Development of In-Vacuum Minipole Undulator

Toshiya TANABE [1)], Hideo KITAMURA [1)] and Peter STEFAN [2)]

1) JAERI-RIKEN SPring-8 Project Team, Kamigori, Ako-gun, Kyogo 678-12, JAPAN
2) National Synchrotron Light Source, Brookhaven National Laboratory, Upton, NY 11973

1. Introduction

As a convention, so-called "minipole" undulator is referred to an insertion device (ID), the period length of which is on the order of 1 cm or less. Various minipole undulators have been developed primarily for linac use, for small magnet gap required for this type of device would prevent its use in storage ring. However, with the advent of the third generation light source, vertical emittance of electron beam (e-beam) has become small enough to accommodate sub-centimeter magnet gap without sacrificing e-beam life-time. Unlike conventional insertion devices whose minimum gap is limited by the thickness of vacuum chambers, in-vacuum insertion devices allow magnetic gap to be closed up to the value allowed by beam dynamics limit. This advantage is even more crucial for minipole devices which inherently require smaller gap than that of conventional ones in order to increase undulator deflection parameter K. With a value of K not much smaller than unity, the use of higher harmonics and modest tunability are also viable.

We are currently developing an in-vacuum minipole undulator (NSLS-IVUN) which will be installed in the X-ray ring (E=2.5 GeV) at National Synchrotron Light Source (NSLS) in Brookhaven National Laboratory (BNL.) Despite the fact that this ring is the second-generation light source, extremely low beam-coupling enables us to achieve the minimum-gap operation of 2.5mm. In this paper preliminary designs of the device are presented.

2. Block Design

In-vacuum minipole undulator imposes extra constraints and difficulties compared to conventional IDs in design of magnet pieces primarily due to the following reasons:

(1) It requires higher machining accuracy simply because of its small physical dimensions.

(2) As the minimum allowable size of good field region (horizontal field roll-off is less than 0.5 %) for stable ring operation remains the same, horizontal dimension of the magnet cannot be decreased indefinitely.

(3) Due to baking process of magnets the permeance of a magnet piece should not be lower than a certain value that is determined by the material. In general, stocky piece is more favorable than thin one, which contradicts the requirement (2).

A type of construction with independent magnet holder and clamp is not appropriate as relative errors in machining with respect to block size become larger and a large number of gaps created by the structure may result in poor vacuum. Hence, we have developed a novel structure to place and hold small magnet pieces in precise locations, and it is delineated in Fig. 1.

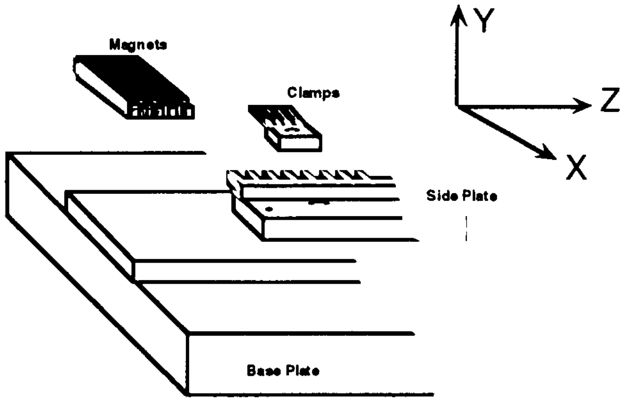

Fig. 1. Magnet and holder structures

As far as the width (in x) of the magnet is concerned, there is an operational requirement to maintain a good field region of at least ± 5mm. Figure 2 shows magnetic field roll-offs with three different width, which has been calculated by Halbach formula [1] and later confirmed by MAFIA calculation. Consequently the width has been chosen to be 22mm. Given the target wavelength for fundamental radiation (our case is 2.6877 Å,) the thickness and height have been optimized to maximize permeance of the magnet and to minimize field reduction due to lower height.

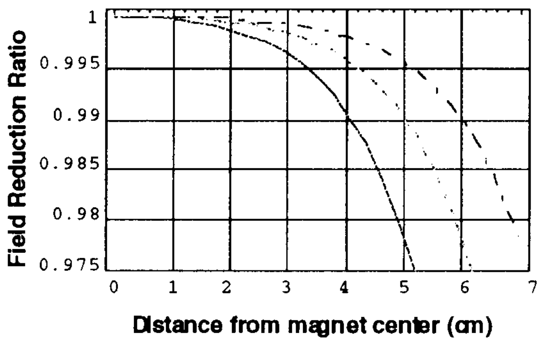

Fig. 2. Field roll-offs due to finite width in the horizontal direction. Solid line indicates width of 18mm, dashed line for 20mm and dash-dotted line for 22mm. Gap is 3.3mm and height of the block is 3.92mm.

3. Magnetic Field Measurement

In addition to those difficulties listed in section 2, there are other impediments to be overcome concerning magnetic field adjustment:

(A) Magnetic field measurement by conventional Hall probe and rotating coil is difficult for a device with a few millimeter gap and sub-centimeter period length.

