STUDY OF COUPLED BUNCH INSTABILITY CAUSED BY ELECTRON CLOUD IN KEKB POSITRON RING

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Abstract

The transverse coupled bunch instability is experimentally studied in KEKB low energy positron ring (LER). Observed mode spectra and growth rates were compared with results of computer simulation, which simulates the coupled bunch instability caused by the electron cloud. The simulation results are consistent with the experimental observation.

1 INTRODUCTION

Blow-up of the vertical beam size caused by the electron cloud has been observed in KEKB LER. To remove the electron cloud a large number of solenoid magnets were installed in LER [1]. The longitudinal magnetic field at the center of a solenoid is about 45 Gauss.

The electron cloud can cause not only the beam blow-up but also the transverse coupled bunch instability [2]. We measured mode spectra and growth rates of the coupled bunch instability observed in LER. The effect of the electron cloud on the coupled bunch instability was studied by turning on and off the solenoids. The results were compared with simulation assuming that the electron cloud causes the coupled bunch instability.

2 EXPERIMENT

The experiment was carried out at the normal operation where 90% of the ring was filled with a bunch train containing 1153 bunches at 3.5 GeV. The bunch spacing was 8 ns and typical beam current was 600 mA. The bunch oscillation was recorded by the bunch oscillation recorder for 4096 turns after turning off the bunch-by-bunch feedback system. The mode spectra were determined by applying fast Fourier transform (FFT) to turn by turn oscillation data after transforming them into the snapshot data [3]. The growth rate was calculated by fitting the oscillation curve to an exponential function.

The mode spectra observed in horizontal and vertical planes with and without applying the solenoid field are shown in Figures 1 and 2, respectively. When solenoid-off the mode spectrum shows a broad peak at the mode number around 800 both in horizontal and vertical plane. When solenoid-on, where the solenoid field covered about 40% of the ring, the mode spectrum shows a peak near mode 0 both in horizontal and vertical plane. The mode spectra in both planes changed due to the solenoid filed, which suggests the instability are caused by the electron cloud.

The observed growth rates are shown in Fig. 3. When solenoid-off the horizontal and vertical growth rates were 2.0 /ms and 1.3 /ms, respectively. It decreased to 25% horizontally and 20% vertically after installing the solenoids which covered 70 % of the ring.

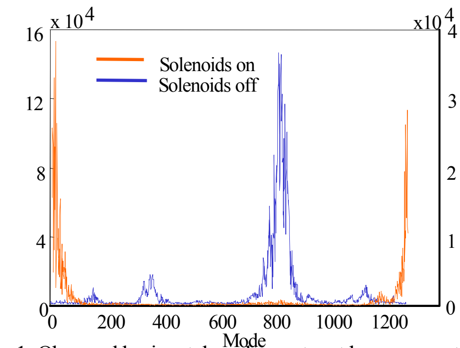

Figure 1: Observed horizontal mode spectra at beam current of 600 mA

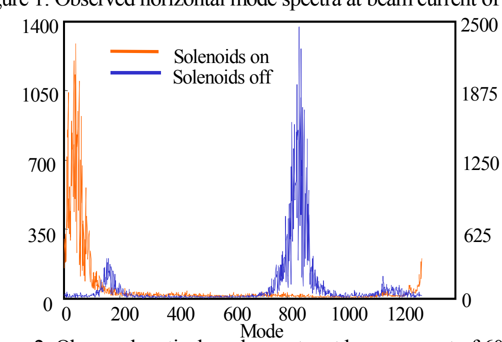

Figure 2: Observed vertical mode spectra at beam current of 600 mA

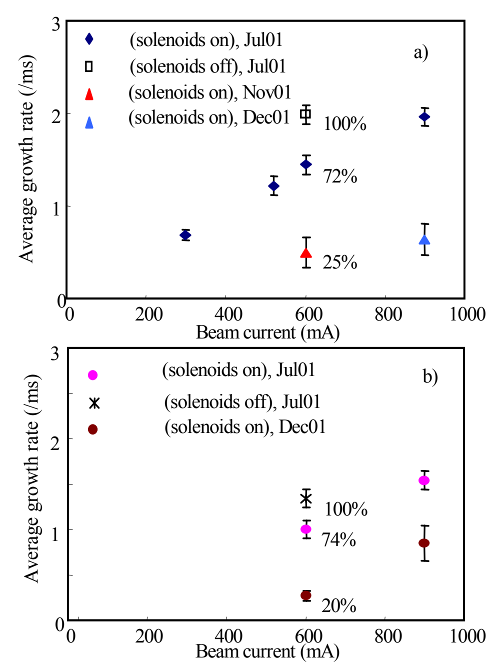

Figure 3: Observed growth rates when solenoid-off and solenoid-on; a) horizontal and b) vertical plane.

