BEAM BASED SEARCH FOR LINEAR IMPERFECTION FIELDS IN 11 M LONG UNDULATOR AT NEWSUBARU

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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 developed by T. Tanaka *et al.* of SPring-8. The imperfection fields were minimized for each of eight units to prevent them from exciting unnecessary betatron resonance in the ring. We measured the gap dependence of linear imperfection fields, dipole and quadrupole field components, using the stored electron beam in the ring. The results confirmed that the field adjustment reduced the imperfection fields. Strengths of the dipole imperfection fields in the undulator were at the same level as the earth field. The normal and skewed quadrupole imperfection fields were about three times of the guideline, but were smaller than the imperfections produced by the ring magnets.

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. The ring has two operation modes: In the 1.5 GeV mode, the beam is accelerated to 1.5 GeV and stored. In the 1.0 GeV top-up mode, the beam current is kept at 250±0.15mA by an occasional injection with the undulator gap closed.

A permanent magnet, planner type, out of vacuum 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. Upon commissioning the LU, we found that its considerably large imperfection field reduced the beam life and the injection efficiency of the ring down to about 60% of those with gap opened. Following that, the second field adjustments took place in 2001, using SPring-8's field measurement system [3]. The acceptable strengths of the integrated multi-pole imperfection fields were set at the same level as those of the ring magnets, bending dipoles, and focusing quadrupoles, etc. These are shown in Table 2.

The LU is separable into eight units and the integrated imperfection field through each unit should be small. Setting the limit to the integration through all eight units was insufficient because the betatron phase advances through the LU were 140° and 50° in horizontal and vertical directions, respectively; two opposite imperfection fields can never be cancelled out if they are apart. The details of this field adjustment is explained in another report of this proceedings [4].

After the adjustment, the beam life and the injection efficiency improved to approximately 80% of those with the gap opened. A part of the reduction of the beam life by 11% was explained by the modulation of the vertical beta function produced by the intrinsic focusing of the LU [5]. The improved spectral line was reported by M. Niibe *et al.* [6] at SRI'03.

The gap dependence of linear imperfections in the LU was measured by observing the electron beam behavior in the storage ring, at points before and at after the second adjustment. Here we report the reduction of dipole and quadrupole imperfection fields with respect to the second adjustment.

We performed some measurements on the strength of non-linear imperfections of LU before the adjustment [7]. However non of them were definite or quantitative proof of the existence and we do not report about them.

2 MEASUREMENTS

The LU's normal dipole imperfection field (ΔBy) was calculated from the currents of the steering magnets, where c.o.d. was corrected to zero. The skewed dipole imperfection field (ΔBx) was calculated from the change of horizontal c.o.d. The imperfections are expressed by kicks (dX' in the horizontal and dY' in the vertical direction) and displacements at the center of the LU (dX in the horizontal and dY in the vertical direction). The

Table 1: Main parameters of the LU.

Type	planner, out of vacuum
Magnet	permanent Nd-Fe-B
Number of Periods	200
Period Length	54mm
Total Length	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

results are summarized and shown in Fig.1

Normal quadrupole field imperfection was estimated from the gap dependence of betatron tune, and the results of the measurements are shown in Fig.2. After the adjustment, the vertical tune shift agreed with the calculation within the margin of uncertainty of the ring lattice model. The field imperfection could be estimated from the horizontal tune shift, which was negligibly small in the calculation. However, the disagreement between the data at 1.0 GeV and at 1.5 GeV, because of the measurement error, was comparable to the shift by the imperfection field

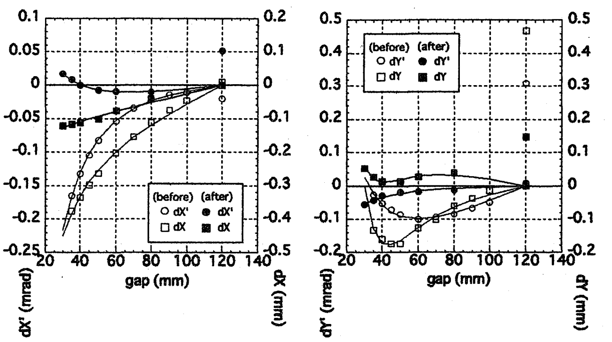

Figure 1: Horizontal (left) and vertical (right) dipole kick errors vs. LU gap at 1 GeV. They are defined to be zero at an LU gap of 120 mm. The non-zero points at the 120 mm gap represent changes of errors by adding a magnetic shield to the undulator field. The open symbols, circles and squares, represent the error before the adjustment, while the shaded symbols represent the error after the adjustment. The lines are the fitted functions using Eq. (1).

