METHODS OF SEARCHING SKEWED QUADRUPOLE IMPERFECTION FIELD ALONG THE STRAIGHT SECTION

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Abstract

Two methods were used to search distribution of skewed quadrupole imperfection field in 11m long undulator of NewSUBARU. One was the measurement of a change of horizontal COD by the vertical orbit displacement. Another was the measurement of a strength of skewed quadrupole correction magnets set at both ends of the undulator. The results of these measurements agreed with each other. The moments of the distributed skewed quadrupole imperfection field along the azimuthal direction were derived from the measurements.

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 up at one of the long straight sections of NewSUBARU. 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]. After the adjustment, the beam life and the injection efficiency improved to approximately 80% of those with the gap opened [4].

In the second adjustment we set an limit of acceptable imperfection field components. The LU is separable into eight units and the integrated imperfection field through each unit should clear the limit level. 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 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 [5]. Here we report two methods, which were used to search distribution of skewed quadrupole imperfection field in LU. The moments of the distributed skewed quadrupole imperfection field along the azimuthal direction (s) were derived from the measurements.

2 TWO METHODS OF SEARCHING SKEW Q IMPERFECTION

2.1 Expression for distribution of skew Q

When there exists a thin single skew quadrupole imperfection we write it as

$$K_S = (1/B\rho) \int (\partial B_X/\partial x) ds . \quad (1)$$

However $\partial B_X/\partial x$ is distributed along the beam direction s. We express the distribution by the N-th moment along s,

$$K_{SN} = (1/B\rho) \int s^N (\partial B_X/\partial x) ds . \quad (2)$$

To calculate K_{SN} we assume that there exists no focusing force at the straight section where we want to search for. In that case the beta function and betatron phase advance, in both of horizontal and vertical direction, are written as

$$\beta(s) = \beta_O + s^2/\beta_O \quad (3)$$

and

$$\Psi(s) = \tan^{-1}(s/\beta_O) . \quad (4)$$

Here we defined that s=0 and $\Psi(0)$=0 at α=0. It was not necessary that s=0 at the center of the straight section.

2.2 Horizontal C.O.D. Produced by Vertical Displacement

We made a vertical local bump orbit which include LU location as shown in Fig.1. If there existed a skew quadrupole imperfection, change of horizontal COD would be observed. When the vertical orbit is displaced by ΔY at this location the shift of the horizontal COD is

$$\Delta X(s) = \sqrt{\beta_X}\sqrt{\beta_{XS}}\, \Delta Y\, K_S/(2\sin\pi\nu_X) \cos(\Psi_X - \Psi_{XS}) . \quad (5)$$

Here we define Ψ_X=0 at the center of LU because α_X=0 there. Substitution of Eq. (3) and Eq. (4) for X-direction into Eq. (2) gives

$$\Delta X(s)/\sqrt{\beta_X(s)} = \Delta Y/(2\sin\pi\nu_X)K_S \left[\sqrt{\beta_{XO}}\cos\Psi_X + (s/\sqrt{\beta_{XO}})\sin\Psi_X\right]. \qquad (6)$$

When ΔY is constant along the LU ($\Delta Y = \Delta Y_F$) and the imperfection is distributed along s direction,

$$\Delta X(s)/\sqrt{\beta_X(s)} = \Delta Y_F/(2\sin\pi\nu_X) \left[(K_{S0}\sqrt{\beta_{XO}})\cos\Psi_X + (K_{S1}/\sqrt{\beta_{XO}})\sin\Psi_X\right] \qquad (7)$$

and when ΔY is tilted and makes an angle at the center of LU as $\Delta Y = \Delta Y'_A\, s$,

$$\Delta X(s)/\sqrt{\beta_X(s)} = \Delta Y'_A/(2\sin\pi\nu_X) \left[(K_{S1}\sqrt{\beta_{XO}})\cos\Psi_X + (K_{S2}/\sqrt{\beta_{XO}})\sin\Psi_X\right]. \qquad (8)$$

These equations shows that the analysis of the horizontal CODs produced by the two types of vertical local bumps give K_{S0}, K_{S1} and K_{S2}.

