Latest Experience on Insertion Devices at the National Synchrotron Light Source-II

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National Synchrotron Light Source-II (NSLS-II) is the latest storage ring of 3 GeV energy with the horizontal emittance of the electron beam being 0.9 nm.rad. Nine In-Vacuum Undulators (IVUs) are utilized at the NSLS-II as of February 2016. All IVUs have a unique side window derived from the experience from the CHESS facility in Cornell University. An R&D activity called “Vacuum Seal Test” was conducted to ensure the viability of aluminum wire seal. Another R&D activity to develop a measurement system for Cryogenic Permanent Magnet Undulator (CPMU) was also performed. Other in-air devices, namely damping wigglers (DWs) and elliptically polarizing undulators (EPUs) utilize extruded aluminum chambers with Non-Evaporable Getter (NEG) coating. The beam-based integral estimates were obtained from the virtual kicks at the upstream and downstream of the undulator that best fit the measured orbit distortion in a model lattice with Tracy. In some cases, there are fairly large discrepancies between magnetic measurement data and observed integrals by the beam. Beam studies were carried out to explain the discrepancies mentioned earlier. The latest experiences on ID development and commissioning are discussed in conjunction with related activities in the world.

1. Introduction

The first in-vacuum undulator (IVU) for a synchrotron light source was developed and installed at the KEK in 1990. Even though IVUs had been extensively used at the SPring-8 in Japan since then, most of the other facilities still depended on conventional in-air devices for their Hard X-ray production until the turn of the century. Then, the advent of a minigap short-period IVU, IVUN at the NSLS in 1997 had a lasting impact on the design of synchrotron light source facilities all over the world. Instead of using high energy rings such as European Synchrotron Research Facility (ESRF), Advanced Photon Source (APS) and SPring-8, it was shown that a medium energy ring (~3 GeV) could be used to cover the spectrum range between 5 keV and 20 keV with short-period IVUs. Now the IVU is a popular choice for a short-period undulator for many light sources in the world such as ESRF, Soleil in France, Swiss Light Source in Switzerland, ALBA in Spain and Diamond Light Source in UK.

Another noticeable change in recent years in terms of vacuum technology for light sources is the more prevalent use of NEG-coated chambers. The apertures of vacuum chambers, especially for short period insertion devices, are getting smaller, resulting in lower vacuum conductance. NEG coating partially alleviates this problem.

In this article, our experience with IVUs and NEG-coated chambers are discussed. The characteristics of NSLS-II IDs are explained in Chapter 2 including the data on NEG coatings. The baking method for IVUs and the details of Vacuum Seal Test (VST) are discussed in Chapter 3. Chapter 4 explains the development of our in-vacuum measurement system. The results of beam-based measurements and related discussion are given in Chapter 5. A detailed description of NSLS-II storage ring’s vacuum systems can be found elsewhere.

2. NSLS-II IDs and other alternatives

The NSLS-II ring employs three different types of IDs, namely, planar hybrid in-air wigglers/undulators, APPLE-II type EPUs and IVUs. There are other types of IDs such as pure-permanent magnet (PPM) planar devices, and various types of EPUs including those utilizing electro magnets (EMs). Superconducting wigglers have been used for many years to obtain higher field than PM- or EM-based devices. A large amount of effort has been made to realize superconducting undulators in the past decades without success. However, the recent effort by Advanced Photon Source (APS) appears to have come to fruition.

2.1 List of IDs

In this subsection, the brief descriptions of the IDs installed in the NSLS-II ring are given with an emphasis on their unique features. Even though all the IDs in the NSLS-II ring are of fundamentally conventional designs, various new features have been introduced to improve their performance. Table 1 shows the specifications of all the IDs funded as of January 2016 where L is the device length and l_u is its period length. The full definition of the acronym for each beam is listed in Ref. 11.

