CONSTRUCTION AND MAGNETIC FIELD MEASUREMENT OF QUASI-PERIODIC UNDULATOR

H. Kobayashi[1], S. Sasaki[2], T. Shimada, M. Takao, S. Hashimoto[3] and Y. Miyahara
SPring-8, Kamigori, Ako-gun, Hyogo 678-12, Japan

K. Kakuno and K. Ohashi
Magnetic Materials R&D Center, Shin-Etsu Chemical Co.,Ltd., Kitago,Takefu,Fukui 915, Japan

M. Yokoyama and M. Kawai
Kawasaki Heavy Industries, Ltd., 118 Futatsuzuka, Noda, Chiba 278, Japan

Abstract

A prototype quasi-periodic undulator (QPU) to generate irrational harmonic of radiation was constructed in order to evaluate the performance of this type of device. A magnetic field of QPU varies quasi-periodically along the undulator axis to kick an electron quasi-periodically. The Nd-Fe-B permanent magnets and aluminum spacers were used for producing a quasi-periodic magnetic field. There were two pole distances of 25mm and 55.9mm in the undulator with the total number of poles 27, whose length was 1245mm. After constructing the QPU, the magnetic distribution was corrected by using shims and bolts. The photon energies of spectral peaks calculated from the measured field agree with the design values of irrational higher harmonics.

1. INTRODUCTION

A normal plane undulator with a periodic magnetic field emits a synchrotron radiation including rational higher harmonics. In many user's experiment using monochromatic radiation, the mixing of higher harmonics is not welcome because it leads to a degradation of the signal-to-noise ratio. The higher harmonics of radiation are usually removed by optics, but it is too difficult to remove perfectly, especially in the hard x-ray region.

Recently a new undulator emitting irrational higher harmonics of radiation was invented[1-2], which has a quasi-periodic distribution of the magnetic field. Because the undulator radiation from the quasi-periodic undulator does not have higher harmonics with integrally factored energies, we can rather easily obtain purely monochromatic light from the QPU by using conventional optics. We constructed a prototype QPU to evaluate the performance of this type of device installed in a storage ring. Here we report the manufactured magnetic circuit and the measurement and adjustment of the magnetic field. In the accompanied papers, the design [3] and first observation of radiation [4] are presented.

2 . MAGNETIC STRUCTURE

A magnet alignment of QPU is as follows.

$$z_n = n + \left(\frac{1}{\eta} - 1\right)\left[\frac{1}{\eta + 1} n + 1\right].$$

Where n is an integer, and z_n is the coordinate which represents the n-th position of the magnet. η is an irrational number, and the bracket [ ] means the maximum integer less than the number in the bracket. We chose $\eta = \sqrt{5}$ in the prototype undulator. When we place the magnets at the z_n positions, the distance between one magnet and its neighbor magnet is d or d' with $d'/d = \eta$.

Figure 1 shows the lower half magnet structure of this undulator. Since neighboring magnets have two center-center distances of d and d', if the thickness of the magnet in z-direction is fixed to the value of d, there is no space between the neighboring magnets or there is a space of $d'-d$. The magnetic field of abutting magnets are canceled each other to some extent, and the magnetic field on-axis are weakened. Therefore the isolated magnet blocks are thinned by a factor of 0.7 in order to reduce the strength of the on-axis magnetic field to the same order of contribution as the nonisolated magnets. The magnet thickness at the end is a half of the isolated magnet for the correction of the electron trajectory. Actual dimension we used are d=25.0 mm and d'=55.9 mm. Table 1 indicates the main parameters of QPU. Nd-Fe-B magnets with 36 MGOe of maximum energy product made of Shin-Etsu Chemical's N36H were used. Since the magnet width of 80 mm is wide enough to obtain a horizontal field homogeneity, the field decreases about 1 % at x=10 mm at most. In order to obtain the fundamental radiation of 1.3 eV at gap =36 mm and electron energy of 200 MeV, the magnet height was selected as 35 mm.

---

[1] Present address: Shin-Etsu Chemical Co.,Ltd., Kitago,Takefu,Fukui915,Japan
[2] Present address: ALS LBNL, Berkeley,CA 94720,USA
[3] Present address: IwakiMeisei Univ., Iwaki,Fukushima970,Japan

