

# Experimental Measurement of Dynamic Aperture at the Photon Factory Storage Ring

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## Abstract

The transverse dynamic apertures were measured as a function of the octupole strength at the Photon Factory Storage Ring (PF-Ring). A remarkable octupole dependence did not appear in the vertical aperture. On the other hand, the horizontal aperture was clearly dependent on the octupole strength. This result agreed well with a prediction of the computer simulation.

## I. Introduction

The nonlinear beam dynamics of the transverse betatron oscillation in circular accelerators has been studied using analytical and numerical methods. In the design of low emittance rings for a high brilliant synchrotron radiation or large colliders with superconducting magnets, the nonlinear dynamics has been important, especially the problem of a dynamic aperture has been serious in such new rings. For the strong sextupole fields used to compensate the large chromaticities or the higher order multipole fields produced by the superconducting magnets, the dynamic apertures tend to be rather smaller than those of the previous rings. Much effort, therefore, has been devoted to develop various correction methods for nonlinear effects and to enlarge the dynamic apertures [1].

The 2.5 GeV PF-Ring, which is a dedicated synchrotron radiation source, has been stably operated for a decade. Recently, we are planning to reform this ring toward much lower emittance ring that can supply a higher brilliant synchrotron radiation [2]. Then, one of the most serious issues in this plan is that the dynamic aperture becomes small due to the strong sextupole fields. From a prediction of the computer simulation using a model of an ideal machine without any errors, the dynamic aperture is still larger than the physical aperture. Since the real machine has various imperfections, however, we need to estimate the quantitative difference of the dynamic aperture between the experimental measurement and the computer simulation.

At the PF-Ring, the dynamic aperture can be reduced by existing octupole magnets employed to suppress the transverse instabilities in usual operation mode. As the first step, therefore, we experimentally measured the dynamic aperture as a function of the octupole strength and compared the result with a prediction of the computer simulation.

## II. Experiment

The basic procedure of this experiment was to measure a beam loss after providing beam with a single kick. The

kicked beam circulates with a large coherent betatron oscillation, and then the beam will be lost when the amplitude of the coherent oscillation is near the dynamic or the physical aperture. Thus, the aperture will be estimated by the relation between the beam loss and the coherent betatron oscillation amplitude. Here, the distinction between the dynamic and the physical aperture is made according to whether the aperture is dependent on the octupole strength.

### A. Ring Condition

The experiment was made under the almost same condition as a usual operation. The single-bunch positron beam was used, and the initial stored current was always set to be about 5 mA to make the collective effects small as possible. In this experiment, betatron tunes were fixed, chromaticities were compensated by sextupole magnets and set to be near zero, and closed orbit distortions were corrected by steering dipole magnets. The insertion devices were set to be maximum gap or turned off to remove the complex effects on beam. The physical apertures of this ring are determined by the ducts of insertion devices in both horizontal and vertical planes. The relevant orbit parameters are listed in Table 1.

Table 1. Relevant orbit parameters of the PF-Ring

Beam Energy	2.5 GeV
Circumference	187 m
Natural Emittance [H/V]	128/2.5 nm-rad
Energy Spread	$7.3 \times 10^{-4}$
Revolution Period	625 nsec
Betatron Tune [H/V]	8.468/3.325
Corrected Chromaticity [H/V]	0.77/0.23
Transverse Radiation Damping Time	7.8 msec
Beta Function at Fast Kicker [H/V]	15.2/9.0 m
at Scraper [H/V]	16.5/8.0 m
at MPW#13 [H/V]	14.0/12.0 m
at VW#14 [H/V]	8.0/7.0 m
Beam Size at Scraper [H/V]	1.6/0.14 mm
Predicted Physical Aperture (Half width)	
at VW#14 / at Scraper [H]	21.0/ 30.2 mm
at MPW#13/ at Scraper [V]	12.0/9.8 mm

