# SIMULATION STUDY OF COUPLED-BUNCH INSTABILITY DUE TO ELECTRON CLOUD IN SUPER KEKB

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*Abstract*

Super KEKB is an upgrade plan of KEK B factory. It aims at luminosity of $1\sim5\times10^{35}$ cm$^{-2}$sec$^{-1}$. To achieve the design luminosity a low and high energy ring will store the beam current of 9.4 and 4.1 A, respectively. The coupled-bunch instability caused by the electron cloud generated by such a large beam current may be an issue for stable operation of the machine. In this paper we present the result of simulation study of the coupled-bunch instability caused by the electron cloud in Super KEKB.

## INTRODUCTION

KEKB has achieved the peak luminosity up to $1.2\times10^{34}$ cm$^{-2}$s$^{-1}$ with the positron beam current of 1.6 A in low energy ring (LER) and the electron beam current of 1.16 A in high energy ring (HER). As the upgrade plan, Super KEKB is aimed at $10^{35}$ cm$^{-2}$sec$^{-1}$ with a beam current of 4.1 A in HER and 9.4 A in LER. The synchrotron radiation is, therefore, much stronger than KEKB. To reduce the photoelectron production due to very high intensity of synchrotron radiation, ante-chambers are to be adopted in both HER and LER [1]. The measures taken to reduce the electron cloud instability will include not only the use of the ante-chamber but also the application of solenoid field to suppress the electrons.

The positron beam is planned to be stored in the HER of 8.0 GeV since there is a possibility of reduction in the electron cloud instability due to its high beam energy while primary photoelectron production is about the same for the operation with 4.1 A at 8.0 GeV or with 9.4 A at 3.5 GeV. However, it is necessary to study how much the electron density would be reduced because the secondary production may be dominant in the ante-chamber. And it is also important to estimate the coupled-bunch instability in solenoid field for 8.0 GeV and 3.5 GeV [2].

Therefore, we performed a computer simulation to estimate the coupled-bunch instability which would be experienced in Super KEKB due to the electron cloud formation in the solenoid field for 8.0 GeV and 3.5 GeV. We present the simulation study of the expected coupled-bunch instability at super KEKB in this paper.

## SIMULATION

For the simulation study we use a code named PEI [3]. The parameters used in the simulation are listed in Table 1. Due to the application of the ante-chambers the production of photoelectron is reduced. Therefore, the photoelectrons are assumed to be produced uniformly at the wall of the chamber with the photoelectron yield of 0.01.

As listed in Table 1, the secondary electron production model is assumed that the secondary electron yield $\delta$ is a step function of the primary electron energy $E_{p.e}$. Namely if $E_{p.e}$ is smaller/larger than $E_{thres}$, $\delta$ is $0/\delta_{max}$.

Table 1: The parameters used in the simulation

| | HER | LER |
|---|---|---|
| Beam energy (GeV) | 8.0 | 3.5 |
| Circumference (m) | 3016 | 3016 |
| Radius of vacuum chamber[a] (mm) | 40.3 | 45.0 |
| Beam current (mA) | 4100 | 9400 |
| Number of bunches | 5018 | 5018 |
| Bunch spacing (ns) | 2 | 2 |
| Number of positrons/bunch | $5.14\times10^{10}$ | $1.17\times10^{11}$ |
| Photoelectron yield[b] | 0.01 | 0.01 |
| Average $\beta_x/\beta_y$ (m) | 10/10 | 10/10 |
| Emittance $\varepsilon_x/\varepsilon_y$ (nm) | 24.0/0.18 | 22.0/0.44 |
| Betatron tune $\nu_x/\nu_y$ | 44.51/41.57 | 45.51/43.55 |
| Initial photoelectron energy (eV) | 10 ± 5 | 10 ± 5 |
| Secondary electron yield $\delta_{max}/E_{thres}$ (eV) | 1.5/100<br>1.5/200<br>1.5/300 | 1.5/100<br>1.5/200<br>1.5/300 |

[a]Radius of the circular pipe having equivalent circumference to the ante-chamber.

