MAGNETIC FIELD ADJUSTMENT OF 11M LONG UNDULATOR

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Abstract

The NewSUBARU storage ring has an 11 m long, permanent magnet planner undulator. We adjusted its magnetic field distribution to minimize the imperfection fields mainly by an in-situ sorting method. The LU is separable into eight units and the imperfection fields were reduced for each of eight units to prevent them from exciting unnecessary betatron resonance in the ring.

1 INTRODUCTION

The synchrotron radiation facility NewSUBARU[1] is an EUV and Soft X-Ray light source at the SPring-8 site. The Laboratory of Advanced Science and Technology for Industry (LASTI) at the Himeji Institute of Technology is in charge of its operation collaborating with SPring-8. A 10.8 m long undulator (LU) [2] is set at one of the long straight sections of NewSUBARU. The main parameters of LU are listed in Table 1. In the initial adjustment of the LU's magnetic field, our effort was focused on the undulation phase to obtain a good undulator light, not on the reduction of multi-pole imperfection fields. The gaps of each magnet pole were adjusted to give good field distribution. However upon commissioning the LU, we found that its considerably large imperfection field reduced the beam life and the injection efficiency of the ring. Following that, the second field adjustments took place in 2001, using SPring-8's field measurement system.

In 2001 we adjusted not only the beam orbit and phase but also reduced multi-pole field components. The field was adjusted mainly by flipping or exchanging magnets in LU [3]. A use of shim plates were limited to an adjustment of skew quadrupole field component. The acceptable strengths of the integrated multi-pole imperfection fields, listed in Table 2, were set at the same level as those of the ring magnets. Setting the limit to the integration through the undulator was insufficient because the betatron phase advances were 140^{O} and 50^{O} in horizontal and vertical directions, respectively; two opposite imperfection fields can never be cancelled out if they are apart. The LU is separable into eight units and the integrated imperfection field through each unit should be small.

The guideline of acceptable level for the photon spectrum was that 7th harmonic light should be usable.

After the adjustment, the beam life and the injection efficiency improved to approximately 80% of those with the gap opened. Beam based measurements of linear imperfection field proved the improvement of the field [4]. The 1*st* harmonic spectral line width agreed with the calculation [4]. Here we report on our second field adjustment of LU.

2 FIELD MEASUREMENT SYSTEM

2.1 Field Measurement

We use Cartesian coordinate with the photon propagation axis as a *z* direction, the horizontal axis as *x* direction and the vertical axis as *y* direction in the following discussions.

The integration of multipole field through 4 units were measured by 6-m long flipping coil. The tension of wires were controlled and the height of wires were -1.0 mm at the centre and +2.0 mm at the edges of the undulator ($z=\pm 2.7$m), because they bended by their weights. The magnetic field distribution was measured by temperature controlled vertical and horizontal Hall probes, which are mounted on a 6 m long scanning table. Figure 1 shows photograph of scanning Hall proves and flipping coil.

2.2 Data Processing

The flipping coil measurement gives an integration of magnetic field through 4 units (*I*) as a function of the horizontal position (*X*) of the electron beam. A least square fitting of measured *I* as a function of *X* gives polynomial representing the integrated multipole components. The measurements of vertical field (*By*) and

Table 1: Main parameters of the LU.

Type	planner, out of vacuum
Magnet	permanent Nd-Fe-B
Number of Periods	200
Period Length λ_u	54mm
Total Length L	10.8m
Gap	119-30mm
K	0.3 - 2.5

Table 2: Guidelines on the acceptable integrated imperfection field for the ring magnets.

Field Type	Guide Line
Dipole	4×10^{-4} T m
Quadrupole	7×10^{-3} T/m m
Sextupole	0.3 T/m^2 m
Octupole	10 T/m^3 m

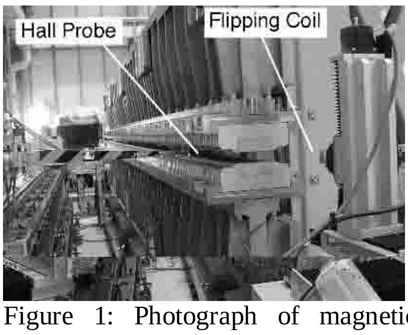

Figure 1: Photograph of magnetic field measurement system.

the horizontal field (Bx) give normal and skewed components, respectively.

The Hall probes were used to measure the magnetic field map in z-x plane. We calculate the first field integral over the range of a specific magnet pole, which is defined as the deflection caused by the n-th magnet pole given by

$$I_{1n} = \int_{z_n}^{z_{n+1}} B(z)\,dz \qquad (1)$$

where $z_n = -L/2 + n\,\lambda_u/2$ is the boundary between the n-th and (n+1)th poles and $B(z)$ is the magnetic field (Bx or By) as a function of z. The calculation of I_{1n} as a function of X gives multipole components at each pole. This was used to find magnets to be sorted (find the worst pole) and to check the uniformity along one undulator unit. We did not use calculations of periods at both ends of the undulator because the combination of 4 units did not always had end magnets.