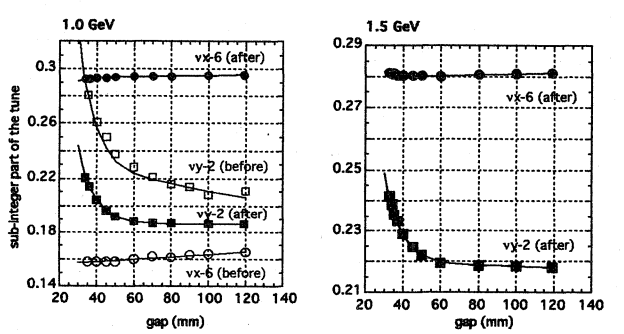

Figure 2: The gap dependence of the betatron tune at 1.0 GeV(left) and at 1.5 GeV (right). The open symbols, circles and squares, represent the imperfection before the adjustment, while the shaded symbols represent the imperfection after the adjustment. The lines are the fitted functions. The tunes at the 120 mm gap were set at different points at before and after the adjustment. There is no data for 1.5 GeV before the adjustment.

The skewed quadrupole imperfection was estimated from the gap dependence of the correction magnet's currents. These magnets were a pair of correction magnets set at the both ends of the LU. Those were adjusted to eliminate the coupling resonance: νx-νy=4. Here, νx and νy are vertical and horizontal tunes. The symmetric component, the sum of them (*SUM*), and the asymmetric component, the difference between them (*DIFF*), are plotted in Fig.3. In addition to this measurement, the imperfection was also estimated by making vertical local bumps in the LU and observing the change in the horizontal c.o.d. The results of the two measurements were consistent with each other [8].

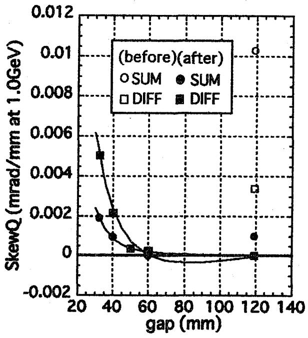

Figure 3: A pair of skew Q magnets are set at both ends of LU. The symmetric component, ***SUM*** = sum of two (circle), and the asymmetric part, ***DIFF*** = difference of two (square) are plotted. They are defined to be zero at the LU gap of 120 mm. The non-zero points at the 120 mm gap represent changes of imperfections by the magnetic shield to the undulator field. The open symbols, circles and squares, represent the imperfection before the LU adjustment, while the shaded symbols represent the imperfection after the LU adjustment. The lines are the fitted functions. The gap dependence was not measured before the LU adjustment.

3 ANALYSIS

The gap dependences of imperfections were parameterized by fitting with the following function,

$$A_O+A_{GAP}(G-120)/100+A_{K1}(K-K_{120})+A_{K2}(K^2-K_{120}^2). \quad (1)$$

Here, A_{GAP}, A_{K1} and A_{K2} were fitting parameters, while K is a K parameter of the LU. The gap G is measured in millimeters, and K_{120} is a K value at G=120. One more parameter, A_O, not obtained by the fit, is the imperfection when the gap is opened (G=120). The results of the fit are summarized in Table 4.

We had observed large dipole imperfections (dY and dY') and skew quadrupole imperfections with the gap opened (A_O terms); however, they almost disappeared after the adjustment. The considerable imperfections, which were proportional to the gap (dY' and the tune shift were observed), also disappeared. The large quadrupole imperfection before the adjustment was thought to be the main reason why the beam life had been worse.

