ELECTRON CLOUD STUDIES IN SuperKEKB PHASE I COMMISSIONING

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Abstract

Beam size blow-up due to electron cloud has been observed in Phase I commissioning of SuperKEKB. Vacuum chambers in LER (low energy positron ring) were cured by antechambers and TiN coating for electron cloud, though some parts, bellows, were not treated by the coating. In the early stage of Phase I commissioning, beam size blow up has been observed above a threshold current. The blow up was suppressed by weak permanent magnets generating longitudinal field, which cover the bellows. Electron cloud current has been monitored during the commissioning. The thresholds for the electron cloud induced fast head-tail instability have been simulated in the operating beam conditions. Coupled bunch instability caused by electron cloud has been measured before/after installation of the permanent magnets. The measurement and simulation results are presented.

INTRODUCTION

Commissioning of SuperKEKB had been performed from February to June 2016 to test performance as low emittance storage rings. Study of electron cloud effects in the low energy positron ring (LER) was important subject in the commissioning.

It is not too much to say that electron cloud effects are history of KEKB [1–5]. Electron cloud effects had been observed since starting of KEKB in 1999. Vertical beam size blow-up, which is caused by fast head-tail instability due to electron cloud, was one of the most serious issue for achievement of target luminosity $L = 10^{34}$ cm^{-2}s^{-1} in KEKB. Weak solenoid magnets with an axial field $B_z \approx$ 50 G wound whole ring of LER worked to suppress the blow-up of vertical beam size. Peak luminosity $L = 2.17 \times 10^{34}$ cm^{-2}s^{-1} and integrated luminosity 1 ab^{-1} was achieved.

In superKEKB, cure of electron cloud was one of the highest priority issue. Table 1 summerizes parameters of SuperKEKB LER. Antechambers with TiN coating and groove surface are adopted in arc section. TiN coating is applied also in straight section chambers.

Since the start of commissioning, the beam current increased with vacuum scrubbing. Normal bunch filling was by 3 (6ns spacing). The total number of bunches were 1576. Beam size blow up was seen near a total beam current I=600 mA. Electron cloud has been monitored at an Aluminum test chamber w and w/o TiN coating [6].

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Table 1: Parameter List of SuperKEKB LER

	Phase I	Design
Energy (GeV)	4	4
Current (A)	1	3.6
Number of bunch	1576	2500
Bunch population (10^{10})	4-9	9
Emittance H/V (nm)	3/0.03	3/0.003
Bunch length (mm)	6	6

BEAM SIZE BLOW-UP

A systematic study for the beam size blow up was performed on June 2016. Bunch filling is represented by 3 numbers: the number of train/number of bunches in a train/bucket spacing between bunches. Frequency of RF cavity is 508 MHz, thus the bucket is every 2 ns.

Figure 1 shows the vertical beam size, measured via x-ray monitor, as a function of beam current for several bunch filling, 2, 3, 4, 6 bucket spacing, where the total number of bunches is 600. Thresholds of the beam current for each bunch spacing are obtained in the figure. Occurrence of electron multi-pacting was suspected at area near bellows in early stage of commissioning, since the area, which occupies about 5% of whole ring, was not coated by TiN.

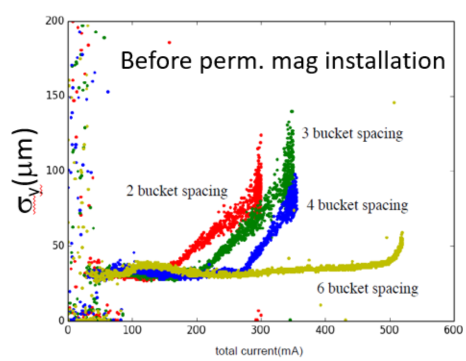

Figure 1: Beam size as function of beam current.

Simulation of electron cloud induced fast head-tail instability has been done using a code PEHTS. Figure 2 shows beam size evolution for various electron density, where the bunch population is 1.6×10^{10}, which corresponds to threshold beam current I=160mA (600 bunches) for 2 bucket spacing. Simulation is carried out during 6,000 turns, where the radiation damping time is 5,000 turns.

The electron density at the bellow area is estimated by measuring density in a test chamber w/o the coating. Figure 3 shows measured electron density at the test chamber. If

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the electrons in the area are dominant, the average electron density of whole ring is 5% of the density at the test chamber.

Table 2 summarizes the threshold current and electron density at the threshold for each bunch spacing. Top 4 lines correspond to the early condition. The density is 5% of measured density, becasue of the length ratio 5%.

