MEASUREMENT OF QUADRUPOLAR TUNE SHIFTS AFTER THE RECONSTRUCTION OF THE PHOTON FACTORY STORAGE RING

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Abstract

The quadrupolar tune shift is a measure of the quadrupole component of wakefields in storage rings. By measuring both dipolar and quadrupolar tune shifts, we can estimate dipolar and quadrupolar kick factors independently. We carried out these measurements before and after the reconstruction of the Photon Factory storage ring at KEK. The results showed remarkable changes in the quadrupolar tune shifts in both horizontal and vertical planes, together with slight changes in the dipolar tune shifts.

INTRODUCTION

In the electron storage rings, we can excite horizontal or vertical quadrupole (beam-size) oscillations of stored bunches by applying oscillating quadrupole fields [1]. The tunes (frequencies) of the quadrupole oscillations are basically twice the betatron tunes, however, they can shift as functions of a bunch current when the motions of the bunches are perturbed by wakefields.

The first quadrupolar tune measurement [2] for the electron storage rings was carried out at the Photon Factory (PF) storage ring in KEK. It showed that the horizontal quadrupole tune shifted upward with the bunch current while the vertical one shifted downward. This result was explained by an effect of the quadrupole component of short-range wakefields induced by a bunch itself. When a bunch passes a rotationally asymmetric structure, it can excite a composite wakefield having several multipole components [3]. A quadrupole component of the wakefield can focus and defocus the electrons in the horizontal and the vertical planes, respectively. We showed that the measurements of dipolar and quadrupolar tune shifts allow us to estimate the dipolar and quadrupolar kick factors of the wakefields independently.

The PF storage ring was largely reconstructed in 2005 [4] in order to increase available space for insertion devices. In this reconstruction, about two-thirds of its lattice was modified, and beam ducts in these sections were replaced to narrower ones [5]. Through this reconstruction, the coupling impedances of the ring might have been changed. The present work was carried out to investigate the potential changes in the transverse impedances. We measured both the dipolar and the quadrupolar tune shifts after the reconstruction, and then, compared results to those before the reconstruction.

MEASUREMENT

Experimental Method

Experimental method is described in detail in [2]. The setup for a horizontal quadrupolar tune measurement is shown in Fig. 1. We applied an oscillating quadrupole field having a peak strength of 3.1×10^{-5} m^{-1} to a stored single bunch. To excite quadrupole oscillations, we tuned the excitation frequency to be close to a frequency of $2f_r\Delta\nu_x$ (≈ 1.96 MHz), where f_r is the revolution frequency and $\Delta\nu_x$ is the fractional horizontal tune. This field induced the quadrupole oscillations with an estimated growth rate of 160 s^{-1}. The betatron tunes were (ν_x, ν_y) = (9.6103, 5.2712) at low beam currents.

The vertical quadrupole tunes were measured on the other day. To excite vertical oscillations, we tuned the excitation frequency to be close to a frequency of $(2\Delta\nu_y+ 3)f_r$ (≈ 5.67 MHz). The strength of the high-frequency quadrupole was set to 9.8×10^{-5} m^{-1}. This induced the quadrupole oscillations with an estimated growth rate of 310 s^{-1}. To avoid rf noise, the quadrupole oscillations were detected at a frequency of $(2\Delta\nu_y + 2)f_r$. The betatron tunes during this measurement were (ν_x, ν_y) = (9.6104, 5.2715) at low currents.

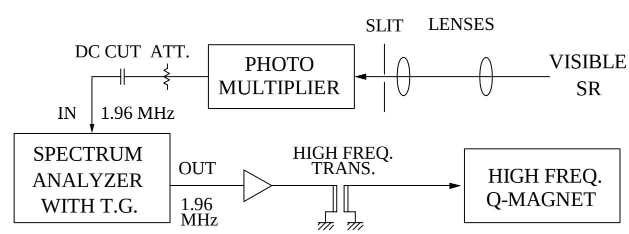

Figure 1: Setup for the horizontal quadrupolar tune measurement.