### B. Hardware Description

The fast kicker magnet system was installed to provide beam with a large coherent oscillation by only a single kick. This system consists of a horizontal and a vertical kicker magnet, a pulser of the pulse forming network (PFN) type with thyatron switchings and a charging high voltage power supply controlled by trigger and timing circuits. The kicker magnets were designed with the conventional type, which has a window frame ferrite core with a double turn coil. The field strength of the kicker magnets was measured as a function of a charging high voltage using a long search coil. The strength increases linearly with the high voltage. The ceramic duct with Ti coating of 2μm is used for these kicker magnets. The

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overall field reduction from the duct was less than 6%. The specification of the fast kicker magnet system is listed in Table 2.

The eight octupole magnets are now used in the usual operation to suppress the transverse beam instabilities. Each magnet can be excited by the independent bipolar power supply within currents of  $\pm 3A$ . The detail about the octupole magnets was described in the previous paper [3].

Table 2. Specification 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 Inductance [H/V]	2.2/1.1 $\mu H$
Maximum Charging Voltage	40 kV
Maximum Repetition Rate	0.5 Hz
Pulse Width [H/V]	425/335 nsec

### C. Measurement procedure

First, we adjusted the discharging trigger timing so that we fit the circulating beam to the peak of the pulse in the kicker magnets. The signal of the circulating beam was picked up from one electrode of the button type position monitors (BPM) in the ring. Since a distance between the kicker magnets and the BPM is fixed, the timing adjustment was made by delaying the trigger signal for pulsing the kicker magnet within the revolution period. The best timing was determined by estimating the trigger delay time to give maximum beam loss when the beam was kicked with a constant charging high voltage.

Next, the amplitude of the coherent betatron oscillation produced by a single kick was calibrated using a beam scraper already installed in the ring. Since the coherent oscillation

amplitude increases linearly with a charging high voltage, it is accurate to calibrate the amplitude at two positions of the scraper. Figures 1 show the beam loss rate as a function of the high voltage set value  $V_k$ , which is proportional to the charging high voltage. The coherent oscillation amplitude  $Z$  is indicated as the following equation,

$$Z = \frac{\Delta Z}{\Delta V_k} \times V_k \quad (1)$$

where  $Z$  represents both horizontal and vertical amplitudes (X and Y). Then,  $\Delta Z$  is the relative difference between two positions at the scraper, and  $\Delta V_k$  the relative difference of the high voltage set values corresponding to  $\Delta Z$ . The  $\Delta V_k$  is estimated from the figures 1. Therefore, the amplitude of the coherent oscillation at the scraper could be obtained until the maximum  $V_k$  through eq. (1). The overall accuracy of the amplitude would be about 10%.

After finishing the timing adjustment and the calibration, the aperture was evaluated as follows. All octupole magnets are excited with a desired current. Then, with increasing the high voltage set value by a proper step, we measured the beam loss after kick and calculated the rate of the beam loss to the initial stored current. Whenever the beam was lost, it was restored for keeping the same condition. This measurement was repeated, and the high voltage was increased until that the beam loss rate reached to 100%. Furthermore, the measurements were made in several octupole excitation currents.

## III. Computer Simulation

The simulation was performed using the computer code similar to the program PATRICIA [4] in which the multipole