2.3 Linear Coupling Resonance

The driving term of the linear coupling differential resonance ($\nu_X - \nu_Y = 4$) is approximated by the following equation

$$\lambda e^{i\chi} = 1/(4\pi)\sqrt{\beta_{XS}}\sqrt{\beta_{YS}}\, K_S\left[\cos(\Psi_{XS} - \Psi_{YS}) + j\sin(\Psi_{XS} - \Psi_{YS})\right]. \qquad (9)$$

We assume that α_X and α_Y are zero at the same location, s=0. Using the Eq (3) and (4) we obtain

$$\lambda e^{i\chi} = 1/(4\pi)\left[K_{S0}\sqrt{\beta_{XO}}\sqrt{\beta_{YO}} + K_{S2}/(\sqrt{\beta_{XO}}\sqrt{\beta_{YO}})\right] + 1/(4\pi)(jK_{S1})(\sqrt{\beta_{YO}}/\sqrt{\beta_{XO}} - \sqrt{\beta_{XO}}/\sqrt{\beta_{YO}}) \qquad (10)$$

The condition $\lambda e^{i\chi} = 0$, which means zero resonance width, is identical to the following equations,

$$K_{S0}(\beta_{XO}\beta_{YO}) + K_{S2} = 0 \qquad (11)$$

and

$$K_{S1} = 0. \qquad (12)$$

3 MEASUREMENTS

3.1 Imperfection of LU

In order to detect the gap-dependent imperfection skew quadrupole field of LU, we performed the following measurements with the gap opened and with the gap of 35mm. The difference of the results between two cases was the gap-dependent imperfection.

In the above calculations we assumed no focusing function along the target straight section. However LU has a vertical focusing with the gap of 35mm. The strength at 1GeV is

$$d^2Y'/dY/ds = -0.0034. \qquad (13)$$

It enlarges vertical beta function by about 10% along the LU. The following results would have small error by the approximation in the order of 10%. We consider that the effect is small enough for our analysis about the imperfection.

3.2 Horizontal C.O.D. Produced by Vertical Orbit Displacement

At first, COD was corrected using steering magnets so that the maximum value was about 0.02 mm or less in both horizontal and vertical directions. The vertical local bump was produced using vertical steering magnet system. The height of the bump orbit was monitored at a pair of beam position monitors (BPMs) set at the up-stream and at the down-stream of LU in the same long straight section. They are called BPM12 and BPM13. The change of the horizontal COD was measured after that.

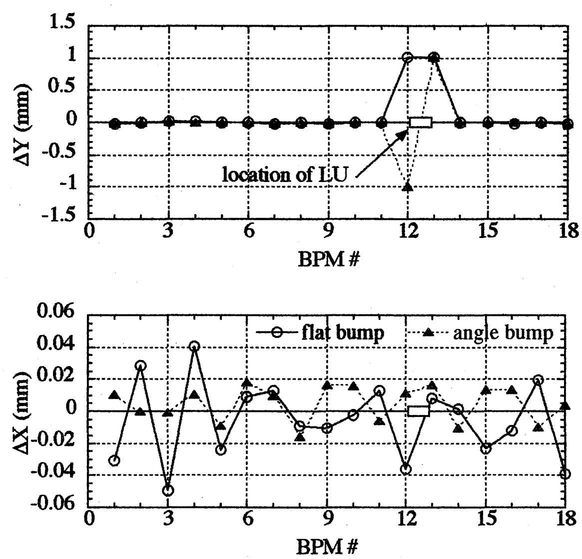

Figure 1: Vertical local bump: ΔY (above) and the shift of the horizontal COD: ΔX (below).

	value	error
As	10.695	0.31876
Ac	-3.7043	0.21227
chai^2	8.9866	NA
R	0.99448	NA

	value	error
As	1.4328	0.24931
Ac	4.1026	0.16602
chai^2	5.497	NA
R	0.98683	NA

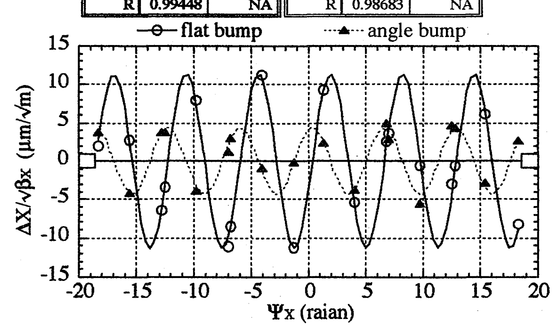

Figure 2: Shits of horizontal COD in the normalized phase space. The origin of Ψ_X is redefined to be at the opposite of the centre of LU, the centre of another long straight section.

