BEAM DECOHERENCE DUE TO COMBINATION OF WAKE FORCE AND NONLINEARITY IN SP-RING-8 STORAGE RING

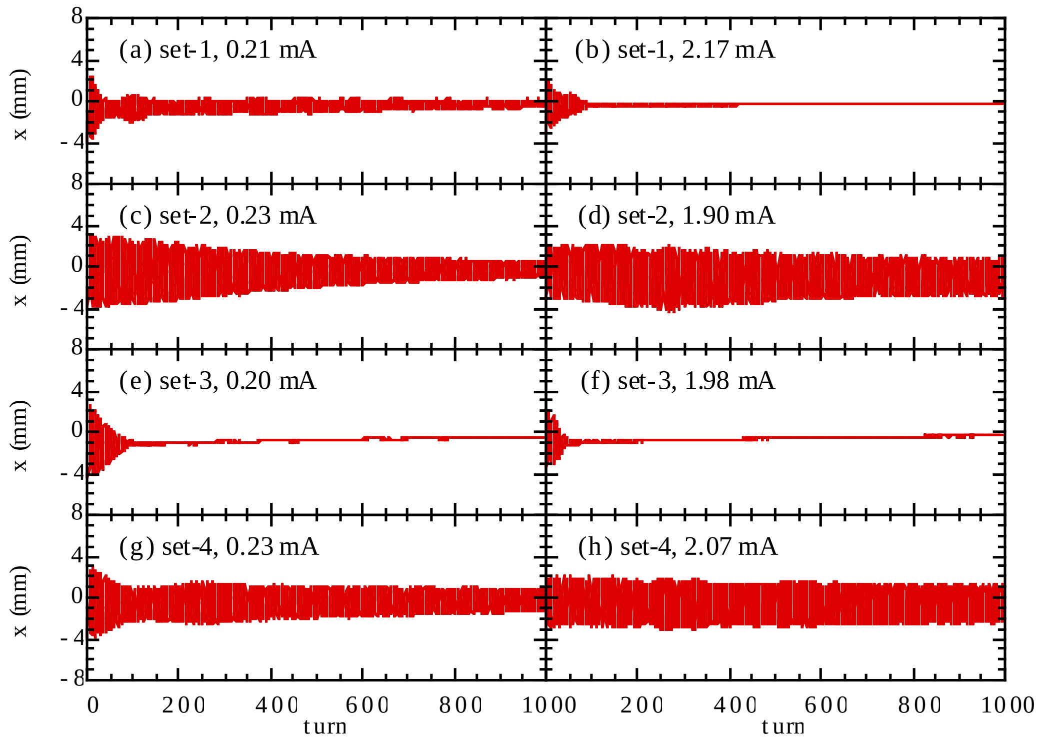
J. Schimizu*, K. Soutome, M. Takao and H. Tanaka
SPring-8/JASRI, 1-1-1 Kouto, Mikazuki-Cho, Sayo-Gun, Hyogo 679-5198, Japan

Abstract

To understand particle behavior from a beam injection state to equilibrium state determined by radiation effects, we have performed a simple experiment to observe the beam decoherence, i.e., temporal variation of the damping of beam coherent motion generated by a single horizontal kicker. We found that the beam decoherence much depends on chromaticities, the sign of amplitude-dependent tune shift and beam current. This suggests that short-range wake force and nonlinearity of ring parameters play important roles in the observed phenomena. Simulations with transverse wake fields show good agreements with the measurements.

1 INTRODUCTION

Top-up operation is planned in the SPring-8 storage ring to maintain the high brilliance of synchrotron radiation during several-bunch operation where beam lifetime is extremely short due to Touschek effect. To realize the top-up operation, we began to investigate the beam loss at in-vacuum insertion devices (IDs) during beam injection, but simulation results could not explain the measured beam loss evolution. We suspect that the initial conditions of the simulation do not coincide with the experiment, because the conditions, such as distribution in 6 dimensional phase space and the trajectory of the beam, have not measured precisely at the injection point of the storage ring. And the bunch length, which may affect wake fields, changes to shorter by radiation damping in the injection mode. In usual operation, the bunch length of injected beam is about five times longer than equilibrium size in SPring-8 storage ring. The initial conditions of the ping experiment, however, are for the equilibrium and the variation of the bunch length is very small. Thus simple ping experiments were performed to understand the collective and nonlinear beam behavior. The simulations were tried by using the multi-particle six-dimensional tracking code [1].



Figures 1: The horizontal beam motions measured at kick angle of 200 μrad are shown as a function of turn number. The set number implies the chromaticity set. See table 1.