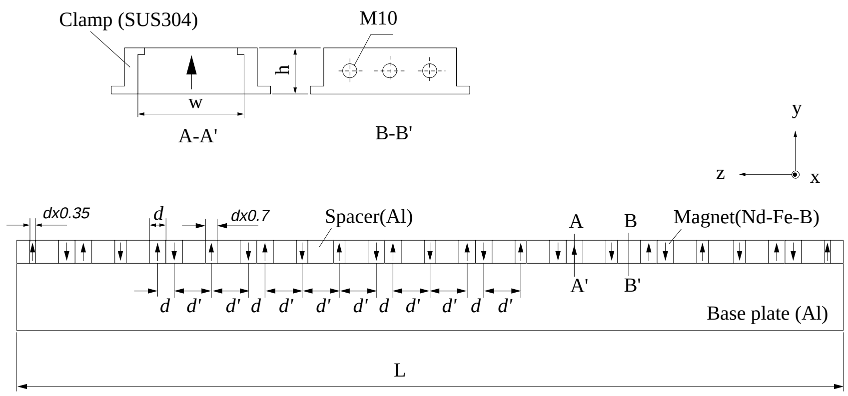

Figure 1 Magnetic structure of the quasi-periodic undulator

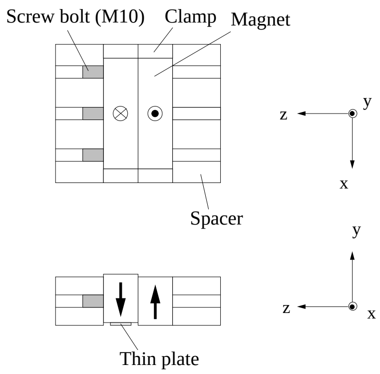

Figure 2 Magnetic field correction structure

The number of poles and the total length were determined to assemble magnets on a frame we already had. Aluminum blocks were inserted in the space between the magnets. The spacers have three penetrating holes of M10 tap in z-direction. Those holes were used to adjust the field distribution by inserting iron bolts. Both end stoppers and base plates are also made of aluminum. Magnets were fixed mechanically by clamps made of SUS304 as shown in Fig. 1.

Table 1 Main parameters of the prototype QPU

Distance between poles	d=25.0 mm
	d'=55.9 mm
Number of poles	N=27
Total length	L=1245 mm
Minimum gap	g=36 mm
Peak magnetic field (gap 36 mm)	B_{yp}=0.24 T
Magnet length	l_1=25.9 mm
	l_2=17.5 mm
	l_3=8.7 mm (edge)
Magnet width	w=80 mm
Magnet height	h=35 mm
Remanent field	Br=1.2 T

4. MEASUREMENT AND ADJUSTMENT OF MAGNETIC FIELD DISTRIBUTION

After setting the magnet arrays, the magnetic field distribution on-axis was measured by a Hall sensor placed on a three dimension movable stage. The Hall probe controlled by computer was scanned with a step of 0.5 mm within 1800 mm of measurable area and it took about one hour for one scanning of 3600 points. In order to check the repeatability of the gap distance, the magnetic field was measured repeatedly changing the gap distance. The error values of the magnetic field were less than 0.1 %, as shown in Table 2. During the measurement, the temperature of 22 degrees was kept within 1 degree.

Three variables for adjusting the magnetic field distribution were determined; 1)Uniformity of peak fields, 2) First integral value less than 100 Gcm, 3)Minimum value of second integral less than 1000 Gcm^2 or around. Since the magnetic field distribution in QPU is not simple like a conventional periodic undulator, we did not determine the value of peak field uniformity.

Table 2 Repeatability of gap distance checked by the magnetic field.

Number	Peak magnetic field(G)
1	2481.9
2	2482.2
3	2482.4
4	2482.5

Figure 2 shows two methods to adjust the magnetic field. One method is to insert iron bolts into three holes with the M10 tap. It reduces the peak field because of the short circuit of magnetic flux. The degree of reduction is able to be varied according to the bolt lengths, bolt positions and bolt numbers. Another method is to insert a thin non-magnetic plate between the magnet and the base plate. Since the effective height of the magnets can be varied according to the thickness of the plates, the peak fields vary. The peak field distribution after and before inserting the thin plates is compared in Fig. 3, where the gap distance is 36 mm. A thin plate of 0.05 mm thickness was inserted under one magnet in the lower jaw. It is found that the increasing rate of the peak field is about 10 Gauss. Figure 4 shows the result of the field correction by using the adjusting bolts, in which three bolts with 15 mm length are inserted into one spacer in each jaw as shown in Fig. 2. Such the adjusting bolts vary the peak field with the degree of about 10 Gauss.

The first and the second integral distributions are varied according to the magnetic field distribution. For example, the adjusting bolts in Fig. 4 affect the first and second integral distributions shown in Fig. 5. It was found that the second integral value remarkably varied at the exit side. Therefore, the peak field was adjusted at first, and then the first and second integral distributions were corrected. The first and second integral values before and after the adjustments at gap 36 mm are shown in Table 3.

