DIRECT OBSERVATION OF TRANSVERSE DYNAMIC APERTURE FOR HIGH-BRILLIANT OPTICS AT THE PHOTON FACTORY STORAGE RING

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Abstract

The transverse dynamic apertures for the high-brilliant optics were directly observed at two operating points of betatron tunes near 3rd order coupling resonance at the Photon Factory storage ring (PF-ring). The measurements were made on the quarter of the transverse plane using the fast kicker magnets and the turn-by-turn monitor system. The dynamic apertures were preciously estimated through the fine control of kicker voltage and turn-by-turn observation of beam loss after the kick. The measured transverse dynamic apertures were quantitatively compared with the prediction of the computer simulation based on the realistic lattice model.

1 INTRODUCTION

The reconstruction for the brilliance-upgrading project at the PF-ring was completed in October, 1997 [1]. Then, the ring has been stably operated with the optics, whose emittance is about 36 nmrad.

However, we have to overcome the dynamic aperture problem to obtain much smaller emittance. Because the strength of the sextupole magnets for the chromaticity corrections increases for the smaller emittance optics, the dynamic aperture is rapidly reduced. The prediction of the computer simulation for the dynamic aperture is quite severe. So, we tried to examine the reliability of the predictions by comparing with the direct observation of the dynamic aperture in the ring.

2 EXPERIMENT

2.1 Method

The basic method of the experiment is similar to the particle tracking method used in computer simulation. The beam was given the initial amplitude by the fast kicker magnets. The kicked beam circulates with a large coherent betatron motion, and then the beam will be lost when the motion is limited by the aperture. So, we measure beam loss together with the amplitude of the motion turn-by-turn. However, it is necessary to judge whether the beam loss depends on the dynamic aperture or not.

2.2 Ring condition

The measurements were made on two operating points of the betatron tune near the 3rd order coupling resonance ($\nu_x + 2\nu_y = 18$); one is above the resonance in the vertical tune (ν_x, ν_y)=(9.60, 4.29), the other is below (ν_x, ν_y)=(9.60, 4.16). The single-bunch electron beam was used, and initial stored current was set to be about 0.5 mA to avoid the collective effects as possible. The chromaticities were compensated to be almost zero by sextupole magnets, and closed orbit distortions were corrected by steering dipole magnets. The insertion devices were set to be maximum gap to remove the complex effects in this time. The relevant orbit parameters during experiments are listed in Table 1.

Table 1: Relevant orbit parameters of the PF-ring

Beam Energy	E (GeV)	2.5
Circumference	C (m)	187
Harmonic Number	h	312
RF frequency	frf (MHz)	500.1
Revolution period	τ (nsec)	624
Emittance	$\varepsilon x,\varepsilon y$ (nmrad)	36, 0.36
Energy Spread	$\sigma\varepsilon$	0.00073
Beam Size at Monitor	$\sigma x,\sigma y$ (mm)	0.58,0.04

2.3 Fast kicker magnets

The fast kicker magnet system was installed to provide beam with a large coherent motion. The system consists of a horizontal and a vertical kicker magnet, which are independently excited. The specifications of the system are listed in Table 2. The excited currents corresponding to the kick angle were controlled with the control voltage (0 - 10 V).

Table 2: Specifications of the fast kicker magnet system

Magnet core material	Ferrite
Coil turn number	2
Core Gap (H/V)	56/96 (mm)
Core length	150 (mm)
Magnet Impedance (H/V)	2.2/1.1 (μH)
Maximum voltage(H/V)	35/40 kV
Pulse full width (half sine)	425/335 (nsec)

2.4 Turn-by-turn monitor system

A block diagram of the turn-by-turn monitor system is shown in Fig. 1. The four signals were picked up from the stripline electrodes, and stretched through band-pass filters. Then, the peak voltage of the signals were detected with the peak-hold circuits, and digitized by the ADC (8-bit 20MHz). The four signals were independently processed turn-by-turn. The digitized data were sent to the memories (256 kbyte RAM) by synchronizing the kicker trigger, and stored in them.