2.2 Damping wigglers

The nominal magnetic field of the NSLS-II dipole is only 0.4 T while the peak field of damping wigglers (DWs) was chosen to be 1.8 T to achieve the most effective horizontal emittance reduction. A hybrid magnetic structure with side magnets is utilized to obtain the maximum field with the given pole gap of 15 mm. The
Table 1  NSLS-II Insertion Devices installed and currently under fabrication.

| Beam Line      | Type    | Cell | L [m] | \( \lambda_o \) [mm] | Peak Field [T] | \( K_{\text{max}} \) | Mag Gap [mm] | Vac Aper [mm] | Total Power [kW] |
|---------------|---------|------|-------|-----------------------|----------------|----------------|--------------|--------------|------------------|
| CSX1/CSX2     | EPU49   | 23   | 4 (2 × 2) | 49                     | 0.57 (heli)   | 2.6 (heli)    | 11.5         | 8.0          | 7.3 (heli)      |
|               |         |      |       |                       | 0.94 (lin)    | 4.3 (lin)     |              |              | 9.9 (lin)       |
|               |         |      |       |                       | 0.72 (vlin)   | 3.2 (vlin)    |              |              | 5.5 (vlin)      |
|               |         |      |       |                       | 0.41 (45d)    | 1.8 (45d)     |              |              | 1.7 (45d)       |
| IXS           | IVU22   | 10   | 3     | 22                    | 1.52          | 1.52          | 7.4          | 7.2          | 4.7 × 2         |
| HXN           | IVU20   | 3    | 3     | 20                    | 1.03          | 1.83          | 5.2          | 5.0          | 8.0             |
| CHX           | IVU20   | 11   | 3     | 20                    | 1.03          | 1.83          | 5.2          | 5.0          | 8.0             |
| SX/(XFN)      | IVU21   | 5    | 1.5   | 21                    | 0.90          | 1.79          | 6.4          | 6.2          | 3.6             |
| XPD/PDF       | DW100   | 28   | 2 × 3.4 | 100           | 1.8           | ~16.5         | 15.0         | 11.5         | 64.5            |
| ESM           | EPU105/ | 21   | 2.7/1.4 | 105/49       | 0.74/0.57 (heli) | 7.23/3.55 (heli) | 16.0         | 11.5         | 4.22/1.2 (heli) |
|               | EPU57   |      |       |                       | 0.90/0.83 (vlin) | 7.23/3.06 (vlin) |              |              | 4.22/0.86 (vlin) |
|               |         |      |       |                       | 1.14/0.83 (lin) | 11.2/4.4 (lin) |              |              | 10.1/2.0 (lin)  |
| SIX           | EPU57   | 2    | 3.5   | 57                    | 0.57 (heli)   | 3.55 (heli)   | 16.0         | 11.5         | 4.4 (heli)      |
|               |         |      |       |                       | 0.83 (lin)    | 4.41 (lin)    |              |              | 6.8 (lin)       |
| ISR           | IVU23   | 4    | 2.8   | 23                    | 0.95          | 2.05          | 6.2          | 6.0          | 7.2             |
| SMI           | IVU23   | 9    | 2.8   | 23                    | 0.95          | 2.05          | 6.2          | 6.0          | 7.2             |
| ISS/XFP       | DW100   | 18   | 2 × 3.4 | 100           | 1.8           | ~16.5         | 15.0         | 11.5         | 64.5            |
| FXI           | DW100   | 8    | 2 × 3.4 | 100           | 1.8           | ~16.5         | 15.0         | 11.5         | 64.5            |
| LIX           | IVU23   | 16   | 2.8   | 23                    | 1.02          | 2.2           | 5.7          | 5.5          | 8.3             |
| FMX/AMX       | IVU21   | 17   | 1.5   | 21                    | 0.90          | 1.79          | 6.4          | 6.2          | 3.6             |

period length of 100 mm was selected to minimize the fan angle of the radiation.

2.3 APPLE-II EPUs

Two 2.0-m-long Apple-II type EPUs with a novel mechanical design to enforce the rigidity of the arrays have been developed by a collaboration between Kyna undulator, srl and BNL. A detailed description of the mechanical structure of these EPUs can be found in Ref. 13. Three more EPUs are being constructed for the NSLS-II Experimental Tools (NEXT) project14). One 1.4-m EPU57 and quasi-periodic 2.7-m EPU105 for Electron Spectro Microscopy beamline and one 3.5-m EPU57 for Soft Inelastic X-ray Scattering beamline are to be installed in 2016.

