DEVELOPMENT OF AN IN-VACUUM MINIPOLE UNDULATOR

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Abstract

An in-vacuum minipole insertion device [1] is currently being developed in collaboration between and the National Synchrotron Light Source (NSLS). The magnetic array is constructed by SPring-8 and it will be installed in a chamber with mechanical parts in the X-ray ring (E=2.584 GeV) at the NSLS. The device is made of permanent magnets with 31 periods and the length of the period is 11mm. It is to produce the fundamental radiation at 4.6 KeV which will be mainly used for X-ray photo-correlation spectroscopy (XPCS), and modest value of deflection parameter (K=0.7@3.3mm gap) enables higher harmonics to be used for a variety of experiments. We describe technical difficulties of constructing this type of device as well as the outline of our collaboration.

1 INTRODUCTION

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. With a value of K not much smaller than unity, the use of higher harmonics and modest tunability are also viable.

2 ARRAY 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 Figure 1.

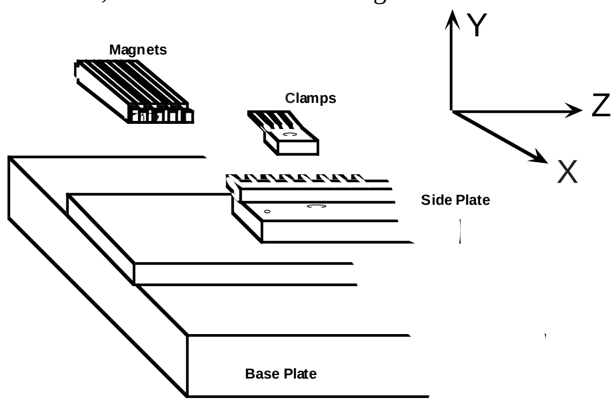

Figure 1. Magnet and holder structures

3 MAGNETIC FIELD MEASUREMENT

A picture of our magnetic field measurement facilities are shown in Figure 2. There are two types of systems; a Hall probe field mapping system which includes a moving stage on a granite bench, holders for magnet arrays and a base plate, and a rotating coil field integral measurement system which is seen at the upper right corner in the picture.

Figure 2. Hall probe field mapping system and rotating coil system.

As for the Hall probe, we use AREPOC HHP-MP which has an active area of 100μm × 100μm, and the thickness of enclosure is 1mm. It is placed in 1.5mm thick copper plate and sandwiched by Kapton tapes. Even though there is no temperature controlling device in the enclosure of the probe, sufficiently low (3.0×10^{-4} / K) temperature coefficient of the probe with software

compensation and reasonable ambient temperature control ensure the accuracy of the measurement. Extra attention was paid to the straightness and flatness of travel. The center of the probe has been found to stay on axis within a range of ± 1 µm vertically, and ± 7 µm horizontally.
The rotating coil device is the same one as is used for SPring-8 IDs [2] except for narrower coil width (1.5mm) and shorter length (1.6m.) Magnetic field correction was made by first using simulated annealing [3] for coarse correction, then inserting magnet chips on the back of magnets for fine adjustment. A stainless chip is always inserted between a main magnet and chip magnets to warrant removability, in case it becomes necessary. The multipole components are measured within a range of x = ±4mm. They are derived from polynomial fitting of the first integral distribution along horizontal axis using the following formula.

$$\int_{-\infty}^{\infty} (B_y + iB_x)\ dz = \sum_{n=0}^{\infty} (b_n + ia_n)(x + iy)^n \qquad (1)$$

where b_n are normal components and a_n are skew ones.
Integrated multipole requirements for NSLS X-ray ring and our measurement results are presented in Table 1. Figure 3-(a) and (b) show gap dependence of measured integrated dipole, quadrupole, respectively.

Table1. Integrated multipole requirements for NSLS X-ray ring versus the results of magnetic field measurement of IVUN arrays at 3.0mm gap

(n) Normal / Skew	Goal (Abs)	Measurement
(0) Dipole	100 G*cm	77 / -70 G*cm
(1) Quadrupole	10 G / 100G	-25 G / -192 G
(2) Sextupole	50 G/cm	161 / 41 G/cm
Norm. 2nd Integral	8 G*m^2	0.031 G* m^2
Skew 2nd Integral	8 G*m^2	N.A.
RMS Phase Shake	2 degrees	1.45 degrees

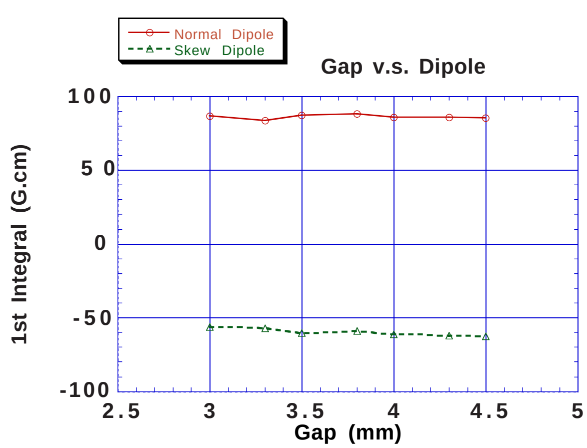

Figure 3-(a). Gap versus dipole components of the field

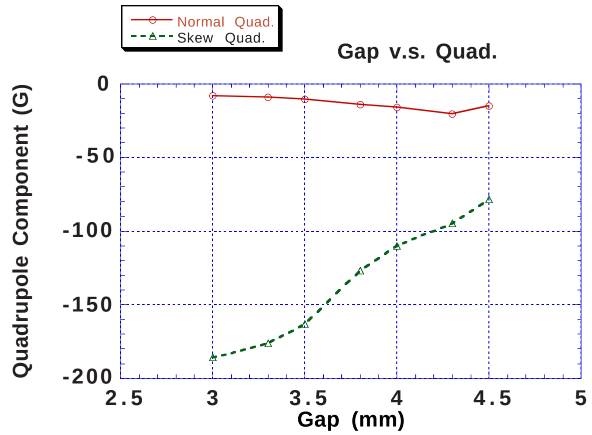

Figure 3-(b). Gap versus quadrupole components of the field.

