RECENT EXPERIMENTAL RESULTS ON THE FAST ION INSTABILITY AT THE 2.5 GeV PLS

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Abstract

We report on the recent experimental results on the fast-ion instability at the 2.5 GeV Pohang Light Source (PLS). In order to enhance the fast-ion instability in the PLS, we inserted helium gas to the storage ring in order to increase the vacuum pressure. With the gaps in the bunch train which is large enough to avoid multiturn ion trapping, we observed increase of a factor of 3-4 in the vertical beam sizes for the increased vacuum pressure up to 40 nTorr. The instability growth rate is obtained as a function of vacuum pressure and is also compared with the simulation results.

INTRODUCTION

Fast-ion instability may be an issue in the next generation of electron-positron B factories and damping rings of linear colliders. This is a transient ion instability that is driven by generated ions during single passage of trains. The ions are cleared by a gap at the end of the train. There have been several experimental studies to investigate the fast-ion instability in ALS[1], TRISTAN-AR[2], KEKB[3], PEP-II[4] and PLS[5,6]. The fast-ion instability was observed at first in the 1.5 GeV ALS storage ring with the injection of helium gas into the storage ring. With the vacuum pressure of about up to 80 nTorr, it was shown that the vertical beam size blew up by a factor of 2 to 3. The beam behavior in the ALS was monitored by using a charge-coupled-device (CCD) camera to measure projected beam size and a spectrum analyzer to observe the frequency spectrum. Fast-ion experiments in the 2.0 GeV PLS storage ring showed that bunch size blowup by about $2\sigma_y$ and the amplitude of the beam centroid oscillation by about $0.75\sigma_y$ with the elevated vacuum pressure of about up to 4 nTorr. In these measurements at the PLS, the streak camera to measure the relative beam size in the bunch train and the digitizing oscilloscope to measure the beam centroid were used.

In this paper, we report results on the fast-ion experiments that were recently performed with the elevated vacuum pressure up to 40 nTorr in the 2.5 GeV PLS storage ring. We have measured the coherent beam oscillation by using a turn-by-turn beam position monitor (BPM) in the ring. We estimated the instability growth rates as a function of vacuum pressure. The amplitude of the coherent beam oscillation was also confirmed in interferometer system. The next section shows the results of computer simulation for the fast-ion instability at 2.5 GeV PLS storage ring. Section III describes the experiment setup and shows the results of experiment. Section IV is devoted to the conclusion.

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COMPUTER SIMULATION

We describe a simulation method for studying the beam-ion instability that is based on the weak-strong model[7]. In this method, a weak beam of ions is expressed by macroparticles, while only the barycenter motion of the strong beam is taken into consideration. We neglected the effect of the magnetic field. The interaction between electrons and ions are calculated by the formula of Bassetti and Erskine. The transverse distribution of the beam is assumed to be a rigid Gaussian and thus deformation of the electron beam due to ions is neglected. The incoherent features of ions can be obtained by our simulation, while that of the electron beam, such as emittance growth, can not be computed. The ring was represented by one ionization point. All of the bunches were set with zero displacement. New macroions were generated at the transverse position of the bunch with a Gaussian distribution. We obtained the time evolution of the growth of the dipole amplitude of the bunches, where the amplitude is half of the Courant-Snyder invariant $J_y = (\gamma_y y^2 + 2\alpha_y yy' + \beta_y y'^2)/2$. The growth times are obtained for the different vacuum pressures and are compared with experiment results in the following section.

EXPERIMENT

A He gas injection system was prepared for elevating pressure. At a cell of the storage ring, a manually operated He gas injection nozzle is placed. There are several reasons for the choice of He gas. Physically, the light mass of helium makes sure that the helium gas is cleared by the long bunch gap. Technically, gases such as nitrogen can not be used in PLS due to the non-evaporable-getter (NEG) pumps installed along the ring. The motivation for using helium gas is that the vertical emittance growth from Coulomb scattering is only a few percent effect. In the 2.5 GeV PLS ring, the beam could be stably stored about up to 200 mA with 400 bunches without transverse and longitudinal feedback systems by adjusting temperatures of rf-cavities precisely to cure the coupled-bunch instabilities due to higher order modes. Several diagnostics were prepared for this experiment; the interferometer system to measure the vertical beam size, the He gas injection system and a turn-by-turn BPM to measure the vertical dipole oscillation.