The moments of integrated imperfection fields along the azimuthal direction (s) were calculated from the results of the above measurements. The results at 35mm gap, after the adjustment, are listed in Table 5 with the results of field measurements using a flipping coil.

The dipole imperfection fields after the adjustment were small enough, even smaller than the contribution of the earth field. The normal quadrupole imperfection calculated from the beam based measurement and that from the flipping coil measurement agreed within the measurement error, however the error was the same level as the guideline. They were roughly three times of the guideline at the gap where the adjustment did not take place. The asymmetric skew quadrupole imperfection was larger than the expected from the flipping coil measurement, roughly three times of the guideline. However, those normal and skewed quadrupole imperfections were smaller than the harmonic imperfections produced by the ring magnets, 0.2 T of normal quadrupole and 0.04 T of skewed quadrupole.

4 CONCLUSION

The measurement of the beam behaviour confirmed that the second field adjustment was effective. As far as we see the linear imperfection fields, the residual imperfections are at the acceptable level.

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Table 4: Parameters of gap dependence of the linear imperfection fields. The values for before and after the adjustment are separated by arrows (befor->after). The fittings were good, as shown by the figures. Where we have no data the column in the table is blank. We used three free parameters for the fit if they were necessary, although this was not always the case. When that happened, the column on unused parameter remained blank. The vertical tune shift after the adjustment was consistent with the calculated shift. The calculated horizontal tune shift was negligibly small, and the values listed below represent either field imperfections or measurement errors.

Field Imperfection		A_O	A_{GAP}	A_{K1}	A_{K2}
Dipole Kick (mrad)	***dX'***	0.02->0.05	0.04 -> 0.029	-0.11-> 0.026	
	dY'	0.31->0.01	0.23 -> 0.014	0.14->-0.024	
Dipole Displacement (mm)	***dX***	0.01->0.00	0.27 -> 0.13	-0.12 ->-0.01	
	dY	0.47->0.15	0.10->-0.11	-0.28 -> -0.16	0.20 -> 0.08
Tune Shift at 1GeV	ν_X		8.6->1.6		-0.02 -> -1.12
	ν_Y		-22.0-> -0.6		34.3 -> 19.8
Tune Shift at 1.5GeV	ν_X		-> 1.8		->0.67
	ν_Y		->-1.6		->10.4
Skew Quadrupole (mm/mrad)	***SUM***	10-> 1	-> 1	-> -1	-> -6
	DIFF	-3-> 0	->12	-> 25	->7

Table 5: Residual imperfection fields at after the second adjustment. The measurements with the flipping coil took place with 30mm gap ($G = 30$) before the re-installation of LU. The imperfections calculated from the beam behavior were those with $G = 35$. Here $\Delta By' = d\Delta By/dx$ and $\Delta Bx' = d\Delta Bx/dx$. The $\int \Delta By' ds$ by the beam based measurement is a value for $\int \Delta By' \beta_X ds / <\beta_X>$ at 1.0GeV. According to the measurement at 1.5GeV, $\int \Delta By' \beta_X ds / <\beta_X> = 0.003$ at $G = 35$ and $\int \Delta By' \beta_X ds / <\beta_X> = 0.000$ at $G = 30$.

Field Imperfection	**Dipole Imperfection (10^{-4}Tm)**				**Quadrupole Imperfection (T)**			
	$\int \Delta By\, ds$	$\int s\, \Delta By\, ds$ / $<\lvert s \rvert>$	$\int \Delta By\, ds$	$\int s\, \Delta By\, ds$ / $<\lvert s \rvert>$	$\int \Delta By' ds$	$\int \Delta Bx' ds$	$\int s\, \Delta Bx' ds$ / $<\lvert s \rvert>$	$\int s^2 \Delta Bx' ds$ / $<s^2>$
Guide Line	4		4		0.007	0.007		
Flip-Flop Coil Meas.	-2.4		-1.8		-0.0007	-0.001		
Beam based Meas.	-0.3	1.4	-1.4	0.3	(<0.017)	-0.003	-0.021	-0.002