From I_{1n} at X = 0 we calculate an error storage ESn defined as

$$ESn = (1/\langle I\rangle) \sum_{m=1}^{n} (|I_{1m}| - \langle I\rangle) \qquad (2)$$

where $\langle I\rangle$ is the mean value of $|I_{1n}|$. The ESn has a storage correlation with the phase error [3]. We also calculate a field storage FSn defined as

$$FSn = (1/\langle I\rangle) \sum_{m=1}^{n} (I_{1m} - (-1)^m \langle I\rangle) . \qquad (3)$$

Here, the peak field at odd poles are assumed to be positive. The FSn shows an accumulation of an error deflection, an extra kick in addition to the normal deflection corresponding to the K value of the undulator. Therefore, FSn is a good approximation of the electron orbit [3].

3 FIELD ADJUSTMENT

3.1 Order of Correction of Magnets

LU was too long to measure all eight units at a time. Measurements and adjustments period was divided into three parts. At the first period, central 4 units (unit 3, 4, 5 and 6) were adjusted. At the second period, the upstream 4 units (unit 1, 2, 3 and 4) were set up. Field distribution of 4 units was measured and the magnets of unit 1 and unit 2 were adjusted. At the third step, the downstream units (unit 5, 6, 7 and 8) were set up and the magnets of unit 7 and unit 8 were adjusted..

Our sorting procedure of a period had three steps. At the first step we cleared the results of the first adjustment, which meant the equal gap for all magnets. The second step was the multipole field reduction. The third step was the spectral improvement. The order of these steps was not definite. It happened many times that we had to go back to the former step.

We were concerned about the dipole (or the on-axis field integral) because steering coils, usually attached at the undulator, can easily correct them. What we should reduce was the deviation of the field integral from the on-axis value.

The field adjustment took place at the gap of 25mm.

3.2 Adjustment of Frames

At the first step we re-set the mechanical magnet gap equal and re-aligned the frame, to which the magnet array was set. After the alignment of the basements of each unit we adjusted the supporting frames measuring the field distribution. The coordinate origin used to set gap, the tilt of the frame in z-direction were adjusted so that the peak field distribution in z-direction be roughly uniform. Fig.2 shows the example of peak field distribution along z-axis at before and at after the adjustment.

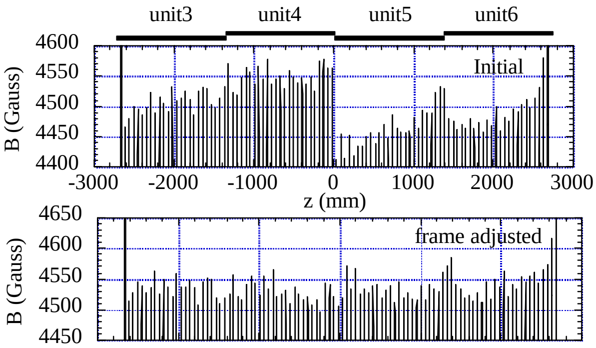

Figure 2: Improvement of peak field distribution of unit 3-6 by the adjustment of the frames. Before (above) and after (below) the adjustment.

3.3 Multipole Field Adjustment

First, the skew quadruple components were reduced by putting shim plates on the magnet pole face. Next we reduced other multipole field components by flipping magnets. Fig.3 schematically shows how the magnets were flipped. A change of multipole field components by the correction is listed in Table 3.

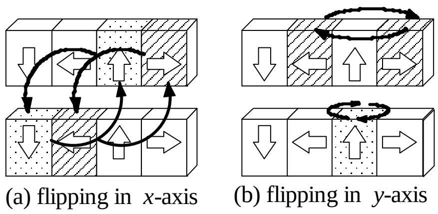

Figure 3: How to flip magnets in x-direction and y-direction. The white arrows in the magnet blocks show the direction of the magnetization. The thick arrow indicate the move of magnets. Both of the flipping of vertically magnetized blocks and azimuthally (z-direction) magnetized blocks work.

Basically the flipping magnets and putting shim plates reduced the multipole components of the integration over 4 units and the exchange of magnets improved the uniformity along z-axis. We exchanged a magnet in the section where the error field storage increased and that where it decreased. Fig.4 shows the X dependence of the integration through 4 units at before and at after the adjustment. Fig. 5 shows an improvement of the distribution of normal quadrupole field component.