(B) Magnetic field correction by shimming is not preferable, for use of adhesive would deteriorate vacuum and roughness created by shims would give rise to negative effects in beam dynamics.

As the length of magnet period decreases, the horizontal size of active area of the Hall probe must decrease as well in order to maintain spatial sampling rate. For the measurement of horizontal field, the size of enclosure should also be minimized. We use AREPOC HHP-MP which has an active area of 100μm × 100μm and the thickness of enclosure is 1mm under temperature controlled environment for the purpose. As for field integral measurement, we plan to use stretched wire method [2] and possibly pulsed-wire method [3].

Magnetic field correction will be carried out in the similar fashion as for SPring-8 devices by first using simulated annealing [4] for coarse correction, then utilizing magnet chips for final adjustment. Integrated multipole requirements for NSLS X-ray ring are presented in Table 1.

Table1. Integrated multipole requirements for NSLS X-ray ring.

Normal/Skew Dipole	100 G*cm
Normal/Skew Quadrupole	10 G / 100G
Normal/Skew Sextupole	50 G/cm
Normal 2nd Integral	8 G*m^2
Skew 2nd Integral	8 G*m^2
RMS Phase Shake	2 degrees

4. Transition Area

According to Reference [5], there are three predominant beam dynamic effects caused by small gap aperture of the minipole undulator and aperture change due to transition from outer vacuum chamber to ID. They are power dissipation due to longitudinal impedance, transverse coupled bunch instability / strong head-tail instability due to transverse resistive impedance and transverse geometric impedance. Power dissipation turns out to be modest. Even with 1mm gap and e-beam current of 0.1 A, it is only 14 W. It can be shown that for gap being smaller than 2mm transverse resistive impedance becomes dominant as it is inversely proportional to the third power of the gap length, whereas geometric one is only to the first power. Two transverse effects are comparable when the undulator is operated at the gap of 3.3mm. Then tapering the transition section to reduce geometric effect may not significantly improve the situation unlike SPring-8 devices.

5. ID Parameters and Spectrum

Pertinent ID parameters are presented in Table 2. Radiation spectrum is shown in Fig. 3 and peak brilliance with varying K is found in Fig. 4.

Table 2 Selected ID parameters

Type	Linear (4 block)
Period Length (λ_u)	11.0 mm
Number of Period	31
B_y , (K) @ 3.3 mm	0.688 T (0.707)
Packing Factor	0.992
Fundamental Rad (λ_1)	2.688 Å
Magnetic Material	NEOMAX 32 EH
Coating Material	TiN (5μm)

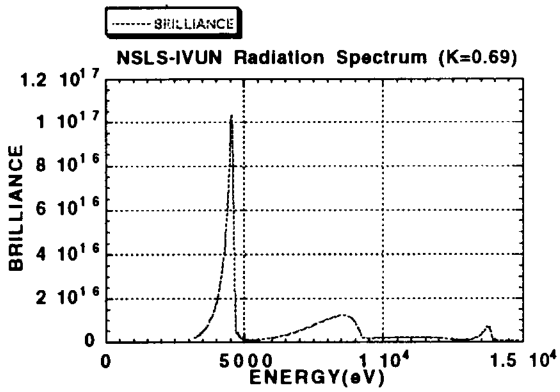

Fig. 3. NSLS-IVUN radiation spectrum

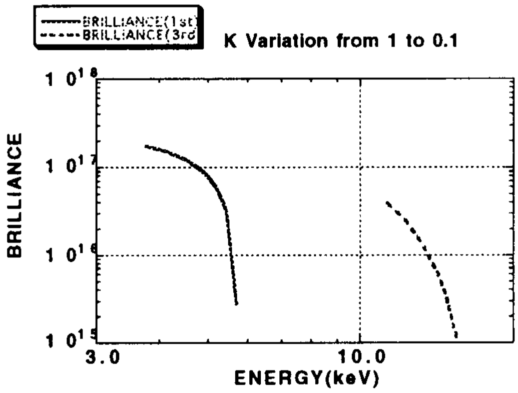

Fig. 4. Peak brilliance with varying K

5. Conclusion

With in-vacuum structure, a minipole undulator having modest tunability and harmonics is currently under construction. There are extra demand in mechanical design and magnetic field measurement, which is deemed to be overcome.

References

[1] K. Halbach, Nucl. Instr. and Meth. **169**, 1 (1980)
[2] R. P. Walker et al, "Status of Ellettra Insertion Deices," Proc. 1995 Particle Accelerator Conference.
[3] R.W. Warren, Nucl. Instr. and Meth. **A272**, 257 (1988)
[4] A. Cox and B. Youngman, Proc. SPIE 582, 91 (1986)
[5] K. Bane and S. Krinsky, "Impedance of the NSLS Prototype Small-Gap Undulator Vacuum Chamber," BNL Informal Report, BNL-48792