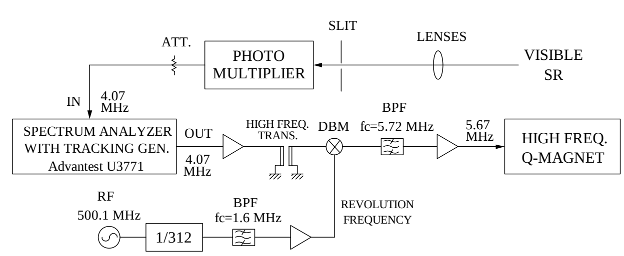

Figure 2: Setup for the vertical quadrupolar tune measurement.

Results

Figures 3 and 4 show the results of the quadrupolar tune measurements, together with those [2] measured before the reconstruction of the PF storage ring. Figures 5

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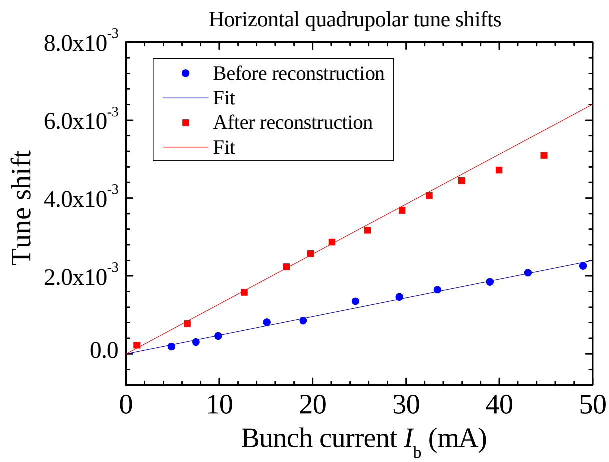

Figure 3: Horizontal quadrupolar tune shifts measured before and after the reconstruction of the PF storage ring.

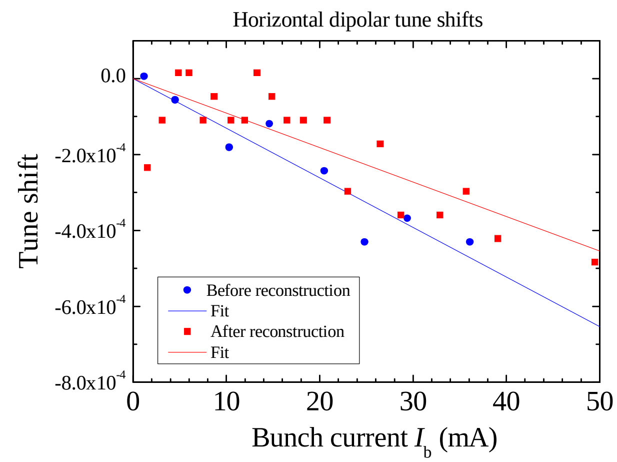

Figure 5: Horizontal dipolar tune shifts measured before and after the reconstruction.

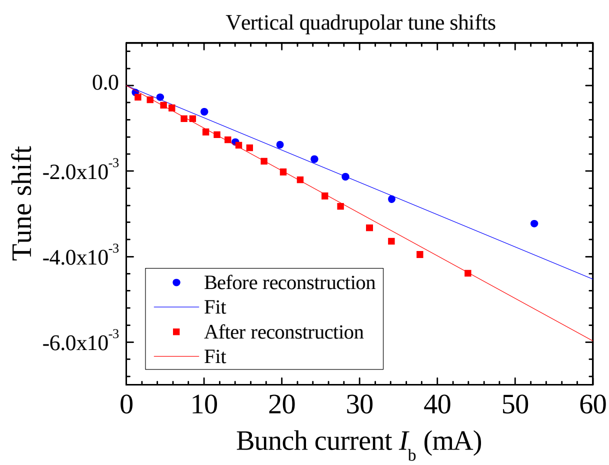

Figure 4: Vertical quadrupolar tune shifts before and after the reconstruction.