3 SIMULATION

The simulation program PEI developed by K. Ohmi [2] was adopted to study the coupled bunch instability due to the electron cloud. The parameters used in the simulation are listed in Table 1. The energy distribution of initial photoelectrons was assumed as Gaussian with mean energy and standard deviation of 10 and 5 eV, respectively. The space charge effect was taken into account in the simulation. The bunch oscillations simulated by the particle tracking in various strengths of the solenoid fields were analyzed by the same procedure as in experimental data analysis to determine the mode spectra. The growth rate was obtained from a wake function calculated by the simulation program.

We assumed two cases for electron production. In case I), the photoelectrons are produced at an illumination point with 30% reflection which means 30% of the photoelectrons are uniformly produced over the surface of the vacuum chamber. In case II), the photoelectrons are produced uniformly over the surface of the vacuum chamber.

Table 1: The parameters used in simulation

Circumference (m)	3016
No. of train/No. of bunches	1/1153
Radius of vacuum chamber (mm)	47
Bunch spacing (ns)	8
Bunch current (mA)	0.52
No. of positrons per bunch	3.3×10^{10}
Average β_x/β_y (m)	10/10
Emittance $\varepsilon_x/\varepsilon_y$ (10^{-8} m)	1.8/0.036
Betatron tune ν_x/ν_y	45.52/43.57
Photoelectron yield	0.1
Secondary electron yield of copper δ_{max}/E_{max} (eV)	1.5/300

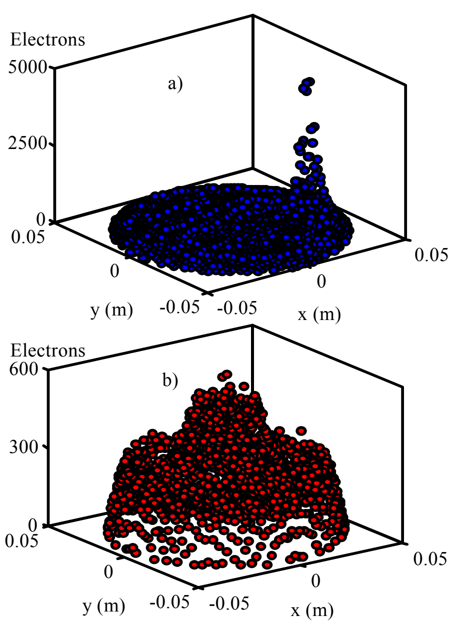

Figure 4: Electron distribution over the cross-section of the vacuum chamber assuming that photoelectrons are produced a) at illumination point with 30% reflection and b) uniformly on the chamber wall.

3.1 MODE SPECTRUM

3.1.1 Mode spectrum in case of solenoid off

The electron density projected over the cross section of the vacuum chamber at the saturation of electron cloud is shown in Fig. 4. Both in case I) and II) the electron density was 9.8 x 10^{11} electrons/m^3 at the saturation of the electron cloud.

The horizontal and vertical mode spectra obtained in case I) without applying solenoid field are shown in Fig. 5. The horizontal mode spectrum shows the peak at mode 200 whose position is different from the experimental observation shown in Fig. 1a. The vertical mode spectrum shows the peak at mode around 1000 and is broader than the experimentally observed one as shown in Fig. 2a. In case II), the horizontal mode spectrum is similar to the vertical mode spectrum as can be seen in Fig. 6. Comparing with Fig. 1a and 2a, each mode spectrum from the simulation in Fig. 6 has a broad peak at mode 800 and

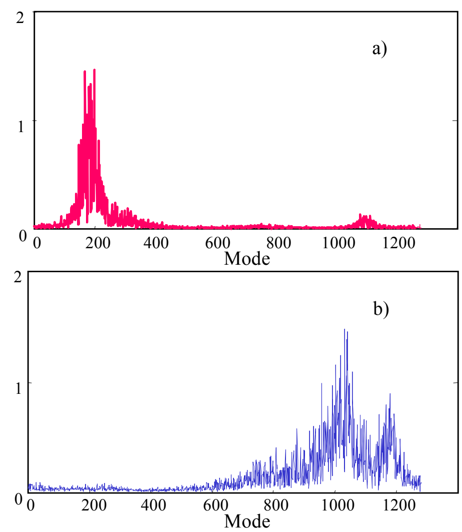

Figure 5: Mode spectra when solenoid-off assuming photo-electrons are produced at the illumination point with 30% reflection; a) horizontal and b) vertical plane.

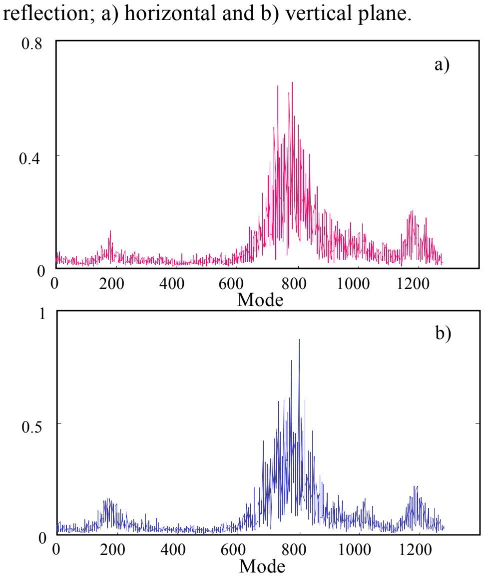

Figure 6: Mode spectra when solenoid-off assuming photo-electrons are produced uniformly on chamber wall;
a) horizontal and b) vertical plane.

small peaks at mode 200 and 1200 which are consistent with the experimental observation.