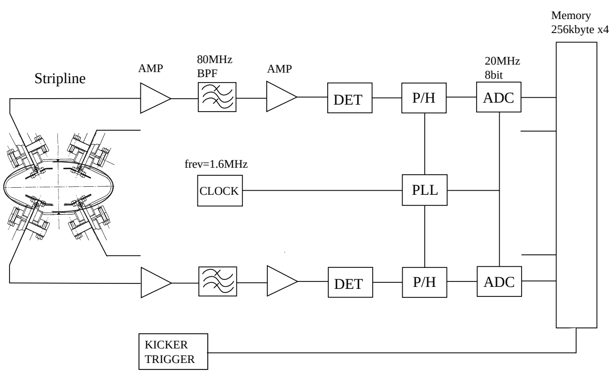


Figure 1: Block diagram of the turn-by-turn monitor system

2.5 Amplitude and current of the kicked beam

The amplitudes and current of the kicked beam were reconstructed as follows. First, we calculated the beam positions from the digitized data of four electrodes by the following equations.

$$U = \frac{v_1 - v_2 - v_3 + v_4}{v_1 + v_2 + v_3 + v_4}, V = \frac{v_1 + v_2 - v_3 - v_4}{v_1 + v_2 + v_3 + v_4}$$

$$S = v_1 + v_2 + v_3 + v_4$$

$$X = \sum_{i=0}^{6}\sum_{j=0}^{6} kx(i, j) \cdot U^i \cdot V^j$$

$$Y = \sum_{i=0}^{6}\sum_{j=0}^{6} ky(i, j) \cdot U^i \cdot V^j$$

Here, vi is the measured peak voltage, and the coefficient kx and ky are obtained from the calculated mapping information of the stripline electrodes. Next, the amplitudes of the kicked beam were deduced and calibrated. The amplitudes were linear for the kicker voltages. The circulated current of the kicked beam was calibrated using the reading value of DCCT. The typical result of the experiment shows in Fig. 2.

2.6 Beam loss rate for amplitude

Figure 3 plot the examined amplitude on the quarter of the transverse plane. The beam loss rate for the radial amplitudes and azimuth angles converted from the X-Y amplitudes are shown in Figs. 4; the upper one is for the betatron tune (ν_x, ν_y)=(9.60, 4.29), and the lower one for (ν_x, ν_y)=(9.60, 4.16). In the case of (9.60, 4.29), the beam loss for azimuth angle in less than 20.4 deg was not clearly observed because of lack in the kick angle and the wider dynamic aperture. In the case of (9.60, 4.16), it was clearly observed and rapidly increased with the amplitude increasing.

2.7 Measured dynamic aperture

Figures 5 show the measured dynamic apertures. By assuming that the beam forms the Gaussian distribution, they were deduced from the probability distribution and reconstructed as the amplitude corresponding to 13% and 50% beam loss.

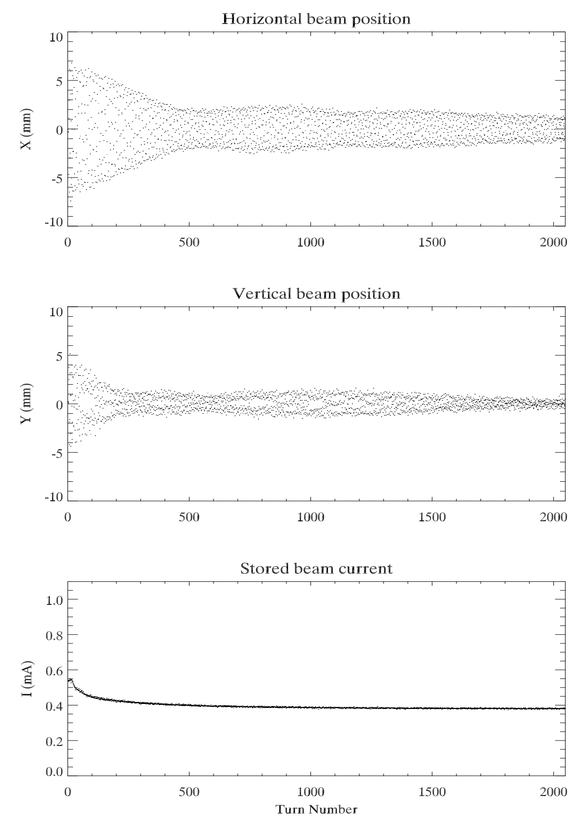


Figure 2: The typical horizontal and vertical coherent betatron motions and current turn-by-turn are shown. The beam loss is observed. It seems to be due to the dynamic aperture.

