Measurement of the Beam Decoherence due to the Octupole Magnetic Fields at the Photon Factory Storage Ring

Y. Kobayashi and K. Ohmi, High Energy Accelerator Research Organization,
Oho 1-1, Tsukuba, Ibaraki 305-0801, Japan

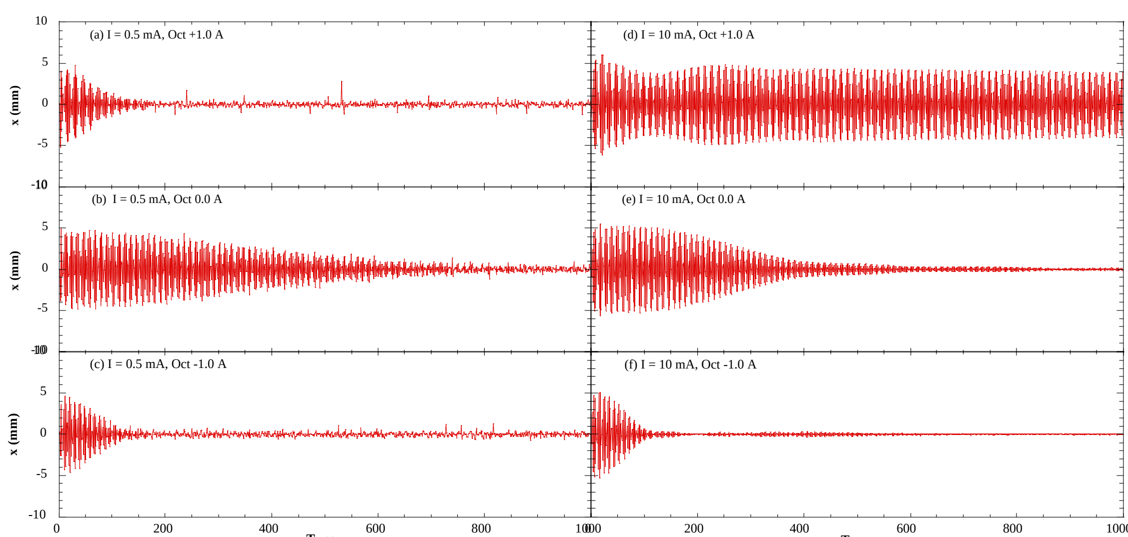
Abstract

The decoherence behavior of the beam centroid motion after a horizontal kick was examined with exciting of the octupole magnets using a turn-by-turn beam-position monitor. The measured results showed various decoherence behavior, which depended on the strength of the octupole magnetic fields and the beam current. Especially, the quite different behaviors were observed between the negative and the positive polarity of the octupoles in higher beam current. In order to understand the phenomena we tried to make a precise data analysis and a simulation using multi-particle tracking method which included the ring lattice parameters and a transverse impedance. As a result, we guess that both of the transverse impedance and the sign of the amplitude dependent tune shift essentially play important rolls in these phenomena.

1 INTRODUCTION

It is well-known that coherent centroid motion rapidly damps if the lattice non-linearity exists in an accelerator. This decoherence behavior is called as nonlinear smear or nonlinear filamentation. On the other hand, it was reported that nonlinear smear was suppressed when the head-tail damping occurred and the coherence centroid motion exponentially damps at TRISTAN MR [1]. In the head-tail damping both of the beam current and the chromaticity, which is an energy dependent tune shift, play important rolls. Therefore, although the relationship between the lattice non-linearity and the head-tail effect due to the chromaticity was investigated, it was not explained why the nonlinear smear was suppressed.

The Photon Factory storage ring (PF-ring) is a dedicated synchrotron light source, which has been stably operated for more than fifteen years. In the ring, many nonlinear magnets existed; twenty-two sextupole magnets for chromaticity corrections, eight octupole magnets, which can produce the large amplitude dependent tune shift to beam [2]. Recently, the fast kicker magnets were installed and a turn-by-turn beam-position monitor was developed in the ring [3,4]. So we have made the similar experiments performed at TRISTAN MR and might find the key to understand the problem on the relationship between the nonlinear smear and head-tail effect.



Figures 1: The horizontal beam centroid motions measured at a current of 0.5 mA and 10mA are shown as a function of turn. The left sides of the figure are for 0.5 mA and the right parts for 10 mA. The upper parts are for +1.0 A, the middle parts for 0.0 A , and the lower parts for –1.0 A.