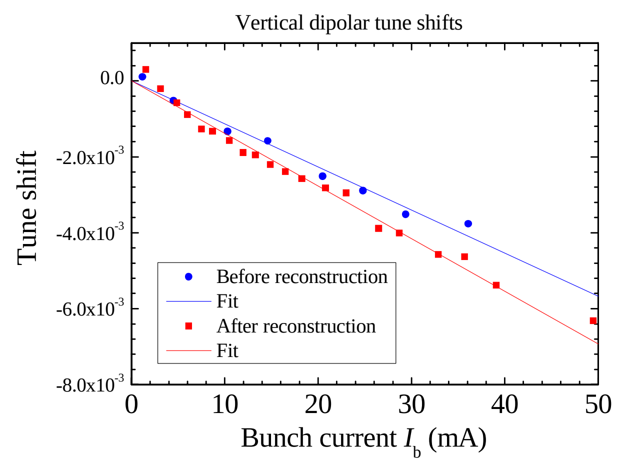

Figure 6: Vertical dipolar tune shifts measured before and after the reconstruction.

and 6 show the measured tune shifts of dipole (bunch centroid) oscillations. A summary of the tune shifts is given in Table 1.

We can see from Figs. 3 and 4 that the quadrupolar tune shifts increased after the reconstruction in both horizontal and vertical planes. Especially, the horizontal quadrupolar tune shift (Fig. 3) increased remarkably. On the other hand, the dipolar tune shifts changed only slightly after the reconstruction (see Figs. 5 and 6).

Table 1: Summary of the measured tune shifts before and after the reconstruction of the PF storage ring. Units: A^{-1}.

Tune shift	**Before** [2]	**After**
Horizontal quadrupole	4.8×10^{-2}	1.3×10^{-1}
Vertical quadrupole	-7.6×10^{-2}	-1.0×10^{-1}
Horizontal dipole	-1.3×10^{-2}	-9.1×10^{-3}
Vertical dipole	-1.1×10^{-1}	-1.4×10^{-1}

DISCUSSIONS

As discussed in [2], the dipolar ($\delta\nu_x^d$) and the quadrupolar ($\delta\nu_x^q$) tune shifts in the horizontal (x) plane are related to the kick factors by

$$\frac{\delta\nu_x^{\mathrm{d}}}{I_{\mathrm{b}}} = -\frac{e}{4\pi E f_{\mathrm{r}}}\sum_j \beta_{x,j}\left[k_{x,j}^{(1)} + k_{x,j}^{(2)}\right], \qquad (1)$$

and

$$\frac{\delta\nu_x^{\mathrm{q}}}{I_{\mathrm{b}}} = -\frac{e}{2\pi E f_{\mathrm{r}}}\sum_j \beta_{x,j} k_{x,j}^{(2)}, \qquad (2)$$

where E is the beam energy, I_b is the bunch current, $\beta_{x,j}$ is the horizontal betatron function at the j-th component, and $k_{x,j}^{(1)}$ and $k_{x,j}^{(2)}$ are the dipolar and the quadrupolar kick factors of the j-th component, respectively. Similar relations hold for the vertical (y) tune shifts.

Applying Eqs. 1 and 2 to the measured tune shifts, we can estimate the sum of the products of the β-functions and the kick factors. Results of the estimation are shown in Table 2. Note that we have not taken account of any dependence of the kick factors on the bunch length.

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Table 2: Estimated products of the kick factors and the betatron functions before and after the reconstruction. Units: VC^{-1}.

	Before	After
$\sum \beta_{x,j} k_{x,j}^{(1)}$	1.9×10^{15}	3.7×10^{15}
$\sum \beta_{x,j} k_{x,j}^{(2)}$	-1.2×10^{15}	-3.2×10^{15}
$\sum \beta_{y,j} k_{y,j}^{(1)}$	3.6×10^{15}	4.5×10^{15}
$\sum \beta_{y,j} k_{y,j}^{(2)}$	1.9×10^{15}	2.5×10^{15}

Table 3: Roughly estimated total kick factors of the ring before and after the reconstruction. Units: $Vm^{-1}C^{-1}$.