3 COMPUTER SIMULATION

The detail description of the computer simulation about the dynamic aperture for high-brilliance optics of the PF-ring is presented in other paper [2]. In this time, more realistic lattice model, which was deduced through orbit response function due to steering dipole magnets, is used in the computer simulation [3]. However, the strength and alignment errors of the magnets are assumed and the only COD was corrected to those errors in the simulation. The predictions of the simulation are added in Figs. 5. Although the ambiguity has yet remained in the employed lattice model, the predictions almost agreed with the measured results.

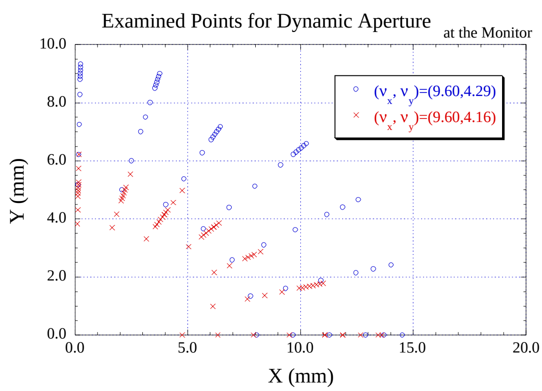
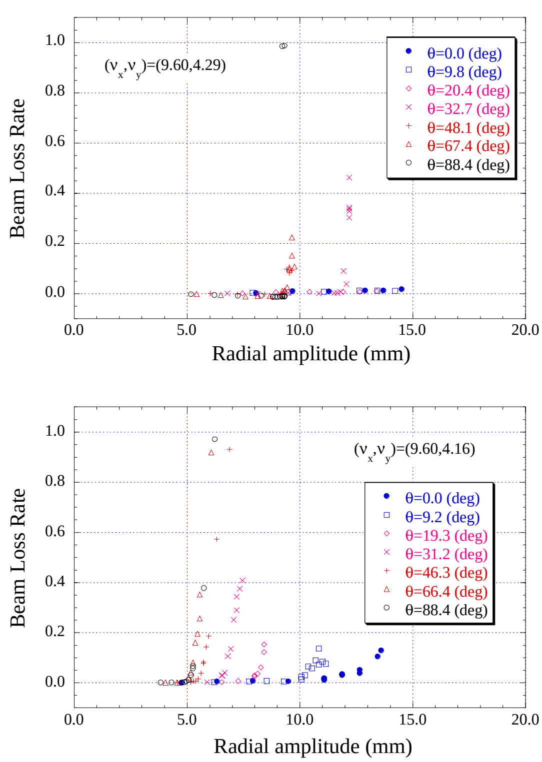


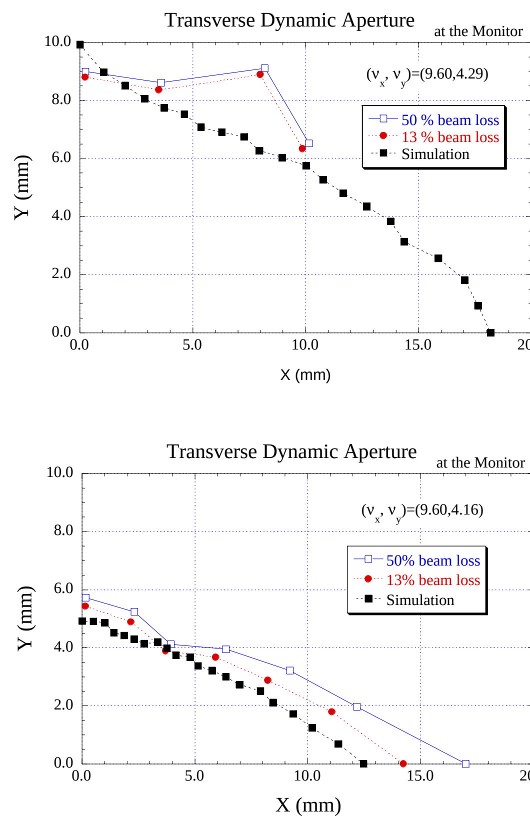
Figure 3: Examined amplitude on the quarter of the transverse plane



Figures 4: Beam loss rate for the radial amplitudes and azimuth angles

4 SUMMARY

The transverse dynamic apertures for the high-brilliant optics were directly observed at two operating points of betatron tune near 3rd order coupling resonance. The measured results were compared with the predictions of the computer simulation based on the realistic lattice model. The predictions almost agreed with the measured results.



Figures 5: Measured transverse dynamic apertures with the predictions of the computer simulation

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