2 EXPERIMENT AND RESULT

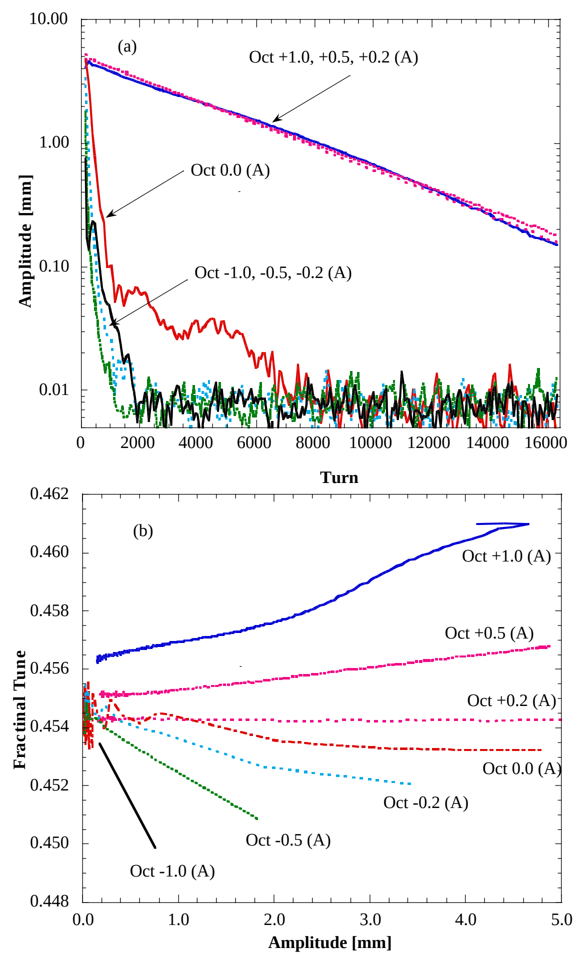
The experiment was performed in the single bunch operation mode at 2.5 GeV PF-ring. The principal parameters of the ring are shown in Table 1. The coherent beam centroid motion was obtained by a horizontal fast kicker magnet and the beam position was measured until 16834 turn by using a turn-by-turn beam-position monitor. The initial beam position was controlled by the kicker voltage to be about 5 mm at a center of a long straight section (βx = 5 m). The initial stored beam currents were set to be in the range from 0.5 to 10 mA. The position resolution was less than 0.08 mm at a current of more than 3 mA, but over 0.16 mm at a current of 0.5 mA. The eight octupole magnets, which were installed to suppress the coupled-bunch instabilities, were excited in the range from +1.0 to -1.0 A. The horizontal chromaticity was fixed to be positive value by the sextupole . Figures 1 show some results measured at currents of 0.5 and 10 mA with three octupole currents of +1.0, 0.0 and –1.0 A, in which the horizontal positions of the beam centroid motion are displayed until initial 1000 turns. The coherent centroid motion rapidly damps in the zero or the negative polarity of the octupole currents for both currents of 0.5 and 10 mA. This behavior is nonlinear smear. On the other hand, two different behaviors are observed between 0.5 and 10 mA in the positive polarity; one is a rapid damping for 0.5 mA, and the other is much slower damping for 5mA. Former behavior is nonlinear smear, but latter one is head-tail damping, whose phenomena were also observed at TRISTAN MR [1]. However, it was seemed that these phenomena were so strange for us, because the head-tail damping have occurred in the positive polarity of the octupole currents in spite that it has never occurred in negative polarity at a current of 10 mA.

Table 1: The principal parameters of the PF-ring

Beam Energy	2.5 GeV
Circumference	187 m
Natural Emittance [X/Y]	128/2.5 nmrad
Revolution Period	624 nsec
Energy Spread	0.00073
Betatron Tune [X/Y]	8.45/3.32
Synchrotron Tune	0.023
Chromaticity [X/Y]	1.5/0.5
Trans. Radiation Damping Time	7.8 msec

3 DATA ANALYSIS

We firstly tried to analyze measured data by using short time fast Fourier transform method (STFT) in order to understand the strange phenomena. In the method, hanning window was adopted as a window function, and time span and time shift was set to be 256 and 64 turn, respectively. The precise amplitude and fractional tune from the measured data of 16384 turns were derived from the FFT spectrum with a cubic spline function. Figure 2(a) show the amplitude of the coherent motion as a function of turn. Data were measured at a beam current of 10 mA. Figure 2(b) displays the amplitude dependent tune shift. Accuracy of the amplitude and tune in the zero and negative polarity was not good because of rapid damping of the coherent centroid motions, but it is clear that the sign of the amplitude dependent tune shift was different between the positive and negative polarity of the octupole currents.