	Before	After
$\sum k_{x,j}^{(1)}$	6.1×10^{14}	1.2×10^{15}
$\sum k_{x,j}^{(2)}$	-3.9×10^{14}	-1.0×10^{15}
$\sum k_{y,j}^{(1)}$	5.2×10^{14}	8.0×10^{14}
$\sum k_{y,j}^{(2)}$	2.8×10^{14}	4.5×10^{14}

We next try to estimate the total kick factors of the ring. Because we have no information of the betatron functions at each source of the wakefield, we use average betatron functions for the $\beta_{x,j}$ and $\beta_{y,j}$. Average betatron functions are: $\langle\beta_x\rangle$ = 3.1 m before and after the reconstruction, and $\langle\beta_y\rangle$ = 6.96 m (before) and $\langle\beta_y\rangle$ = 5.65 m (after), respectively. The modification of the beam optics after the reconstruction occurred in the straight sections. Accompanying to this modification, the operating point (ν_x, ν_y) changed approximately from (9.60, 4.28) to (9.61, 5.27). As a result of above-mentioned estimation, we obtained total kick factors, as given in Table 3.

Table 3 indicates that the dipolar kick factor in the horizontal plane increased by a factor of two after the reconstruction, while the quadrupolar kick factor increased by a factor of 2.6. In the vertical plane, the dipolar and the quadrupolar kick factors increased by factors of 1.5 and 1.6, respectively.

The beam ducts in the straight sections were replaced to narrower ones during the reconstruction [5]. Original quadrupole-magnet ducts were 146-mm wide and 70-mm high while new ducts are 90-mm wide and 38-mm high. We suppose that the observed (but roughly estimated) increases in the kick factors were primarily caused by the narrower apertures of the new beam ducts. Accompanying the replacement of the beam ducts, unshielded bellows in these sections were replaced to shielded ones, and this should contribute to decreasing the kick factors. It is worth noting that the bunch lengths as a function of the bunch current did not change much after the reconstruction [6].

We also mention that the quadrupolar kick factors after the reconstruction in Table 3 has a ratio,

$$\left(\sum k_{x,j}^{(2)}\right):\left(\sum k_{y,j}^{(2)}\right) = (-2.2):1, \qquad (3)$$

while the ratio for each component should theoretically be given by

$$k_{x,j}^{(2)} : k_{y,j}^{(2)} = (-1):1. \qquad (4)$$

This suggests that our estimations in Table 3 are not very accurate. To discuss more precisely, we need to calculate the kick factors of the principal components of the ring using computer simulations.

In above discussions, we have ignored the dependence of the kick factors on the bunch current through the bunch lengthening. More accurate discussions including this effect will be possible by a frequency domain analysis using the coupling impedances.

CONCLUSIONS

After the reconstruction of the PF storage ring, we measured the dipolar and the quadrupolar tune shifts, and compared them to those obtained before the reconstruction. We found remarkable changes in the quadrupolar tune shifts, together with slight changes in the dipolar tune shifts. These results can be explained by the increases in the kick factors due to narrower beam ducts. We showed that the quadrupolar tune measurement is very useful for diagnosing the transverse impedances of the storage rings.

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REFERENCES

[1] S. Sakanaka, Y. Kobayashi, T. Mitsuhashi, and T. Obina, PAC01, p. 393; S. Sakanaka, Y. Kobayashi, T. Mitsuhashi, and T. Obina, Jpn. J. Appl. Phys. **42**, 1757 (2003).

[2] S. Sakanaka, T. Mitsuhashi, and T. Obina, Phys. Rev. ST Accel. Beams **8**, 042801 (2005).

[3] S. Heifets, A. Wagner and B. Zotter, "Generalized Impedances and Wakes in Asymmetric Structures", SLAC Report No. AP110, 1998.

[4] T. Honda et al., AIP Conf. Proc. **879**, p. 87.

[5] Y. Tanimoto, Y. Hori, T. Nogami, and T. Uchiyama, EPAC'06, p. 3371.

[6] T. Obina and T. Mitsuhashi, "Measurement of Bunch Lengthening Effects using a Streak Camera with Reflective Optics", DIPAC 2007, Venice, May 2007 (to be published).

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