The Latest Status of NSLS-II Insertion Devices

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Abstract. The National Synchrotron Light Source-II (NSLS-II) project is now in the final stage of construction. The Linac, the Booster synchrotron, and the Storage Ring magnets girder assemblies have been installed. The first damping wiggler has been delivered and its field characteristics are carefully measured. A Three Pole Wiggler (3PW) and Apple-II type elliptically polarizing undulators (EPUs) have been fabricated by the vendors. Two 3.0m long in-vacuum undulators (IVUs) and one 1.5m long IVU are almost complete and waiting for factory acceptance tests. One 3.0m long IVU for Inelastic X-ray Scattering beamline is in fabrication by a different vendor. Recently two 2.8m long IVUs for long straight sections (LSSs) have been added to the project for “future beamlines”. In addition, two 1.5m long IVUs and one 2.8m long IVU for LSSs have been procured for Advanced Beamlines for Biological Investigations with X-rays (ABBIX) project funded by National Institute of Health (NIH). Further, two 3.5m long EPUs for LSSs are being designed for NSLS-II Experimental Tools (NEXT) - Major Item of Equipment (MIE) project. To succeed these conventional IVUs, PrFeB based cryo-permanent magnet undulator (CPMU) is considered as next generation device of hard X-ray sources. An In-Vacuum Magnetic Measurement System (IVMMS) for cold in-situ Hall probe mapping of CPMUs up to 1.5m in length has been developed. Summary of the current status of each project and future plans for the NSLS-II ring will be discussed.

1. Introduction
The Photon Sciences Directorate at Brookhaven National Laboratory is constructing the National Synchrotron Light Source II (NSLS-II) facility. NSLS-II will be able to accommodate at least 58 beamlines for scientific programs, with additional beamlines possible through canted insertion devices and multiple hutch. There are two avenues of beamline development: Type I – in which NSLS-II is responsible for securing the funding, designing and constructing the beamline; and Type II – for which a group external to NSLS-II is funding, designing and constructing the beamline. Currently funded insertion device beamlines are (6 +2 branches) NSLS-II project beamlines, three NIH-funded ABBIX beamlines, six NEXT-MIE project beamlines and two Type-II beamlines by NIST and the other by Columbia University. All the acronyms for the different NSLS-II beamlines can be found in ref [1].

2. List of Insertion Devices
Table 1 shows a list of NSLS-II project insertion devices. Two 2.8m long U23s have been added recently to equip the facility for future beamlines. The insertion devices used for NEXT-MIE are shown in Table 2.
Table 1: NSLS-II Project Baseline Insertion Devices

| Type        | U20 | U21 (SRX) | U22 (IXS) | U23L | EPU49 (CSX) | DW | 3PW |
|-------------|-----|-----------|-----------|------|-------------|----|-----|
| Length [m]  | 3.0 | 1.5       | 2 x 3.0   | 2.8  | 2 x 2.0     | 2 x 3.4 | 0.3 |
| Period Length [mm] | 20.0 | 21.0 | 22.0 | 23.0 | 49.0 | 100.0 |
| Magnetic Gap [mm] | 5.2 | 6.4 | 7.5 | 6.1 | 11.5 | 15.0 | 28.0 |
| $B_{\text{peak}}[T]$ | 1.0 | 0.9 | 0.78 | 0.95 | 0.94 (lin) / 0.57 (heli) | 0.72 (vlin) / 0.41 (45°) | 1.8 | 1.13 |
| Maximum $K$ | 1.8 | 1.8 | 1.5 | 2.05 | 4.3 (lin) / 2.6 (heli) | 3.2 (vlin) / 1.8 (45°) | 15.2 |
| Fundamental Photon Energy | 1830 | 1560 | 1800 | 180 (lin) / 230 (heli) | 285 (vlin) / 400 (45°) | |
| $E_c[\text{KeV}]$ | 10.7 | 3.6 | 4.5 x 2 | 7.2 | 8.8 (lin) | 64 | 0.34 |

Table 2: NEXT-MIE Insertion Devices

| Type        | EPU105 (ESM) | EPU49 (ESM) | EPU57 (SIX) |
|-------------|--------------|-------------|-------------|
| Length [m]  | 2.8          | 1.4         | 2 x 3.5     |
| Period Length [mm] | 105.0 | 49.0 | 57.0 |
| Min. Magnetic Gap [mm] | 16.0 | 16.0 | 16.0 |
| $B_{\text{peak}}[T]$ | 1.14 (lin) / 0.74 (vlin) | 0.72 (lin) / 0.47 (vlin) | 1.14 (lin) / 0.74 (vlin) |
| Maximum $K$ | 11.2 (lin) / 7.23* (heli) | 3.27 (lin) / 2.53 (heli) | 4.41 (lin) / 3.55 (heli) |
| Fundamental Photon Energy | 12.8 (lin) / 15.3* (heli) | 275 (lin) / 236 (heli) | 140 (lin) / 110 (heli) |
| Max Total Power [kW] | 10.1 (lin) | 2.0 (lin) | 2 x 7.0 (lin) |

* For EPU105, $K_{\text{eff}}$ values for Circular (C) and Linear Vertical (LV) shown here are the maximum values permitted owing to the power loading issues on Bend Magnets and/or ID chamber walls in the vertical plane.