4 ID PARAMETERS AND SPECTRUM

Pertinent ID parameters are presented in Table 2. Predicted radiation spectrum is shown in Figure 4 and peak brilliance with varying K is found in Figure 5.

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 (5mm)

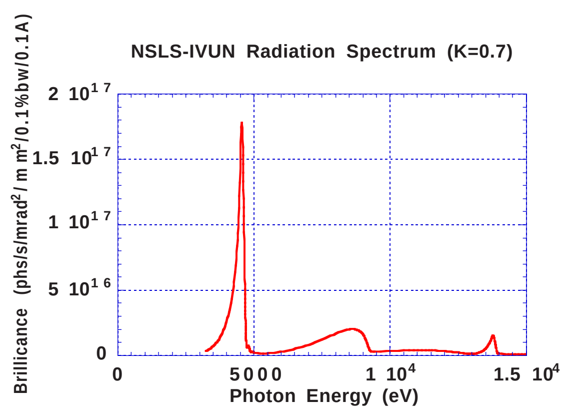

Figure 4. NSLS-IVUN radiation spectrum

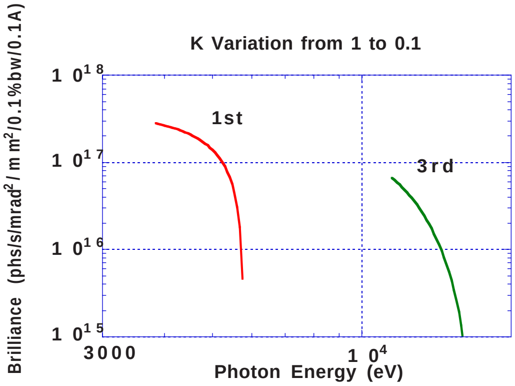

Figure 5. Peak brilliance with varying K

5 TRANSITION AREA

According to Reference [4], 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. 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.

6 UHV TEST

After magnetic field correction was finished, a vacuum test in UHV minichamber was conducted to make sure of no degassing elements in the magnet-arrays before installation. Figure 6 shows schematic of the vacuum testing facility. The final value of vacuum reading by an extractor gauge (IONIVAC IM520, Leybold) reached 2×10^{-9} Pa, which indicates sufficient ultra-high-vacuum (UHV) compatibility of the arrays.

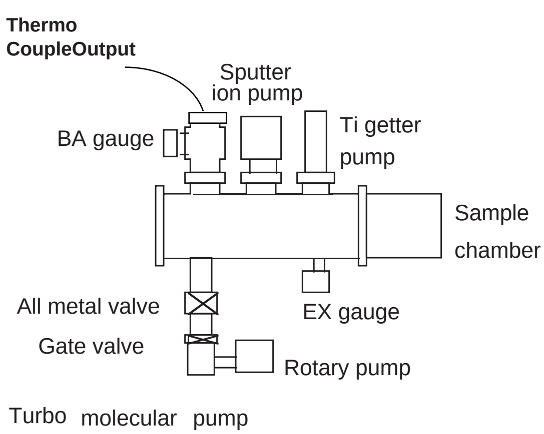

Figure 6. Schematic of the vacuum testing facility

7 MECHANICAL SUPPORT AND VACUUM SYSTEM (BNL)

IVUN is comprised of three major components: a rectangular vacuum chamber with bellows feedthroughs, magnet array units with drive system, and an elevator base stage, upon which all of the above components are supported.

The chamber is equipped with three forms of pumping, a 300 l/s ion pump, a titanium sublimator, and a non-evaporable getter. Precise alignment of the magnet arrays is facilitated by removable top and bottom rectangular flanges on the chamber: With the central section of the vacuum chamber removed, the magnet arrays are precisely aligned, with full access to the arrays. Then, using auxiliary pneumatic cylinders on the magnet drive, the magnet gap is opened to nearly 300 mm, and the central section of the vacuum chamber is replaced, without disturbing any of the adjustments.

The undulator magnet arrays are mounted on the water-cooled beams of the drive system, directly in the accelerator ultra-high vacuum. The drive system enables magnet gaps between 1 mm and 10 mm. The elevator base stage provides mounting fixtures for the IVUN vacuum chamber and the undulator magnet drive. In addition, it provides a 3 mm vertical translation of the combined chamber/magnet assembly about the nominal beam height.

8 CONCLUSION

With in-vacuum structure, a minipole undulator having modest tunability and harmonics has been constructed. The magnetic field quality is found be satisfactory after spectral and mutipole correction, and the magnet arrays show excellent UHV compatibility. A clever design of vacuum chamber greatly improves accessibility of magnet arrays. A complete device is expected to be installed in the X13 R&D straight section of the NSLS X-ray Ring in May 1997.

9 ACKNOWLEDGEMENTS

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10 REFERENCES

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[3] A. Cox and B. Youngman, Proc. SPIE 582, 91
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