A typical vertical local bump (ΔY) and the shift of the horizontal COD (ΔX) at that time is shown in Fig.1. The measured ΔX is translated into the displacement in the normalized phase space, $\Delta X(s)/\sqrt{\beta_X(s)}$ - $\Psi_X(s)$ plane, with a small correction of energy shift, and separated into a symmetric 'cosine term; *Ac*' and the anti-symmetric 'sine term; *As*'. Fig. 2 shows the fit using the following equation

$$\Delta X(s)/\sqrt{\beta_X(s)} = Ac \cos\Psi_X(s) + As \sin\Psi_X(s) \qquad (14)$$

The difference of two measurements with gap opened and with the gap of 35mm gave the gap-dependent imperfection, which were listed in Table 1.

3.3 Linear Coupling Resonance

The betatron tunes were set at very close to the linear coupling resonance, ν_X-ν_Y=4. The ring has a pair of skew quadrupole correction magnets set up at both ends of LU. Independent parameters, which drive the resonance, are the symmetric component, the sum of their strengths (*SUM*), and the anti-symmetric component, the difference between their strength (*DIFF*). These two parameters were adjusted so that resonance-driving term was zero.

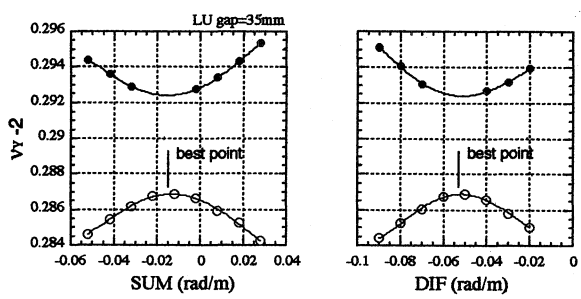

Figure 3: The measured coupled tunes varying the parameters of skew quadrupole magnets, *SUM* and *DIFF*.

We measured coupled tunes varying *SUM* or *DIFF* as shown in Fig.3. The driving term was zero when the separation was minimum. The results, the changes of *SUM* and *DIFF* by closing the gap to 35mm, are listed in Table 1.

3.4 Consistency of Measurements

The results are summarized in Table 1. The moments K_{SN} were calculated from the results using Equations (7), (8), (13), (11) and (12). The other parameters used in the analysis were ΔY_F =0.83 mm, $\Delta Y'_A$=0.111 mrad, ν_X=6.30, β_{X0}=2.5m and β_{Y0}=14m.

The three independent measurements on K_{S1} agreed with each other. The consistency of $K_{S0}(\beta_{X0}\beta_{Y0})+K_{S2}$ calculated from two measurements was not bad considering the measurement error.

4 DISCUSSION

The methods used here was similar to that by Y. Fukuda *et al.* [6], who searched the distribution of skew quadrupole field along the whole ring making 18 local bumps. However they assumed one single error in each of local bumps. When there was a location with one big skew quadrupole field, it should be triple counted because their bumps were overlapped.

Our analysis was completely different because we searched the distribution in one local bump.

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Table 1: Results of the measurements on the skew quadrupole imperfection.

	flat bump		angle bump		resonance	
	As	A_C	A_S	A_C	*SUM*	*DIFF*
Result of the Measurements						
As, Ac (μm/√m)	-13.3	-0.4	-0.5	-5.4		
SUM,DIFF(mrad/m)					-0.6	-3.2
Calculated K_{SN}						
K_{S0} (mrad/m)		-0.2				
K_{S1} (mrad)	-20			-25		-19
K_{S2} (mrad m)			-6			
$K_{S0}(\beta_{X0}\beta_{Y0})+K_{S2}$ (mrad m)		-14			-43	