[b]The use of the ante-chamber will reduce the amount of photoelectrons. Therefore, the photoelectron yield is assumed to be 0.01.

Without solenoid field the electron cloud density reaches its saturation after the passage of about 150 bunches. The electron cloud density in 8.0 GeV is $1.9\times10^{13}$ m$^{-3}$ while it is $2\times10^{13}$ m$^{-3}$ in 3.5 GeV as shown in Figure 1 a).

In 60 G solenoid field, the electron cloud density is still increasing after the passage of about 500 bunches as shown in Figure 1 b). The electron cloud density in 8.0 GeV is $7.4\times10^{11}$ m$^{-3}$. In LER after 150 bunches the electron cloud density is higher. However, after 200 bunch passage the density decreases and slowly increases further up to $7.1\times10^{11}$ m$^{-3}$.

In this simulation we use the step function in the secondary electron production model. Figure 2 shows the electron cloud density at the beam energy of 8.0 GeV with various threshold energies of secondary electron production. Although the build-up time is about the same, as can be seen in Figure 2, the saturated electron density

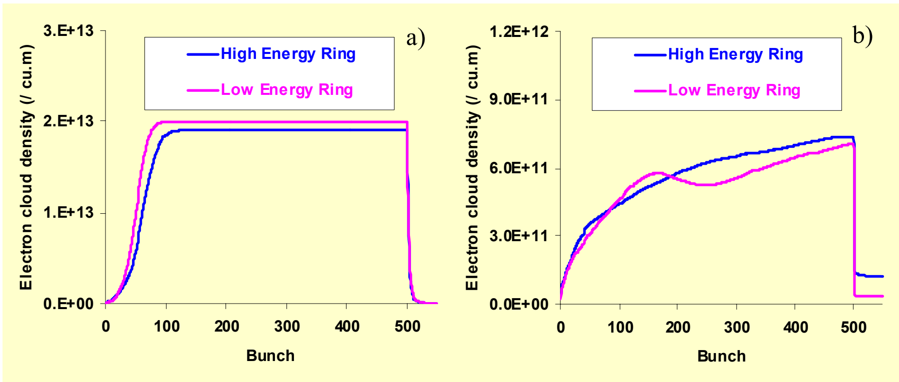


Figure 1: Electron cloud density at positron energy of 8.0 GeV and 3.5 GeV

depends on the threshold energy of the secondary electron production. Therefore, the secondary electron production model will be modified to more realistic model in future study.

Figure 3 a) and b) show the electron distributions in 8.0 GeV and in 3.5 GeV without solenoid field. The electron cloud is concentrated at the center of the chamber. In the solenoid field the electrons are localized near the wall. The electron distributions in 60 G solenoid field at the beam energy of 8.0 GeV and 3.5 GeV are shown in Figure 3 c) and d). The distribution is like a donut and the thickness is about 8 mm.

The coupled-bunch bunch oscillation due to the electron cloud is calculated by the tracking. The growth rate of the coupled-bunch instability is estimated by the exponential curve fitting to the growth part of the bunch oscillation.

Figure 4 a) and b) show the bunch oscillations in the horizontal and vertical planes at the beam energy of 8.0 GeV in 60 G solenoid field, respectively. The bunch oscillations at the beam energy of 3.5 GeV are shown in Figure 4 c) and d) for the horizontal and vertical directions in 60 G solenoid field. The amplitude of the bunch oscillation is larger in the LER than in the HER. In 60 G solenoid field, the growth rate of the coupled-bunch instability is about 10 $ms^{-1}$ for 8.0 GeV and is about 22 $ms^{-1}$ for 3.5 GeV.

The wake force experienced by a bunch train when it passes through the electron cloud is calculated after passing 200 bunches. The 201st bunch is slightly displaced in its transverse position when passing through the electron cloud and disturbs the electron cloud. The successive bunches experience a wake force due to a disturbed electron cloud [3].

