NSLS-II ID group.

The Three Pole Wiggler (3PW) prototype built by ADC USA Inc., is the first device for which the validation of the magnetic performance was solely of NSLS-II ID group responsibility. The device shown in figure 3 uses a hybrid design with four NdFeB permanent magnet and six poles. The two central poles are made of Vanadium Permendur and the four side poles are made of Low Carbon Iron Steel. The remanence of the magnet blocks is 1.24 T and the intrinsic coercivity is 24 kOe.

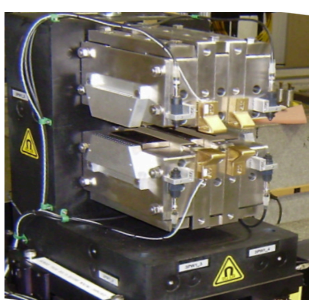

Figure 3: 3PW Prototype.

Currently the NSLS-II ID group activities are focusing on the in-house production of six Three Pole Wigglers. These devices will be used as alternative broadband radiation sources for conventional bending magnet users. These 3PWs have a lower angular power density of 0.067 kW/mrad and a critical energy of 6.8 keV, making them very useful continuum hard X-ray sources up to 25 keV. Furthermore, the 3PW devices will be employed as diagnostic tools to monitor the electron beam emittance of the NSLS-II. The 3PW has a fixed gap of 28 mm. The magnets and poles are held together with tie rods and mounted to the strong-back by magnet holders. The entire 3PW assembly can be moved 200 mm in the X direction. The movement is driven on a ball screw by a stepper motor driving a 3:1 gear reducer. A Renishaw incremental linear encoder tracks position. "Magic fingers" used for the magnetic fine tuning were mounted on both ends of the upper and lower magnet array.

Field integrals and local field measurements were performed in order to verify the basic design performance requirements. A peak field higher than 1T and fan angle larger than 2 mrad were achieved. Figure 4 shows the measured vertical field (By) and the corresponding electron angle.

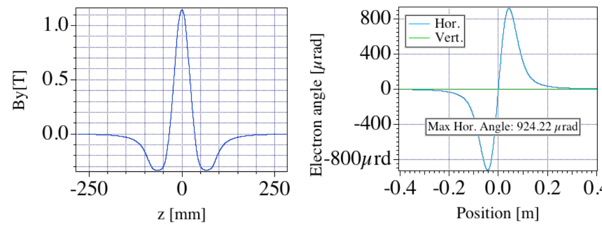

Figure 4: (Left) Vertical magnetic field on-axis. (Right) Vertical (green line) and horizontal (blue line) electron angle.

The measured peak field value is 1.143 T and the maximum horizontal angle is about 9.2 mrad. Figure 5 (left) shows the transverse X and vertical Y field profiles of the magnetic field By. The absolute horizontal variation of the field (red dots) is about 10 G (0.09%) within a range of ±10 mm. While the peak field values (blue dots) measured at several vertical locations (± 2 mm) shows a vertical misalignment error of about 2 μm with a corresponding field error of 0.01%.

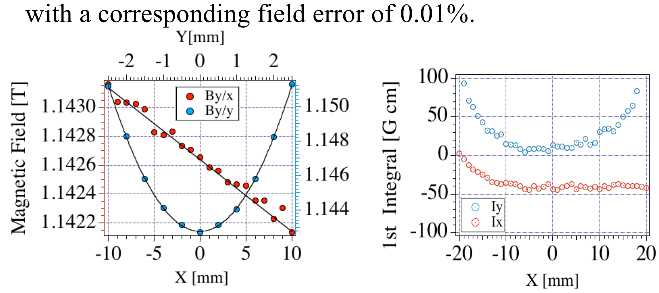

Figure 5: (Left) Transverse (red dots) and vertical (blue dots) peak field distribution. (Right) Vertical (blue dots) and horizontal (red dots) first field integrals.

Figure 5 (right) shows the field integral components determined by Flip-Coil measurements. Normal and skew integrated multipoles calculated by a polynomial fit of third order and radius 14 mm meet the specifications over the interval $|x| \leq 10$ mm.

The 3 GeV electron trajectory is shown in figure 6. Systematic measurements off-axis in the range of ±10 mm were performed in order to estimate the maximum excursion of the horizontal and vertical trajectory.