The experimental procedure was to measure the vertical beam size and the coherent dipole oscillation in the bunch train with 400 buckets filled both at nominal and the elevated pressure. Fig. 1 shows the spontaneous dipole oscillations at the elevated vacuum pressure of 39 nTorr measured by the turn-by-turn BPM. The oscillation typically exhibited a growth and damp pattern. In order to obtain a growth rate of the oscillation the growth part was fitted to an exponential function. Furthermore the vertical rms amplitude of the oscillation was calculated and compared with the vertical beam size measured by the interferometer. Figs. 2 and 3 display the vertical rms beam size (reds) and the vertical rms amplitude (blues) as a function of the vacuum pressure and the beam current, respectively. Figs. 2 and 3 show a clear correlation between the beam size and the rms amplitude, and also show that a part of the beam size measured by the interferometer came from the dipole oscillation. Fig. 4 shows the vertical growth rate as a function of the vacuum pressure. Growth rate is linearly increased with the vacuum pressure as predicted by the theory of the fast-ion instability. The damping time at zero pressure, which is obtained by extrapolating the measured growth rate to zero pressure, is about 7.1 ms which is comparable to the radiation damping time of 8.0 ms. Fig. 5 shows the comparison between the measured growth rate and simulated growth rate, where the measured one is the values that the damping time is deducted from the measured growth rate of Fig. 4. The measured and simulated ones show a good agreement. Fig. 6 shows the oscillation of a bunch train that was measured by a streak camera at 58 mA and 40 nTorr. The signal from a oscilloscope in Fig. 7, shows the relative bunch current along the bunch train after fast-ion instability occurred. The beam loss at the rear part of the bunch train means the increasing vertical oscillations along the bunch train.

Table 1: Nominal PLS parameters.

Symbol	Description	Value
E	beam energy	2.5 GeV
C	circumference	280 m
f_{rf}	rf frequency	500.08 MHz
σ_ϵ	rms $\delta E/E$	8.6×10^{-4}
h	harmonic number	468
ϵ_x	horizontal emittance	18.9 nm
ϵ_y	vertical emittance	0.189 nm
α	momentum compaction factor	1.8×10^{-3}
$Q_{x,y}$	tune(x/y)	14.28/8.18
Q_s	synchrotron tune	0.01
τ	Transverse damping time	8.0 ms
σ_z	rms bunch length	8.5 mm

Table 2: Parameters used in our simulation.

Description	Value
electrons/bunch	1.47×10^9
number of bunches	400
average β_x	6 m
average β_y	9 m
β_x spread	5 m
β_x spread	5 m
residual gas	He
ion density(1/m)	1.47 /nTorr

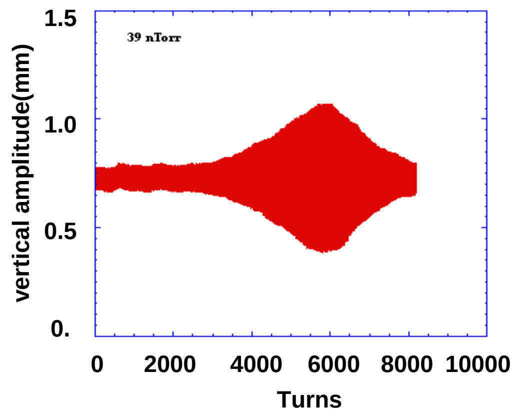

Figure 1: Rms vertical amplitude in turn-by-turn BPM in 39 nTorr.

CONCLUSION

We presented the experiment results on the fast ion instability that were recently performed at the 2.5 GeV PLS storage ring. In the PLS the fast-ion instability is not observed at the normal operating pressure of 0.6 nTor. When 40 nTorr helium gas was added to the vacuum system, the vertical beam sizes that are measured by the interferome-

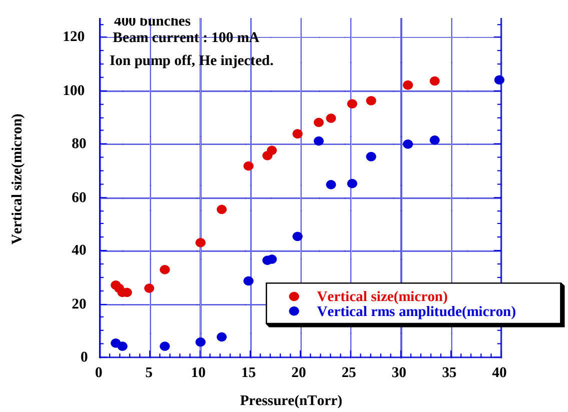

Figure 2: rms vertical size(red) in the interferometer and rms vertical amplitude (blue) in turn-by-turn BPM as a function of vacuum pressure.