Table 3 Comparison of first and second integral values before and after the adjustment

	Before adjustment	After adjustment
First integral (Gcm)	-178.0	-76.9
Second integral (Gcm^2)	-19343.9	1743.2

After the adjustment, the maximum error of the measured peak field was 1.7 %. The first integral values were less than 100 Gcm at gap 36 mm, 50 mm and 60 mm.

The spectrum of synchrotron radiation was calculated from the measured magnetic field distribution after the adjustment, which is shown in Fig. 6. The broken lines in Fig. 6 stand for the positions of odd harmonics such as the third and the fifth harmonics by assuming the peak of lowest energy as the fundamental. As can clearly be seen in the figure, no rational harmonics are observed. This result agrees very well with the design calculation in lower photon energy region, but the intensities of the higher harmonics decrease compared to the designed one due to the error of the magnetic field distribution (phase error).

5. CONCLUSIONS

The prototype of QPU was constructed. The specification of the magnetic field distribution was determined by calculating the radiation spectrum expected from QPU. The magnetic circuit was composed of magnets, aluminum spacers and clamps made of SUS304. The peak field distribution and the integralfield distributions were adjusted by using two methods. The radiation spectrum calculated from the measured field does not have rational harmonics, and the peak energies agreed with the design values.

REFERENCES

[1] S. Hashimoto and S. Sasaki, Nucl. Instrum. Methods Phys. Res., A361, 611(1995)

[2] S. Sasaki, H. Kobayashi, M. Takao, Y. Miyahara and S. Hashimoto, Rev. Sci. Instrum., 66(2), 1953(1995).

[3] M. Takao et al., In this proceedings .

[4] M. Kawai et.al., In this proceedings .

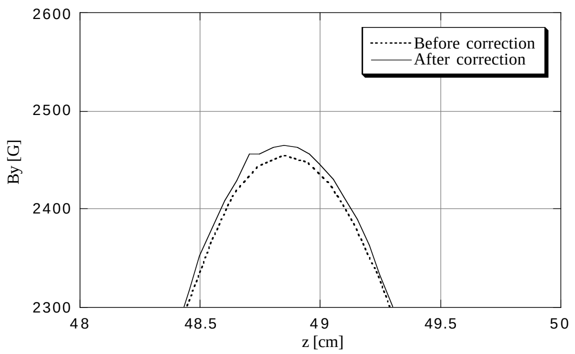

Figure 3 Magnetic field correction by a thin plate. Thickness of plate is 0.05mm. gap=36mm

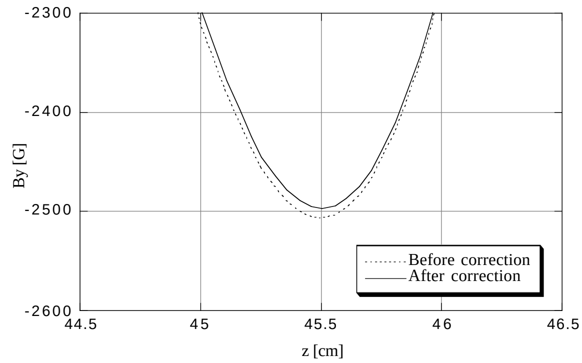

Figure 4 Magnetic field correction by flux shunt. gap=36mm

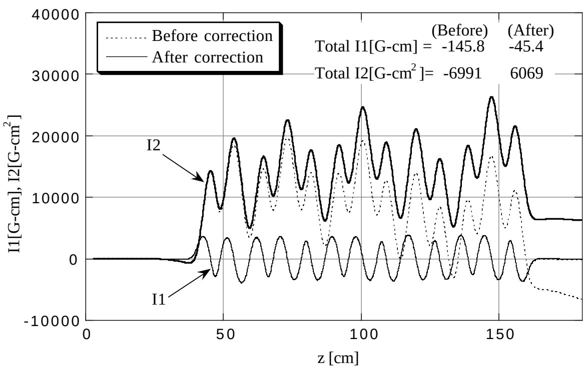

Figure 5 The 1st-integral(I1) and 2nd-integral(I2) distributions at gap=36mm.

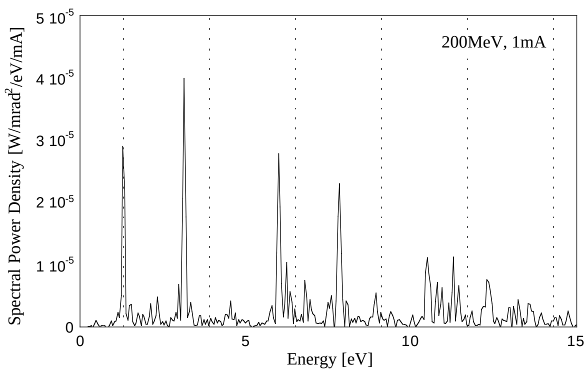

Figure 6 The radiation spectrum calculated from measured field data. gap=36mm