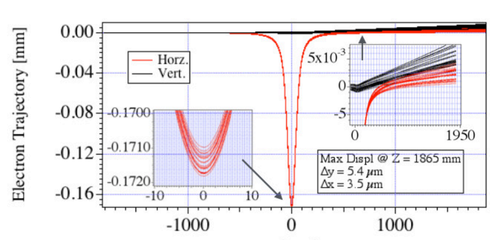

Figure 6: Horizontal (red line) and vertical (black line) electron trajectory off-axis measured at different X positions in the range ±10 mm.

As shown in the figure 6 the maximum displacement at the exit of the device is just a few microns for both components as well as the maximum orbit deflection in the horizontal plane at Z=0. Off-axis measurements clearly demonstrate the effectiveness of the correction on the trajectory.

MGU In-vacuum Undulator X25

The second device measured and optimized by NSLS-II ID group is the Mini-Gap In-Vacuum Undulator (MGU X25), shown in figure 7. Designed and built by ADC USA Inc. it has been employed for almost 10 years at NSLS in the Macromolecular Crystallography X25 beamline [6].

The device is a 1 m long, 18 mm period, hybrid PM-type with a minimum operating gap of 5.6 mm and a peak on-axis field of 0.91T. The MGU design incorporates a provision for cryo-cooling the magnet arrays down to 150K to increase the magnetic field and the radiation resistance of the magnets, but has yet to be utilized.

Figure 7: In-Vacuum Undulator X25.

The device is a useful and almost readily available X-ray source for NLSL-II beamline, therefore it was extracted in early 2014 from the NSLS X-ray ring after its decommissioning. The Micro-diffraction beamline (NYX) at NSLS-II will utilize the X25-MGU as a bright and tunable X-ray source over the photon range of 5-20 KeV in the short cell 19-ID. However, the NSLS-II electron beam properties are significantly different from the NSLS ones and the field integral requirements to be met by NSLS-II IDs are more stringent. Consequently, the device was brought to the NSLS-II ID lab for magnetic tuning. It is also a unique opportunity to characterize the magnetic performance of an ID after 10 years of operation in a storage ring. Compared to the 2006 measurements, a decrease of the field amplitude was measured, as shown in figure 8 (left). However, the 5^{th} harmonic spectral flux computation in figure 8 (right) shows no substantial impact on the spectral performance due to the field decrease. As a result, no magnetic shimming was needed. On the other end, some “Magic finger” corrections were necessary to reduce the field integral errors. The optimization of the “Magic finger” was carried out using “IDBuilder”, a genetic algorithm based computer code for magnetic tuning of undulators [7,8]. Figure 9 shows the results for the horizontal and vertical field integrals at a gap of 5.6 mm by using 20 magnetized cylinders with remanent field of 1.2 T, diameter 2 mm and height 4 mm.

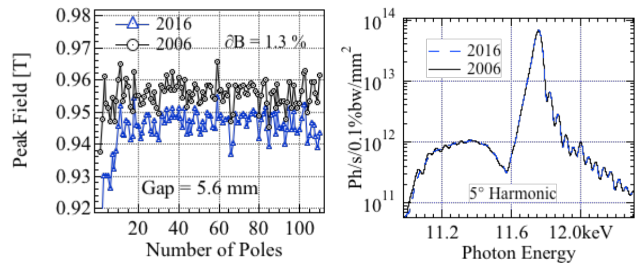

Figure 8: (Left) Comparison of the peak filed distribution measured in 2006 (black dots) and in 2016 (blue dots). (Right) Comparison of the on-axis flux intensity calculated from the magnetic measurement in 2006 (black line) and in 2016 (dashed blue line).

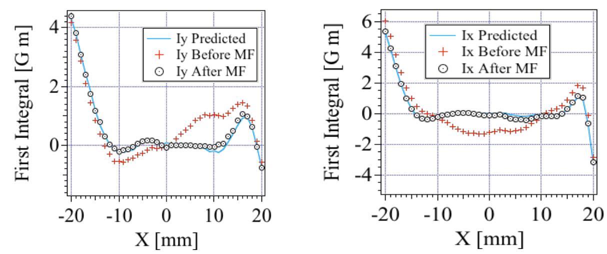

Figure 9: Comparison between measured field integrals before and after MF corrections and the “IDBuilder” predictions

CONCLUSION

The magnetic measurements and adjustments have been successfully completed within the timeframe required and the devices are ready to be installed in the NSLS-II storage ring. Although all IDs measured so far have distinct characteristics and peculiarities with different levels of complexity, the ID lab at NSLS-II is recognized to be fully capable of measuring and characterizing these devices with high accuracy and precision.

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