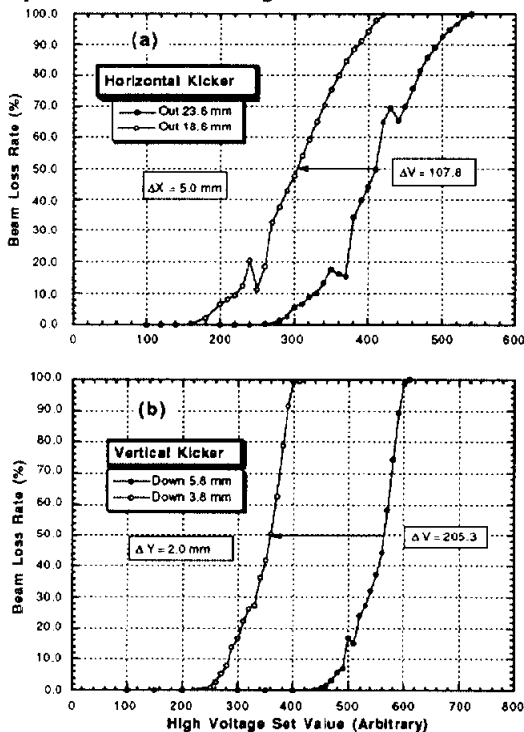


Figure 1. Calibration of the coherent oscillation amplitude at the scraper. (a) is in horizontal plane and (b) in the vertical plane.

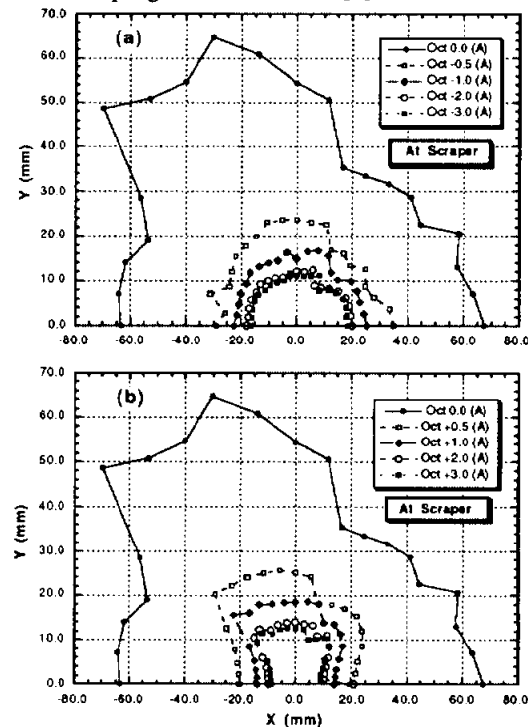


Figure 2. Results of the computer simulation using on-momentum particles. (a) is the result in the negative excitation currents of the octupole magnets and (b) in the positive ones.

field was treated as a kick using thin lens approximation to transform the particle trajectories. The simulation model was an ideal lattice without any errors, but with the same betatron tunes as the usual operation. The dynamic aperture is defined as a maximum initial amplitude to give the circulation of 1000 turns in the particle tracking. Figures 2 show the dynamic aperture surveyed on the two-dimensional x-y plane at the scraper. We see that the dynamic aperture rapidly shrinks with increase of the octupole strength.

## IV. Measurement Result and Discussion

### A. Horizontal plane

The measurements were made at six different excitation currents of the octupole magnets. Figure 3 shows the beam loss rate as a function of the coherent oscillation amplitude at the scraper. Because the beam has some sizable distribution and circulates more than 10000 turns until that the coherent oscillation damps after kick, the inevitable spread of the amplitudes corresponding to several times beam size from the beginning of the beam loss to 100% exist. For this reason, we defined the aperture as the spread amplitude from 10% to 90% in this experiment. This situation is quite different from the case of the computer simulation using a single particle tracking. Nevertheless, we tried to compare the experimental result with a prediction of the computer simulation. Figure 4 shows the coherent oscillation amplitude with three cases, 10%, 50% and 90% loss, as a function of the octupole excitation currents and includes the tracking result at the scraper in the horizontal plane. It is clearly understood that the aperture is physically determined without the octupole excitation. In fact, the effective physical aperture at the scraper is about 30mm that is calculated from the duct size of VW#14. On the other hand, when the octupole magnets are excited, we see that the aperture is dynamically limited because it is dependent on the octupole strength. Furthermore, the measurement result agrees with the prediction of the computer simulation under the different definition of the dynamic aperture. This is almost consistent with the result at Aladdin [5].