Table 3: The effectiveness of putting shim plates and flipping magnets. The multipole field components represented by D, Q, S and O are dipole, quadrupole, sextupole and octupole field component. The correction changes the multipole component labeled by “C” and do not labeled by “N”.

Multipole field	**normal**				**skew**			
Correction	**D**	**Q**	**S**	**O**	**D**	**Q**	**S**	**O**
Shim plate	C	N	C	N	N	C	N	C
A pair of shim plates	N	N	N	N	N	C	N	C
Flipping in x-axis	C	C	C	C	N	N	N	N
Flipping in y-axis	N	C	N	C	C	N	C	N

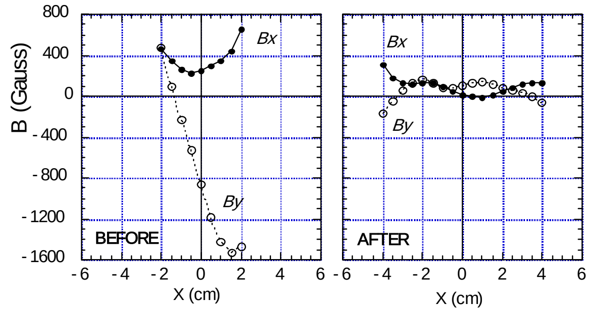

Figure 4: Improvement of integrated multipole field distribution through unit 3-6.

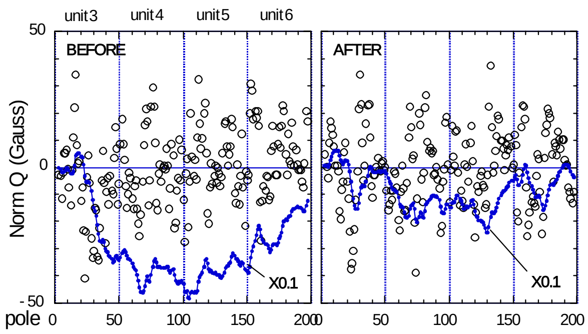

Figure 5: Improvement of normal quadrupole field distribution of unit 3-6 before (left) and after (right) the adjustment. The circles are contributions of each poles. The lines are the integration (error field storage) divided by 10. The maximum error per unit before the adjustment was -341 Gauss of unit3. After the adjustment it was reduced to -132 Gauss of unit4.

3.4 Adjustment of Undulator Field

Exchanging magnets under the limitation, that the exchange did not damage uniformity of multipole distribution, reduced the *ESn* and *FSn*.

A control of space between units was efficient to minimize *ESn* (phase error). The spaces were adjusted to be less than 0.2 mm, with which the contributions of space was negligibly small. Fig.6 shows an example of the adjustment.

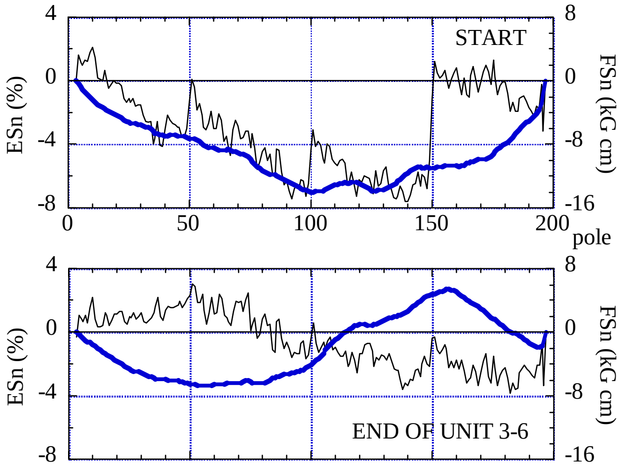

Fig.6 Magnetic performances as a function of the pole number at before (above) and after (below) the adjustment. The thin lines are *ESn* and the thick lines are *FSn*.

3.5 Results of total 8 units

The total field of 8 units was estimeted from two measurements, that of unit 1-4 and that of unit 5-8. The integrated multipole fields were small enough as are listed in Table 4. The total standard deviation of phase error was 4.4 degrees, which was capable of usage of higher harmonic undulator light.

Fig. 4 Total multipole field components through 8 units.

Field	Multipole	Initial	Corrected
By (normal)	dipole (Gauss cm)	-70	180
	quadrupole (Gauss)	-290	-10
	sextupole (Gauss/cm)	80	-10
	octupole (Gauss/cm^2)	40	-3
	decapole (Gauss/cm^3)	-35	2
Bx (skew)	dipole (Gauss cm)	60	-240
	quadrupole (Gauss)	900	70
	sextupole (Gauss/cm)	130	-30
	octupole (Gauss/cm^2)	-90	-11
	decapole (Gauss/cm^3)	24	4

4 ACKNOWLEDGEMENT

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5 REFERENCES

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