2.4 NEG-coated chambers for DWs and EPUs.

DWs and EPUs employ NEG-coated Al extrusion vacuum chambers fabricated by a commercial vendor. The NEG coating applied by the vendor which had invested to establish the coating facility was found to be ineffective in the first batch of DW chambers. An Energy Dispersive X-Ray (EDX) analysis was performed by BNL on the BPM blanks which were removed after coating. It was found that the NEG compositions deviated from the recommended values by CERN (Ti: 16–35%, Zr: 30–51%, V: 25–42%). This vendor (company A) had to give up coating those chambers and sent them to CERN to remove the coating and had another company which specialized in NEG coating (company B) to apply the coating. Table 2 shows the comparisons of EDX measurement data provided by these vendors and those provided by BNL. EPU chamber has 20 current strips on each side for dynamic compensation of the second order kicks15), which added extra constraint on the activation temperature of the NEG coating.

2.5 IVUs

There were two deficiencies in the design of IVUs used elsewhere. The first is a lack of ability to confirm the field quality after the vacuum chamber is assembled. In a conventional IVU design, the field measurement is conducted without the vacuum chamber. After magnetic tuning is done, the magnetic arrays are detached to allow the installation of the vacuum chamber. There, the field quality depends on the mechanical repeatability of assemblies, which is not guaranteed. The second is the difficulty of measuring the field quality after vacuum bake-out. BNL’s internal data show that the field quality of an IVU can change albeit slightly after the magnets experienced high temperature during the baking process. BNL developed an IVU with a side window in its main vacuum chamber in 200616). Figure 1(a) shows approximately 0.4 percent peak field reduction of this IVU before and after the bake-out at 90°C for twelve hours. Further tuning was conducted after the prebake to improve the field characteristics. Figure 1(b) shows the 0.15 percent change after the second bake-out at 85°C for five days. This 1.0-m-long device used a custom-made aluminum sheet for vacuum seal.

An NSLS-II IVU can be 3-m long, and other sealing methods were also investigated. One candidate was Helicoflex spring energized seal. However, the product...
of this size was available on special order, and was found to be cost prohibitive. Cornell High Energy Synchrotron Source (CHESS) had the experience of using aluminum wire to seal various rectangular openings in their accelerator\(^{17}\). As a part of R&D, we fabricated a 4-meter-long vacuum seal test (VST) chamber and conducted various tests on thermal cycling with changing rigidity of the opening. Details on the VST can be found in Chapter 3. After successful VST experience, it was decided that all NSLS-II IVUs should have a side window which allows the field measurement without removing the vacuum chamber. This feature was especially important for the NSL-II project in which all the IVUs were fabricated and vacuum tested by commercial vendors. It meant that BNL must certify the field quality after the first baking of magnet arrays. After the certification, BNL conducted a pre-baking at the insertion device magnetic measurement facility (ID-MMF). Then a final baking was carried out after it was installed in the ring. The baking temperature for the second and third baking must be lower than the first bake in order to avoid further demagnetization. Figure 2 shows a 2.8-m-long IVU undergoing a Hall probe measurement.

### Table 2(a) Comparison of EDX data by vendor A and BNL.

| Sample | Ti  | Zr  | V   |
|--------|-----|-----|-----|
| S007493 V | 26  | 36  | 38  |
| S007493 B | 25  | 16  | 47  |
| V - B     | 1   | 20  | -9  |
| S007495 V | 29  | 35  | 36  |
| S007495 B | 31  | 16  | 53  |
| V - B     | -2  | 19  | -17 |
| S007501 V | 27  | 33  | 40  |
| S007501 B | 28  | 15  | 56  |
| V - B     | -1  | 18  | -16 |
| S007500 V | 25  | 34  | 41  |
| S007500 B | 24  | 26  | 49  |
| V - B     | 1   | 8   | -8  |