* Permanent address: The Japan Research Institute, Ltd., 3-10-19 Minamisemba, Chuo-ku, Osaka 542-0081, Japan

2 EXPERIMENT AND RESULT

The experiment was performed with a single bunch at SPring-8 storage ring. The main parameters of the ring are shown in Table 1. The beam centroid motion was initiated by a horizontal kicker and the beam position was measured by using single path beam position monitors (SPBPMs) until 1024 turns. The initial kick angles were set to 100, 200 and 300 μrad at β_x = 22 m, and the initially stored beam currents were about 0.2, 1.0 and 2.0 mA/bunch. In the usual operation, chromaticity set-1 in the table 1 is used. Set-1 has large positive chromaticities and others have nearly zero chromaticities. Figures 1 show horizontal beam motions measured at kick angle of 200 μrad, beam current of about 0.2 mA/bunch and 2.0 mA/bunch. It is clear that the beam centroid motions are dependent on both chromaticity and beam current. Amplitude-dependent tune shifts calculated with tracking code for each set are shown in Fig. 2. These curves represent the measured amplitude-dependent tune shifts rather well. The $d\nu_x/dx$ of set-1 and 4 are positive, $d\nu_x/dx$ of set-2 is nearly zero for small amplitude region, and $d\nu_x/dx$ of set-3 is negative. The coherent beam centroid motion rapidly damps for $d\nu_x/dx < 0$ (Figs. 1(e) and (f)). The damping of coherent centroid motion is much slower for $d\nu_x/dx > 0$ and chromaticities ~ 0 (set-4) and for $d\nu_x/dx \sim 0$ (set-2).

Table 1: The main parameters of the SPring-8

Beam energy	8.0 GeV
Circumference	1436 m
Horizontal emittance	7 nmrad
$\varepsilon_y/\varepsilon_x$ coupling ratio	0.0014 (set-2)
Betatron tune(H/V)	40.15 / 18.36
Energy spread	0.0011 (rms.)
Chromaticity	
set-1(H/V)	6.9 / 6.4
set-2(H/V)	0.2 / 0.2
set-3(H/V)	0.1 / 0.1
set-4(H/V)	0.3 / 0.2

3 COMPUTER SIMULATION

The beams decoherence behavior in the Photon Factory storage ring (PF-ring) was reported [2], where the transverse impedance and the amplitude-dependent tune shift play important roles. Thus the lowest order wake field effects for very short beam bunch [3] were installed into the multi-particle six-dimensional tracking code [1]. The kick angle θ_j for the j-th macro-particle is described as

$$\vartheta_j = \frac{I \cdot Cw \cdot \sqrt{\sigma_s}}{M} \sum_i x_i \, , \qquad (1)$$

where I is beam current, σ_s is bunch length, x_i is amplitude of i-th particle, M is number of macro-particles, and Cw is a coefficient. Thousand macro-particles are used in this simulation and these are generated randomly by Gaussian distribution in the 6 dimensional phase space. The strength of Cw is obtained from ref. [3] with slight modification. Summation of amplitude is performed for macro-particles going before j-th particle. SPring-8 has 4 RF-stations named A to D, and there are 8 cavities in each RF-stations (total 32 cavities). Wake field effect is treated as a thin element and set at exit of RF-D-station.

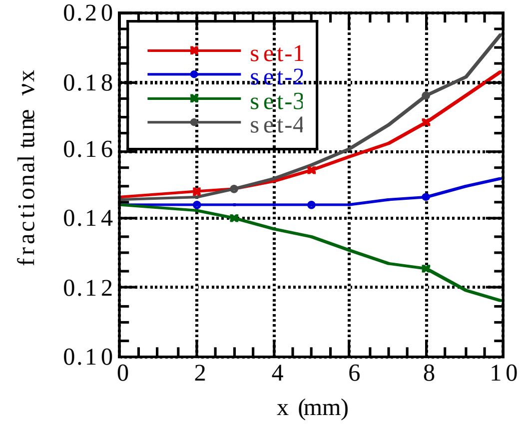
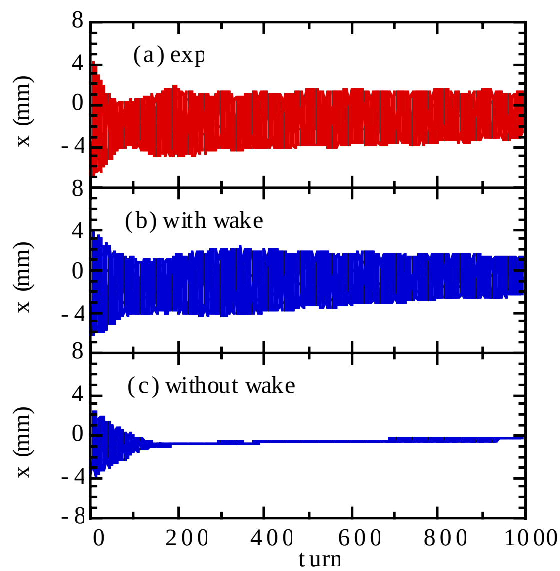


Figure 2: Amplitude dependent horizontal tune shift.



Figures 3: Experimental result of set-2, 0.23 mA and 300 μrad is compared with simulation results.

(a) Experimental result. (b) Simulation with transverse wake field. (c) Simulation without wake field.