The beam size blow up was suppressed by installation of permanent magnets at the bellows area, The magnets produce a axial field ($B_z \sim 100$ G) at the chamber surface effectively. Figure 4 shows measured beam size after installation of the magnets. Threshold of beam size blow-up is 330mA for 3 bucket spacing and higher than 600mA for 4 bucket spacing. Lower 3 lines in Table 2 shows the threshold current and electron density. The density is measured at the test chamber with TiN coating.

Phase II targets collision with positron current, 1A for 1000-1560 bunches. The beam size blow-up must be safe at the target current for 3-4 bucket spacing.

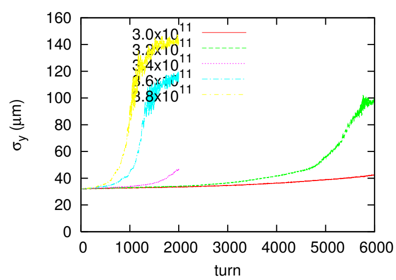

Figure 2: Beam size blow-up in simulation PEHTS.

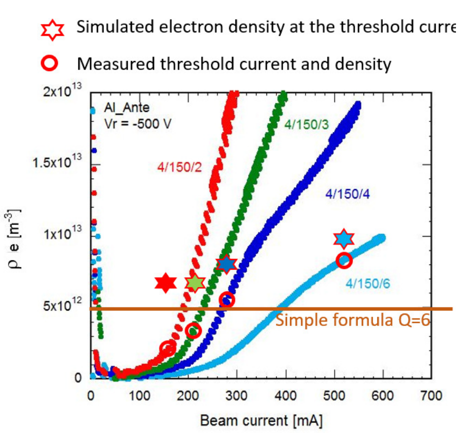

Figure 3: .Electron density

COUPLED BUNCH INSTABILITY DUE TO ELECTRON CLOUD

Coupled bunch instability caused by electron cloud was measured in bunch filling with 2, 3 and 4 bucket spacing. Figure 5 shows unstable mode spectra for 2 bucket spacing at beam currents, I=300mA and 400mA. Unstable modes appear at slightly right of the filling harmonics at I=300mA. These modes are characteristic for electrons moving in solenoid (axial) field. While unstable modes appear

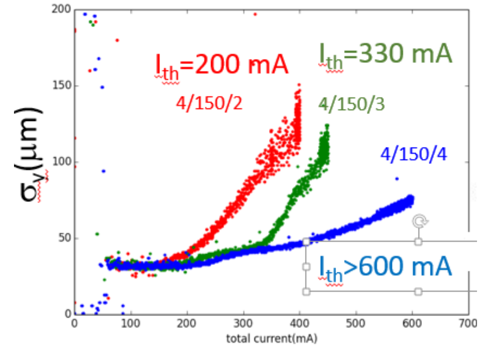

Figure 4: Measured vertical beam size after permanent magnet installation.

Table 2: Summary of Threshold of Beam Size Blow-up

$N_{p,th}$ 10^{10}	$\omega_e\sigma_z/c$	$\rho_{e,sim}$ 10^{11}	$\rho_{e,mon}$ m^{-3}	spacing	$I_{p,th}$ mA
1.6	7.7	3.2	1.1	2	160
2.1	8.9	3.2	1.6	3	200
2.7	10.1	3.6	2.7	4	260
5.2	14.0	4.6	4.1	6	500
2.1	8.9	3.4	2.5	2	200
3.65	11.5	3.8	3.0	3	350
>6.25	15.3	4.2	<2.0	4	>600

at left of 400-700 revolutions at I=400mA. These mode are caused by electrons moving in drift space.

Figure 6 shows relation of unstable modes and their growth time for various filling patterns and beam currents after installation of the permanent magnets. For 4 bucket spacing, the unstable modes are caused by electrons from solenoid origin in $I = 350$ and 600 mA. Electron cloud is well controlled for 4 bucket spacing, but electrons produced at drift area dominate in 2 bucket spacing. These results may be related to the seriousness of the beam size blow-up in the narrow bunch spacing, and may indicate difficulties for control of electron cloud in the narrow bunch spacing.