### Table 2(b) Comparison of EDX data by vendor B and BNL.

| Sample | Ti  | Zr  | V   |
|--------|-----|-----|-----|
| 1-Vendor | 29  | 25  | 46  |
| 1-BNL   | 25  | 31  | 43  |
| V - B   | 3   | -6  | 3   |
| 2-Vendor | 29  | 26  | 45  |
| 2-BNL   | 27  | 33  | 40  |
| V - B   | 2   | -7  | 5   |

3. **Vacuum Seal Test**

3.1 **Construction of test vacuum chamber**

Aluminum wire seal was tested on a 4-meter test chamber which had a modular design shown in Fig. 3. A spacer plate having grooves cut for O-ring seals was placed between the front plate and the base plate. The distance between the front plate and the base plate is 0.75" (1.905 cm). This is maintained to a minimum in order to keep enough room for bowing of the chamber inwards. O-ring seals were used on either side to seal the...
of the cover plate, two set screws 1/2 in away from the center and towards either end of the sequence was specified to move the crushed wire material to create more torque to compress the seal. The bolting sequence was required to bolt the chamber at the cross point to avoid holes.

The longitudinal length of the vacuum chamber was 4 meters. Stiffening ribs were welded on to the surface of the front plate towards the cover plate. The main reason for the stiffening ribs was to have a chamber with adjustable stiffness which could be either increased or decreased by inserting support brackets. In order to seal the face it is essential to have a specified bolting pattern between the bolts of 1.457 cm–24, along with washers, were used with spacing between the bolts of 1.457 cm (3.7 cm). At each of the corners of the cover plate, two set screws 1/2 in (1.27 cm)–20 in size were used to avoid the cover plate from coming in contact with the wire during initial alignment. The set screws were loosened initially to maintain a gap of more than 1 mm, which was the thickness of the wire.

Four wire seal adjusting fixtures were set at each end of the cover plate. The wire fixtures were designed as such that the tension in the wire as well as the position with respect to the wire placed on the cover flange is adjustable using a spring held linkage.

3.2 Test procedure

The chamber was tested in the vertical position in order to replicate the actual sealed ID chambers while in operation. This also helped determine the effect of sag of the wire.

Wire seal adjusting fixtures were then installed with the wires and their position adjusted with the linkages. It was critical to have the wire not more than 1/8 in (0.3175 cm) of an inch away from the edge of the center bolting hole.

At the cross point of the wire seal, 1/2-20 inch bolts were required to bolt the chamber at the cross point to create more torque to compress the seal. The bolting sequence was specified to move the crushed wire material away from the center and towards either end of the chamber. This was essential to maintain a uniform seal. The chamber was then pumped down to the UHV range through the pump ports on the cover plate. A leak test was done to determine if the chamber was UHV compatible.

The chamber was baked in an oven at 150 degrees C. This was done to replicate the actual baking procedure for all ID vacuum chambers at NSLS-II and to study the baking effect on the wire seal. During the baking process the temperature was ramped to 150 degrees C, in steps of 10 degrees per minute from room temperature, which is 25 degrees C. The pressure within the chamber was monitored during the entire baking process. The chamber was baked for a period of approximately 4 hours at 150 degrees C. The chamber was then left to cool down for a day within the oven. The vacuum chamber was then removed from the oven and tested for leaks. Four bake cycles were carried out on this chamber.

3.3 Test results

It was observed that the vacuum chamber pressure reduced from $2.86 \times 10^{-3}$ Pa to $1.16 \times 10^{-3}$ Pa, when the surface finish was reduced from 32 micro-inches to 16 micro-inches. The position of the seal from the bolt edge also affected the seal. For optimal results, it was found that the wire seal should not be placed any more than 1/8 in away from the edge of the sealing bolt. Bolts used for sealing should have washers. It is advisable to have bolts with a maximum permissible torque (> 250 inch-lb). In case of a leak at certain spots, torquing down the bolts around the leak spots would mostly seal the leak. After the first baking cycle, a few leaks were noticed at the edges; these were eliminated by progressively tightening the bolts in sequence, and hence causing a progressive deformation of the wire seal.