Figures 2: (a) Amplitudes of coherent centroid motions are derived by STFT method. (b) Amplitude dependent tune shift

4 COMPUTER SIMULATION

Next we performed the multi-particle tracking as a computer simulation. In the computer code all magnets and cavities are expressed by 6 dimensional map. An element inducing the wake force, which is a transverse impedance, is installed at a position of the ring. Macro-particles are generated randomly by Gaussian distribution in the 6 dimensional phase space. The horizontal and vertical beam size at a place of $\beta x=\beta y=5$ m is about 0.8 mm and 0.1 mm, respectively. Macro-particles are shifted 5 mm to horizontal direction in the initial condition. Thousand macro-particles are used in this simulation, but it was enough for us to understand the phenomena. Figures 3 show the simulation results, in which the expected horizontal position of 1000 macro-particles is displayed as a function of turn. The conditions of the simulation are set to be the same as experimental conditions shown in figures 2. The simulation results are almost agreed with the measured results at both beam currents of 0.5mA and 10 mA. Especially, the much slower damping of the coherent motion was observed at a beam current of 10mA and octupole current of +1.0 A shown in fig.3 (d). However, this phenomenon was not realized without a transverse impedance.

5 DISCUSSION AND SUMMARY

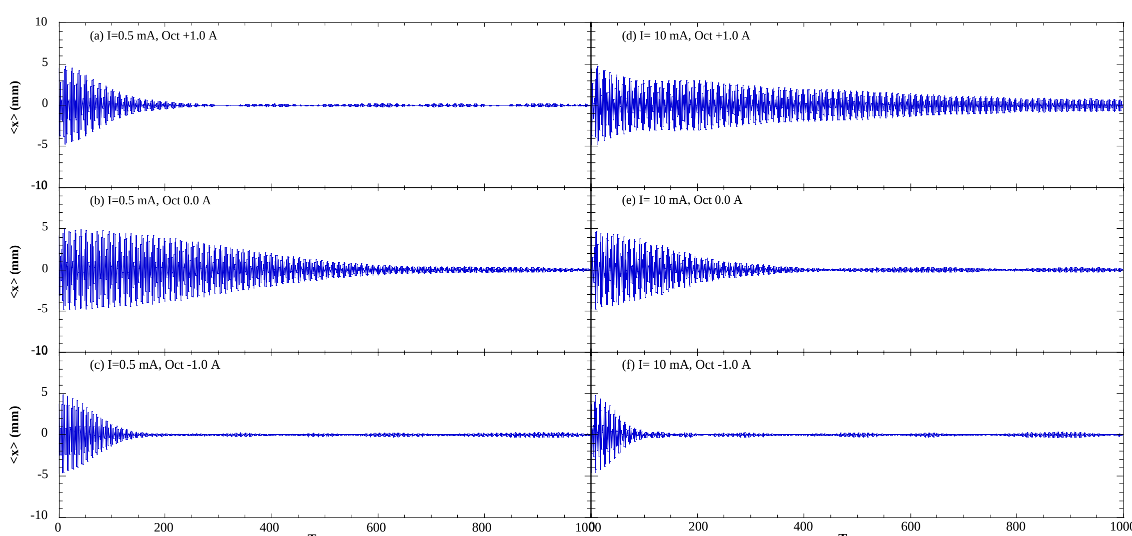
The coherent centroid motion after a horizontal kick was examined with various excitations of the octupole magnets. In the lower beam current (0.5 mA), only nonlinear smear behavior was observed in both of positive and negative polarity of the octupole currents. On the other hand, in the higher beam current, the two different behaviors were observed ; one is nonlinear smear for the negative polarity and the other is head-tail damping for the positive polarity. This phenomenon was remarkable when the beam current was higher. After precise data analysis and a computer simulation, we guess that both of the transverse impedance and the sign of the amplitude dependent tune shift essentially play important rolls in these phenomena. Now we are going to understand the phenomena through theoretical approach in detail [5].

6 ACKNOWLEGEMENT

The authors wish to thank Director M. Kobayashi, and other staff of the Light Source Division of the Photon factory for supports of the experiment. They also thank Prof. S. Kamada and Prof. H. Kobayakawa for their suggestions.

REFERENCES

[1] M. Akasaka and S. Kamada, “Experimental Study of Head-Tail Damping and Nonlinear Filamentation based on Precise Analysis of Coherent Betatron Oscillations in Electron Storage Rings ”, EPAC’96, Sitges, June 1996.
[2] M. Katoh et al. , “Dynamic aperture of the Photon Factory Storage Ring”, Particle Accelerators, Vol.28, p.17, 1990.
[3] Y. Kobayashi et al., “Experimental Measurement of Dynamic Aperture at the Photon Factory Storage Ring”, PAC’93, Washington D.C., May 1993.
[4] Y. Kobayashi et al., “Phase Space Monitor System at the Photon Factory Storage”, EPAC’96, Sitges, June 1996.
[5] K. Ohmi and Y. Kobayashi, to be published.



Figures 3: The expected horizontal beam centroid motions calculated at a current of 0.5 mA and 10mA by multi-particle tracking method are shown as a function of turn. The left sides of the figure are for 0.5 mA and the right parts for 10 mA. The upper parts are for +1.0 A, the middle for 0.0 A, and the lower for –1.0 A.