The AMX/FMX beamlines for ABBIX project will use an identical configuration to the straight section where the SRX-IVU in the project beamlines is located. The LIX-IVU will be almost identical to a U23L except for the minimum gap (5.7mm) and the vacuum chamber length.

3. Status of the NSLS-II project devices

3.1. Damping Wiggler
The first article damping wiggler was delivered by Danfysik to BNL on November 12, 2012. Various modifications to control system have been implemented to avoid motor stall in certain test modes. Magnetic field measurement has been completed. Figure 1-a and 1-b show a comparison between the vendor’s result and BNL’s in terms of peak field and period length analysis, respectively. They indicate excellent correspondence between two independent measurements. Other results such as field integrals and multipoles are also satisfactory. The second device has been delivered in June 2013, and the last device is scheduled to arrive at BNL in October 2013.
3.2. Elliptically Polarizing Undulator (EPU)
Apple-II type EPUs have been fabricated by Kyma SRL. Vendor field measurement results have been found satisfactory and the devices are almost ready to be shipped. Active field correction scheme by current strips [3] will be implemented on the EPU vacuum chamber. Figure 2 shows a photograph of an EPU at the vendor site and the vacuum chamber including supports is delineated in Fig 3.

![Figure 2: One of two EPU49s at the vendor’s site.](image1)

![Figure 3: A schematics of CSX-EPU vacuum chamber](image2)

3.3. In-Vacuum Undulator (IVU)
Four IVUs are being fabricated by Hitachi Metal America. The first U20 is in its final tuning stage at the SPring-8 Magnetic Measurement Facility (MMF) shown in Fig. 4. The second U20, as well as the first U21 are in the mechanical system construction phase, while a U22 is still in the design stage. Figure 5 is a CAD rendering of a U22 in a long straight section.

![Figure 4: The first U20 at the SPring-8 MMF.](image3)

![Figure 5: CAD rendering of U22 in a long straight section](image4)
4. IVMMS
An in-Vacuum Magnetic Measurement System (IVMMS) to be used to measure future 1.5m long CPMUs has been fabricated. Field measurements of PrFeB magnet arrays at LN2 temperature have been conducted (Fig.8). A similar result (Fig.7) has been obtained to that taken by our Vertical Test Facility [2].

5. Beam dynamics issues with NEXT-EPUs.
The impact of APPLE-II type EPUs on the storage ring electron beam dynamics has been extensively studied in recent years [3]. Given electron beam parameters in the straight sections where these EPUs are installed, significant impact on the beam dynamics is predicted if no mitigation measures are taken. The main source of this detrimental effect comes from the so-called “dynamic field integral (or multipole) effect”. The integrated field seen by sinusoidally wiggling electrons is given by [4]

$$\int B_y(x) \, dx = \frac{L}{2k^2B} \, B_y(x) \left( \frac{dB_y(x)}{dx} \right)$$

where $L$ is the length of the device, $k=2\pi$/period length, $\rho$ is the radius of curvature of the beam trajectory, and $x_i$ is the horizontal displacement of the electron. This effect scales as the ID period length squared and as the derivative of the transverse field roll-off. Field integral measurement capabilities at most insertion device magnetic measurement facilities utilize straight coils and cannot quantify the transverse field roll-off experienced by wiggling e-beam. After vigorous tracking studies, the impact of 7m long SIX-EPUs on the dynamic aperture will not be negligible since they are installed in a long straight section where the vertical beta function is three times bigger than that of a short straight. Searching for a better working point and possible addition of octupole magnets to suppress nonlinearity will be investigated.

[1] http://www.bnl.gov/ps/nsls2/beamlines/

[2] Tanabe, T., et. al., “Cryo-temperature field measurement of Pr2Fe14B undulator and performance enhancement options at the NSLS-II,” The proceedings of the tenth International Conference on Synchrotron Radiation Instrumentation (SRI 2009), September 27 – October 2, 2009, Melbourne, Australia.

[3] J. Bahrdt et al., “Active Shimming of the Dynamic Multipoles of the BESSY UE112 APPLE Undulator” EPAC08, WEPC097 p. 2222.

[4] J. Safranek, et. al., “Nonlinear dynamics in a SPEAR wiggler,” Phys. Rev. ST, Acc. and Beam, Vol. 5, p.010701 (2002).