4. In-Vacuum Magnetic Measurement System (IVMMS)

CPMU is a natural progression of IVU technology. Magnetic characteristics of a CPMU must be measured in vacuum. Various attempts have been made by laboratories worldwide. As far as a Hall probe measurement system is concerned, none of the existing systems has a capability to scan ranges of off-axis areas without manual adjustment. BNL has developed a prototype in-vacuum magnetic measurement system (IVMMS) in collaboration with Toyama, Co., Ltd. in Japan, which can perform cryo-temperature Hall probe scans for CPMUs of up to 1.5 m length. Thanks to the mechanism to use a side window, the IVUMMS can be used during magnetic tuning as well as for final measurements. If necessary, it can be used in the ring tunnel without disconnecting the device from the end sections. This section describes the details of IVMMS.

4.1 System Requirement

An IVMMS can be considered a Hall probe bench inside of a vacuum enclosure. Therefore the requirement for the motion accuracy of the probe unit is similar to what is required for a conventional in-air bench. A 1.5 m-long CPMU, with a minimum gap of 4.5 mm, should be measured inside its own vacuum chamber. The
IVMMS will be temporarily mated and sealed to the vacuum chamber.

The Hall probe, affixed to a motion controlled assembly mounted on a carriage, shall translate along a guide-beam (Z-axis). The motion controlled assembly carried by the Z-axis carriage is comprised of an X and Y linear stage, a right angle mounting bracket if required, an R-axis rotary stage, and a Hall probe mounting fixture. Therefore, the Hall probe can be translated longitudinally in Z, horizontally in X, and vertically in Y, and can be rotated 360° by the R-axis rotary stage. All axes shall have motion limit protection. Shock absorbing hard-stops were provided at either end of the Z-axis motion which could stop the carriage moving at full speed without damage to the assembly. Thus the IVMMS can be operated unattended without failure. The Z and Y axes have a brake the motion controller can apply. The brake would always be on when the power is off. The Z-axis carriage has 1750 mm of travel. The IVMMS is designed to be scalable to 4500 mm of Z-axis travel for a future application to longer devices. For this reason, a linear motor was chosen for the Z-axis mover.

To minimize disturbing effects upon the magnetic measurement being performed, the guide-beam and the bench components are made of non-magnetic materials. Whatever motor configuration is used to drive the X, Y and Z axes, the magnetic field leakage from the motors does not interfere with the Hall probe measurement. Table 3 summarizes the specifications for the X, Y, Z axis motions and the R axis motion as well as their corresponding achieved values. Note that NSLS-II insertion levelers. The dimensions of the granite surface plate are 2000 mm × 500 mm × 250 mm.

### 4.2 Mechanical Design

The Z stage is mounted on the LM guides and is moved by an Airex LMC-P16 linear motor. The guide beam is made of stainless steel 316LN. A copper tube is provided on the stage surface to keep the stage temperature constant. A RENISHAW RLE laser linear encoder system is provided to monitor the Z-axis. The RLE system is also used to generate the trigger for the data acquisition. All of these UHV compatible stages are in-house designs by Toyama, Co. The linear motor coil is attached under the middle of the Z-stage and the linear motor track is attached on the guide beam surface. The stops are provided at both ends of the Z-axis. They have both shock absorber and limit switch functions. The encoder scale is positioned along the LM guide on the guide beam. The reference mark is attached at the middle of the guide beam near the encoder scale.

Three manual adjustment pads are provided under the guide-beam assembly. Each pad consists of a wedge mount and the X and Z axis positioning adjusting screws and they provide the X, Y, and Z translations for the tilt, roll, and yaw motions. When connecting to the IVU, the IVMMS is moved to it by using a set of air pads which will be temporarily inserted under the guide-beam assembly. After the adjustment using the air pads, the fine adjustment will be achieved with using the three manual adjustment pads. The guide beam assembly consists of a granite surface plate and a support frame. The granite base is supported by three wedge mount Precision Levelers from the support frame. The level of the guide beam will be adjusted with bubble levels and the wedge mount levelers. The dimensions of the granite surface plate are 2000 mm × 500 mm × 250 mm.