3.1.2 Mode spectrum in case of solenoid on

The mode spectra were simulated for several strengths of the solenoid field. As the electron cloud distribution changes due to the solenoid field the mode spectrum also changes. In case I), the simulated mode spectrum applying 10 G solenoid filed is consistent with the experimental one both in horizontal and vertical planes as shown in Fig. 7. In case II), the simulated mode spectrum applying 10 G solenoid filed is also consistent with the experimental one both in horizontal and vertical planes as shown in Fig. 8.

3.2 GROWTH RATES

The growth rates calculated using the wake function with and without solenoid field are shown in Table 2 for case I) and II).

When solenoid-off, the simulated horizontal and vertical growth rate is 4 and 65% higher than the experimentally observed value in case I) and 9 and 46% higher than the observed one in case II). While the horizontal growth rate by the simulation is almost same as that observed experimentally, the vertical growth rate by the simulation is about 50% higher than the observed value.

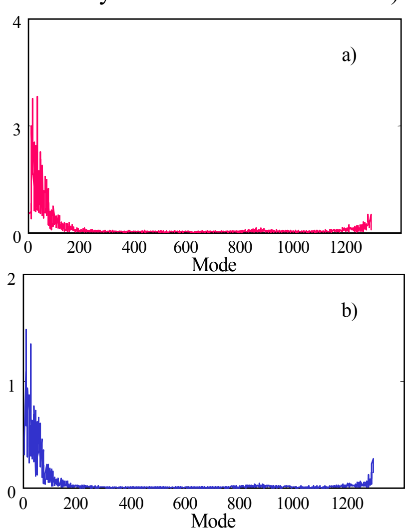

Figure 7: The mode spectra due to 10G solenoid field assuming photoelectrons produced at illumination point with 30% reflection; a) horizontal and vertical plane.

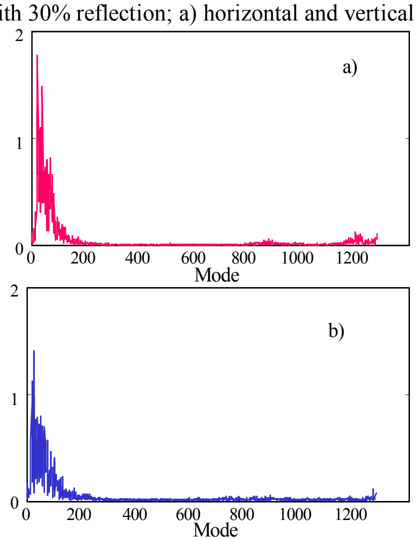

Figure 8: The mode spectra due to 10G solenoid field assuming photoelectrons produced uniformly on the chamber wall; a) horizontal and b) vertical plane.

When solenoid-on, the horizontal and vertical growth rates obtained by the simulation applying the solenoid field of 10 G are approximately same as the experimental values in case I). The difference of simulated growth rates between case I) and II) are less than ±25% for the solenoid fields of 5, 10 and 20 G.

Table 2: Growth rates when solenoid-off and solenoid-on

Growth rate (/ms)		**Horizontal**	**Vertical**
Solenoid-off		2.08[a]	2.21[a]
		2.18[b]	1.96[b]
Experimental data		2.00	1.34
Solenoid field	5 G	1.51[a]	1.03[a]
		1.23[b]	1.36[b]
	10 G	0.55[a]	0.38[a]
		0.50[b]	0.31[b]
	20 G	0.22[a]	0.18[a]
		0.29[b]	0.22[b]
Experimental data		0.49	0.26

a. The photoelectrons are produced at the illumination point with 30% reflection.

b. The photoelectrons are produced uniformly over the surface of vacuum chamber.

4 SUMMARY

When the solenoids are turned off, the simulated horizontal and vertical mode spectra reproduce the experimentally observed ones if the photoelectrons are produced uniformly over the surface of the vacuum chamber. While the simulated horizontal growth rate is almost same as the observed value the simulated vertical growth rate is about 50% higher than the observed one.

When the solenoids are turned on, the simulated mode spectra applying the solenoid field of 5~10 G are consistent with those from the experiment. The simulated growth rates applying solenoid field of 10G are consistent with the experimentally observed values.

The simulation suggests that the electrons are produced uniformly over the surface of the vacuum chamber at least when the solenoids are turned off and the effective solenoid field is 5~20 G to explain the observed mode spectrum and the growth rate of the coupled bunch instability in LER.

REFERENCES

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