TUNE SHIFT DUE TO ELECTRON CLOUD

Electron cloud causes a positive tune shift due to the attractive force. Tune shift depends on the electron density and distribution. For static round charge distribution, tune shift is expressed by

$$\Delta\nu_x = \Delta\nu_y = \frac{\rho_e r_e \langle\beta_{x,y}\rangle}{2\gamma} C \qquad (1)$$

For flat distribution along x,

$$\Delta\nu_x = 0, \qquad \Delta\nu_y = \frac{\rho_e r_e \langle\beta_{x,y}\rangle}{\gamma} C \qquad (2)$$

Transverse tune was measured along the bunch train for 3 bucket spacing filling. Figure 7 shows horizontal (top)

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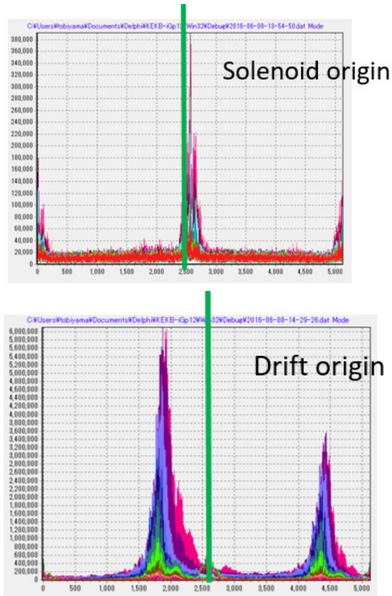

Figure 5: Mode spectra for I=300 (top) and 400 (bottom) mA at 2 bucket spacing.

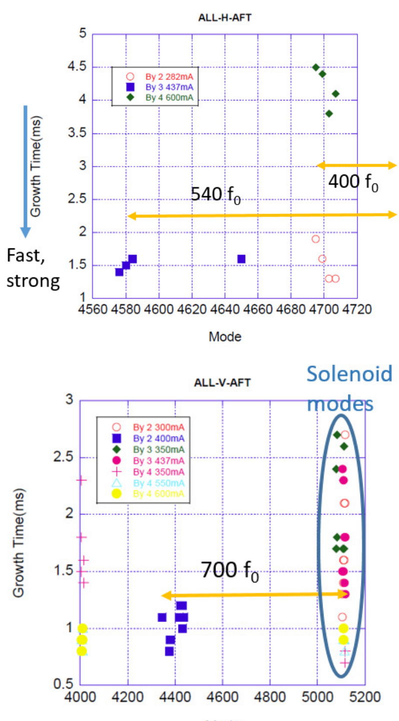

Figure 6: Unstable mode and growth time for various current and filling. Top and bottom are horizontal and vertical, respectively.

and vertical (bottom) tune of bunches at 0, 150,300,450-th bucket.

The horizontal tune shift depends on the beam current, $\nu_x = 0.003$ for $I = 400$ mA and $\nu_x = 0.001$ for $I = 300$ and 400 mA. The horizontal tune shift seems to be ambiguous. The vertical tune shift is $\nu_y = 0.005$. The electron density

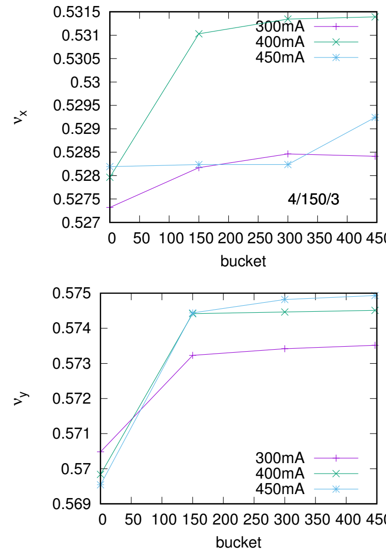

Figure 7: Tune shift along bunch train for 3 spacing filling.

is estimated $\rho_e = 4 \times 10^{11}$, if only the vertical tune shift is considered. For $\nu_x + \nu_y = 0.006 - 0.008$, the density is $\rho_e = 5 - 6 \times 10^{11}$ m^{-3}. The density is in good agreement with that directly measured in the test chamber with/without TiN coating.

CONCLUSION

Phase I commissioning of SuperKEKB was done during Feb to June, 2016. Study of electron loud effects was one of the highest priority issue. Electron production and density was measured. Fast head-tail instability due to electron cloud was observed at predicted density, and was suppressed by axial field in uncoated bellow area of TiN as expected. Coupled bunch instability has been observed as predicted including the behavior on axial (solenoidal) field/drift. Tune shift was consistent with the threhsold value of the electron density.

Threshold current is higher than 1A in 3-4 bucket spacing. It is target current for Phase II commissioning, in which beam-beam collision starts. Further improvements in the vacuum system have been done toward Phase II,III [7].

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