### 4.3 Vacuum System Design

For the vacuum chamber, the flange will be connected to the IVU through a nipple. The opening of the flange is 2000 mm wide and 200 mm high. Five maintenance ports are provided on the side plate of the chamber. The two ports are provided at both longitudinal ends of the chamber. Another three ports are provided on the other side chamber plate of the racetrack flange. Five viewing ports are provided on the chamber. Two ports with a 140-mm viewing diameter are provided to the longitudinal end maintenance flange and to the center maintenance flange to the side plate, respectively. A 64 mm port is provided to the top plate. Two ports for introducing the laser light are provided to the end plate and to the end maintenance flange, respectively. The port provided to the end plate is for the RENISHAW RLE laser linear encoder system. The other port is used for the accuracy inspection of the factory acceptance test. Seven electric feedthrough ports are provided to the three maintenance ports side. Five of seven ports are used for the stepper motors, linear motor, encoders, and limit switches. One port is for the Hall probe. The last one port has two connectors. One is for temperature sensors and another one is a spare 25 pin connector. A water feedthrough port and an electric port for ground wire are provided to the bottom plate. A burst disk ports is provided to the top plate. Another nine spare ports are provided to the chamber. Three ICF 70 blank flanges are provided to the top plate. Two ICF152 blank flanges are provided to the top plate. Two ICF 203 blank flanges are provided to the

| Specifications | Values achieved |
|----------------|-----------------|
| X-axis (Horizontal–100 mm) |                |
| Accuracy < ±5 μm | ±3.28 μm        |
| Repeatability < ±1 μm | ±0.89 μm        |
| Y-axis (Vertical–50 mm) |                |
| Accuracy < ±5 μm | ±1.66 μm        |
| Repeatability < ±1 μm ±0.74 μm [Pass] | ±0.74 μm        |
| Z-axis (Longitudinal–1750 mm) |                |
| Accuracy < ±5 μm | ≈ ±10 μm        |
| Repeatability < ±1 μm | ≈ ±2 μm        |
| R-axis (Probe Rotation) |                |
| Accuracy < ±40 arcsec | ±8.19 arcsec     |
| Repeatability < ±2 arcsec | ±1.80 arcsec     |
| Backlash < 20 arcsec | 15.12 arcsec     |
| Eccentricity < ±5 μm | 3.55 μm         |
| Wobble < 10 arcsec | 8.52 arcsec |
side plate. Two ICF 70 blank flanges are provided to the bottom plate. This chamber will be operated at high vacuum environment (10−4 Pa) when it connects to an IVU or a CPMU. The ICF 152 and ICF 203 flanges could be used as vacuum pumping ports. A burst disk is attached in case LN2 used for CPMU leaks to the vessel and builds up pressure.

Extensive FEA calculations for thermal and mechanical characteristics were conducted to ensure the IVMMS met the performance specifications. The following analyses have been conducted to optimize the design: 1) Vacuum chamber deformation by atmospheric pressure. 2) Guide beam deformation by atmospheric pressure. 3) Guide-beam deformation by gravity force. 4) Heat load to CPMU from the chamber. Figure 4 shows the external view of the IVMMS.

4.4 Control System

Motion controller is a Brick Motion Controller 5xx-603869-xUxx by DELTA TAU. X, Y, R-axis Five phase stepper motor is a GD-5510E Melec (Japan) and encoder amplifier is a REF2000A20A × 4 by RENISHAW as well. This amplifier has the function of suppressing the vibration. At the beginning, we struggled to tune the linear motor system and damaged coils, but eventually all the electrical issues were resolved. Each pedestal has a yellow “Soft Stop (Motor Off)” button. Activating this switch will cause the motors to stop by activating a “stop all” motion input on the Geo-Brick. In addition, each pedestal will have a red Emergency (Power Off) button. Activating this switch will drop AC power to the Geo-Brick, thereby cutting off power to the motors. However, the motion controller will be kept alive with 24 VDC to preserve the encoder positions. Each type of activation will require the operator to take action to restore servo control. The trigger source is generated from the Z axis encoder (RLE10-SC-XE). The trigger is generated by the Geo-brick. The triggers timing can be programmable. Timing generator is the Geo-Brick’s internal 36Bit counter and timing change is done in the software. For the alignment of the Hall sensor, selecting triggers source to the drive pulse R-axis, Y-axis, and X-axis is possible. The triggers electrical specifications are equivalent to the 26L31 LINE-DRIVER. Termination resistor is not implemented.