### B. Vertical plane

The measurements were made at nine different excitation currents. Figure 5 shows the same as figure 4, but in the

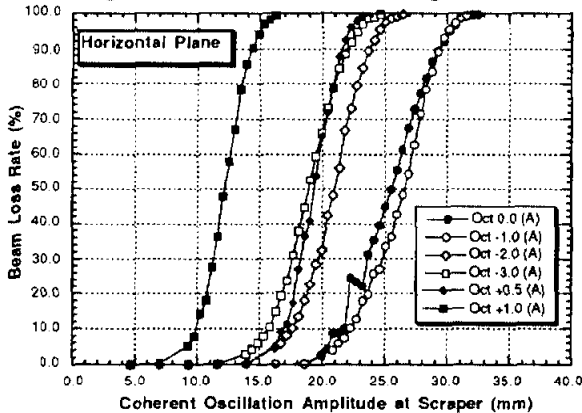


Figure 3. Beam loss rate as a function of the coherent oscillation amplitude at the scraper in the horizontal plane.

vertical plane. A remarkable octupole dependence is not observed. It suggests that the vertical aperture is physically determined in this experimental condition even if the octupole magnets are strongly excited. The effective physical aperture at the scraper becomes about 8.0mm that is estimated from the measurement. However, since it is smaller than the predicted one from the duct size of MPW#13 (about 9.8mm), we are now investigating the vertical physical aperture by another method.

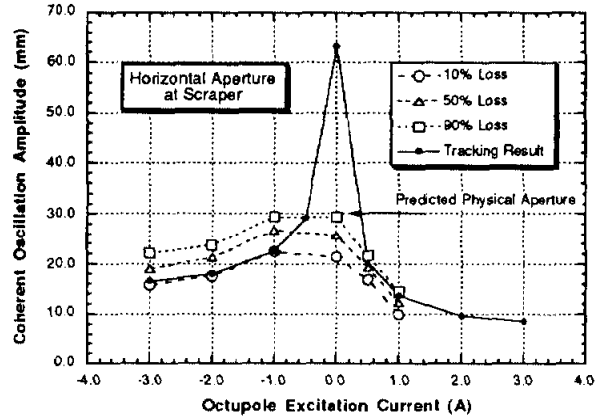


Figure 4. Coherent oscillation amplitude at the scraper as a function of the octupole excitation current in the horizontal plane.

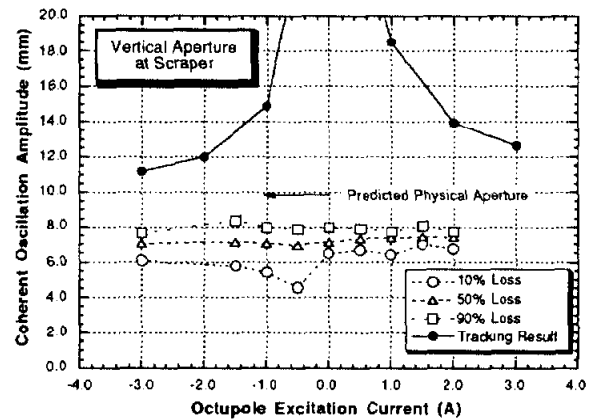


Figure 5. Coherent oscillation amplitude at the scraper as a function of the octupole excitation current in the vertical plane.

## V. Acknowledgment

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## VI. References

- [1] See, for example, "Proceedings of the Second Advanced ICFA Beam Dynamics Workshop", Lugano, CERN 88-04, 1988
- [2] M. Katoh and Y. Hori, "Report of the Design Study on a High Brilliance Configuration of the PF Storage Ring", KEK Report 92-20, 1993, in Japanese.
- [3] M. Katoh et al., "Dynamic Aperture of the Photon Factory Storage Ring", Particle Accelerators, Vol.28, p.17, 1990
- [4] H. Wiedemann, PEP Note-220, 1976
- [5] J. Bridges et al., "Dynamic Aperture Measurement on Aladdin", Particle Accelerators, Vol.28, p.1, 1990