Figure 3(a) shows an experimental beam centroid behavior of set-2, 0.23 mA and 300 μrad case. Figures 3(b) and (c) are the results of simulation with and without wake field. The result of simulation shown in figure 3(b) includes transverse wake field only. Because amplitude-dependent tune shift is nearly zero, there occurs no tune slip for small amplitude (Figs. 1(c) and (d)). But $d\nu_x/dx$ for large amplitude becomes positive, thus tune slip originate rapid damping if ignoring the wake field effect (Fig.3(c)). Thus sign of amplitude-dependent tune shift and wake field were expected to play essential role. Figure 4 shows the simulation results considering wake field. The simulation results almost agree with the measurements, especially for low beam current. If four wake field elements were set at each exit of RF-stations and the strength of Cw was multiplied by 1/4, almost the same results were obtained.

The agreement with experiment and simulation for high chromaticity and high current seems not so good. We also tried longitudinal wake field effect described as

$$\Delta U_j = \frac{I \cdot Cw_2}{M\sqrt{\sigma_s}} N_j, \qquad (2)$$

where ΔU_j is the energy loss of j-th particle, Cw_2 is a coefficient, N_j is number of macro-particles going before j-th particle. In this case, transverse and longitudinal wake fields were set at exit of each RF-stations and strength of Cw_2 is also obtained from ref. [3]. Though the value of Cw needs to be modified slightly, almost similar results as the simulation ignoring the longitudinal wake field effect were obtained. We expected that the longitudinal wake field effect improved high chromaticity results (set-1), because longitudinal wake field affects the macro-particle energy. But the simulation results, especially for high chromaticity case set-1, are not improved though the simulated bunch length becomes longer for high current cases. The transverse wake field plays essential roles but the longitudinal one does not in the damping of coherent beam centroid motion.

4 SUMMARY AND CONCLUSION

We measured the damping behaviors of the horizontal coherent motions initiated by a horizontal kicker to understand particle dynamics. We found that the beam decoherence much depends on chromaticity, the sign of amplitude-dependent tune shift and beam current. This suggests that short-range wake force and nonlinearity of ring parameters play important roles in the observed phenomena. We tried computer simulation by using the multi-particle six-dimensional tracking code with transverse and longitudinal wake field effects. The agreement of experiment and simulation with transverse wake force is rather well. Thus it is concluded that longitudinal wake field does not play essential roles in these phenomena. Now we are going to include next order wake effects to fit the experimental results of high chromaticities and high currents.

5 REFERENCES

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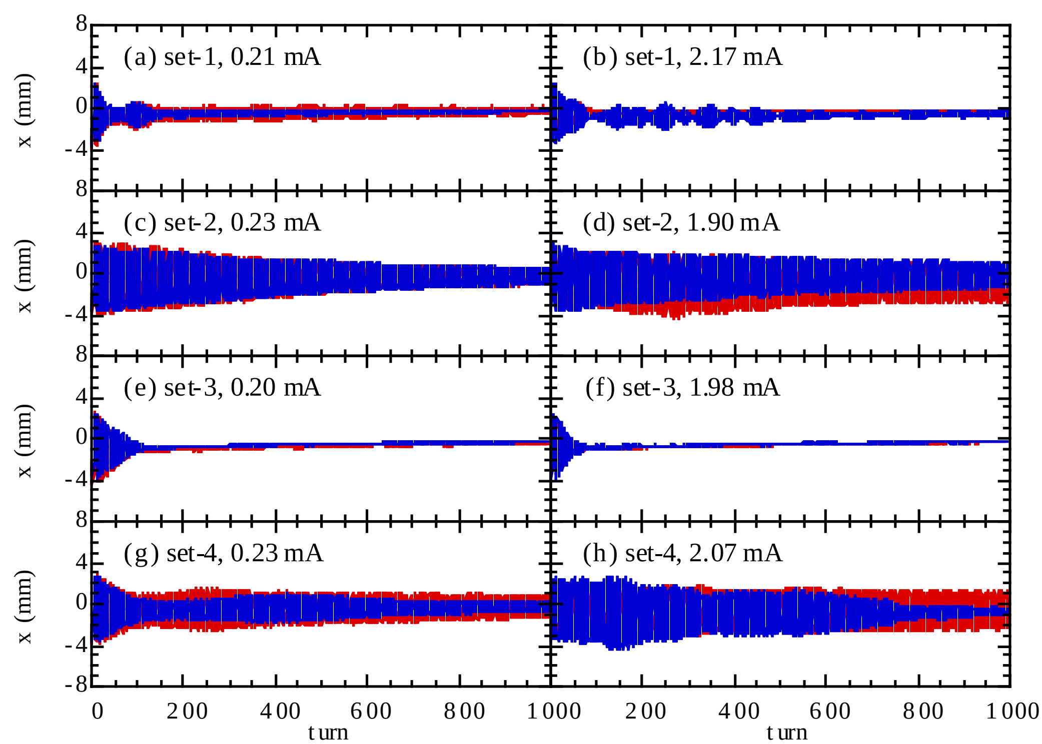

Figures 4: The horizontal beam motions calculated (blue lines) and measured (red lines) at kick angle of 200 μrad are shown as a function of turn number. The set number implies the Chromaticity set. See table 1.