4.5 Vacuum lubricant test

Even though the requirement of vacuum level for magnetic field measurement at cryo-temperature is only high vacuum (HV) level, the in-vacuum insertion device needs to be maintained at the level of cleanliness required for ultra-high vacuum (UHV). Therefore cross contamination from IVMMS to IVU must be avoided. We conducted various tests to check the durability of Dicronite® initially chosen for a type of dry lubricant for this system. Balls used for ball bearings were coated with Dicronite. We moved a linear stage with the balls back and forth at a speed of 10 mm/sec. Dipped or coated balls had very short life time and even balls sputtered by Dicronite drastically increased the resistance after approximately 1000 meters of travel. Then we switched the coating material to Defric coating with the same condition. Resistance increase occurred after 10000 meters of travel, which is an order of magnitude longer, but still not sufficient. Figure 5 shows the day-to-day data of the measured force to move the stage. On November 16th, 2011, the motion speed was increased from 1 mm/sec to 10 mm/sec to expedite the experiment. The total distance moved by November 24th was approximately 2400 m. For Defric coat 30X701(−10), the rail was cleaned and...
4.6 Cold measurement test with PrFeB magnet arrays

The original idea of CPMU was to use conventional Neodymium Iron Boron (Nd2Fe14B) magnets for the magnetic circuit of an undulator. However it is known that maintaining the array at optimal temperature of around 130 K is not easy with varying heat load in a storage ring undulator. At lower temperatures, magnetization is reduced by the Spin Reorientation Transition (SRT) phenomenon. Not only the reduction of magnetization, but also the susceptibilities of the magnet, especially in the hard direction increase rapidly, which makes magnetic circuit design more complicated. On the other hand, Praseodymium Iron Boron (Pr2Fe14B) magnets do not show SRT up to 4 K or below. Therefore liquid nitrogen can be used as a coolant. For this test, a newly developed “bakeable” PrFeB magnet (Neo-max CR47, Br = 1.24 T and Hcj = 2480 kA/m) was used to make a small undulator of 17-mm period length and a fixed pole gap of 5 mm. Figure 6 shows the PrFeB arrays in a 1.5-m-long IVU chamber to be mated with the IVMMS for cryo-measurement. The measurement results in Figure 7 demonstrate approximately 14% increase of peak field with LN2 cooling.

5. Comparison with beam-based measurement

As shown in Ref. 22, the first field integral values inferred from the electron beam could be significantly different from those expected from the magnetic field measurement at the ID-MMF. Since multiple measurement results at the ID-MMF were cross checked by other facilities, it is almost certain that the electron beam must be experiencing a different field when it passes through the ID. This difference is assumed to be caused by various reasons such as the variation in the Earth’s magnetic field, other environmental field change due to the existence of ferromagnetic structures nearby or stray magnetic fields from other accelerator components. Misalignment in the installation could be also another cause for this discrepancy.

Magnetic field survey was conducted in various straight sections in the ring tunnel. However no significant environmental field deviation was observed. Recent beam study with the SRX beamline shows significant improvement on the spectral characteristics by applying significant taper adjustment (50 μm) to the undulator and by adding electron beam angle of approximately 40 μrad. More study is required to draw a definitive conclusion on the sources of these discrepancies.

6. Summary

NSLS-II insertion devices are fundamentally of conventional design with various features for improvement over the past generation of IDs used elsewhere. Large rectangular side opening of the IVU’s vacuum chamber greatly simplifies the measurement and tuning of the devices. The novel mechanical design of EPUs would ensure the good field quality in any polarization mode. Effectiveness of NEG coating in ID vacuum chambers is somewhat questionable, especially in the early stage of commissioning, as excess degassing and need to vent the chamber could reduce the pumping speed of the coating due to repeated activation. A scalable in-vacuum magnetic measurement system has been developed for CPMUs. It is still required to use the electron beam to find the condition to maximize the performance of IDs in a storage ring even though modern laser tracker technology is used to fiducialize the system.

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