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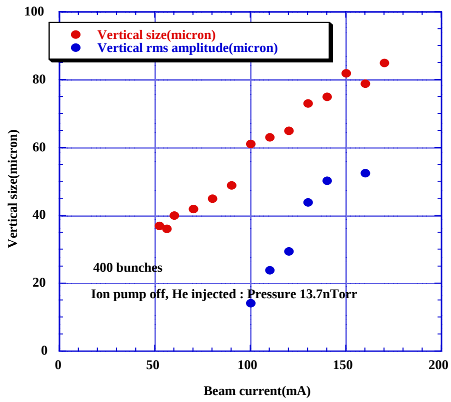

Figure 3: Rms vertical size(red) in the interferometer and rms vertical amplitude (blue) in turn-by-turn BPM as a function of beam current.

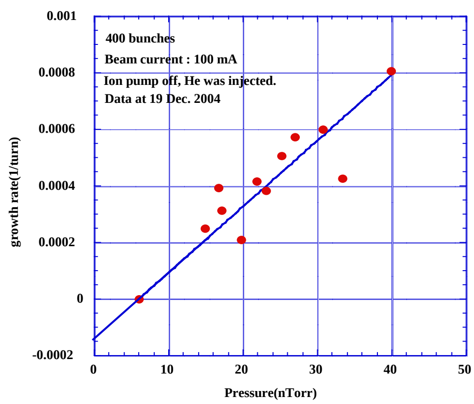

Figure 4: Measured growth rate vs. vacuum pressure.

ter shows increases of a factor of 3-4. The centriod oscillation of the instability was measured by the turn-by-turn BPM and the growth rate of the instability was obtained from the oscillation data as a function of the vacuum pressure. We compared the measured growth rates with those of the computer simulations. The observations show a good agreement with the simulations for the fast-ion instability.

ACKNOWLEDGEMENTS

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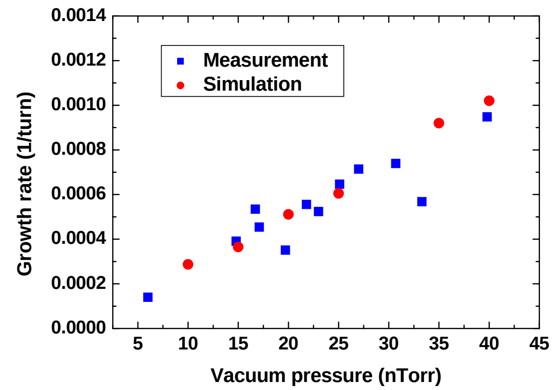

Figure 5: Measured and simulation growth rates vs. vacuum pressure. The measured one is the values that the damping time is deducted from the measured growth rate of Fig. 4.

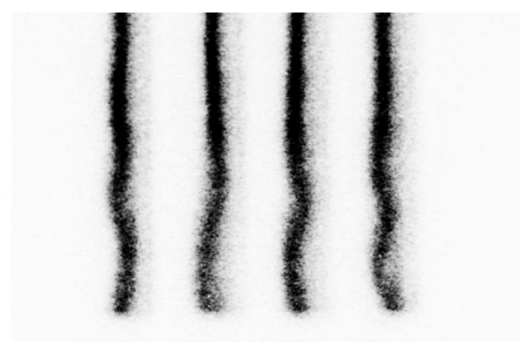

Figure 6: Oscillations of a bunch train with 400 bunches at different times that is shown by streak camera at 58 mA and 40 nTorr.

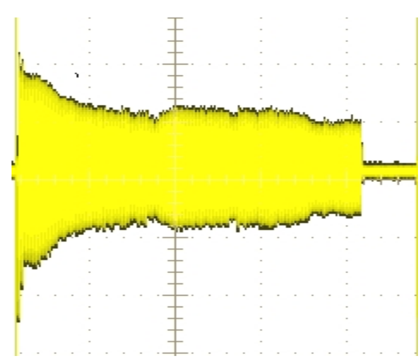

Figure 7: Beam current along a bunch train of 400 bunches. It shows the beam loss at the rear part of the bunch train.