Figure 5 a) and b) show the vertical wake force without solenoid field for the beam energy of 8.0 GeV and 3.5 GeV, respectively. The short-range wake force is seen in both beam energies of 8.0 GeV and 3.5 GeV. In 60 G solenoid field, a long-range wake field is seen in both beam energies as shown in Figure c) and d). At the energy of 3.5 GeV the wake force is stronger than the case when the beam energy is 8.0 GeV. The long-range wake force in the solenoid field might be cause of large growth rate of the coupled-bunch instability.

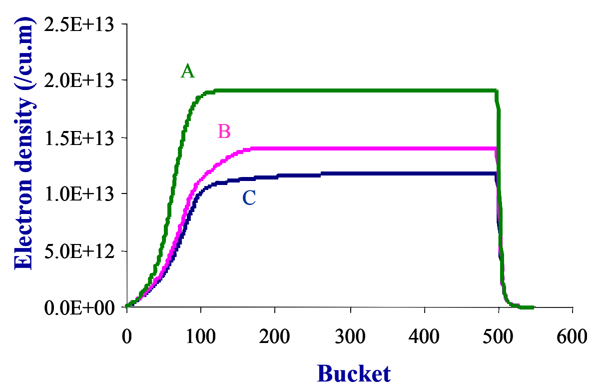


Figure 2: The electron cloud density depends on threshold energy of the secondary electron production; A: 100 eV, B: 200 eV, and C: 300 eV

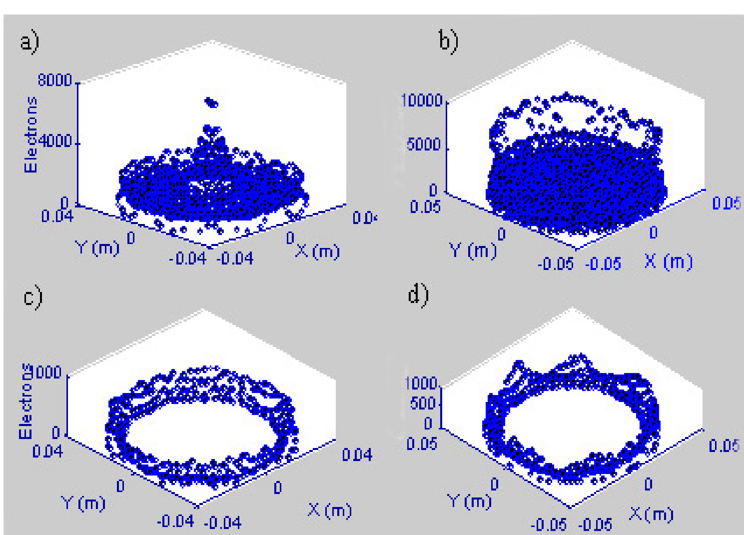


Figure 3: Electron distribution; a) at 8.0 GeV without solenoid field, b) at 3.5 GeV without solenoid field, c) at 8.0 GeV in 60 G solenoid field, and d) at 3.5 GeV in 60 G solenoid field.

## SUMMARY

In this paper we compare the coupled-bunch instability caused by the electron cloud in Super KEKB between HER at 8.0 GeV and LER at 3.5 GeV by computer simulation when solenoid field is applied.

The electron cloud density at electron saturation in HER and LER is about $2\times10^{13}$ $m^{-3}$ without solenoid field. In 60 G solenoid field, the electron cloud density is about $7.4\times10^{11}$ $m^{-3}$ in HER and about $7.1\times10^{11}$ $m^{-3}$ in LER. The growth rate of the coupled-bunch instability in 60 G solenoid field is as fast as 10 ~ 22 $ms^{-1}$. The growth rate in LER is larger than that in HER, which may be due to the lower beam energy of LER. The growth rates of the coupled-bunch instability in HER and LER are larger than a target value of the damping rate of the bunch-by-bunch feedback system. The large growth rates in 60 G solenoid field may be caused by the trapped electrons by the solenoid field [4]. An experiment and a further simulation are necessary to study whether the trapped electrons really cause the strong coupled-bunch instability or not.

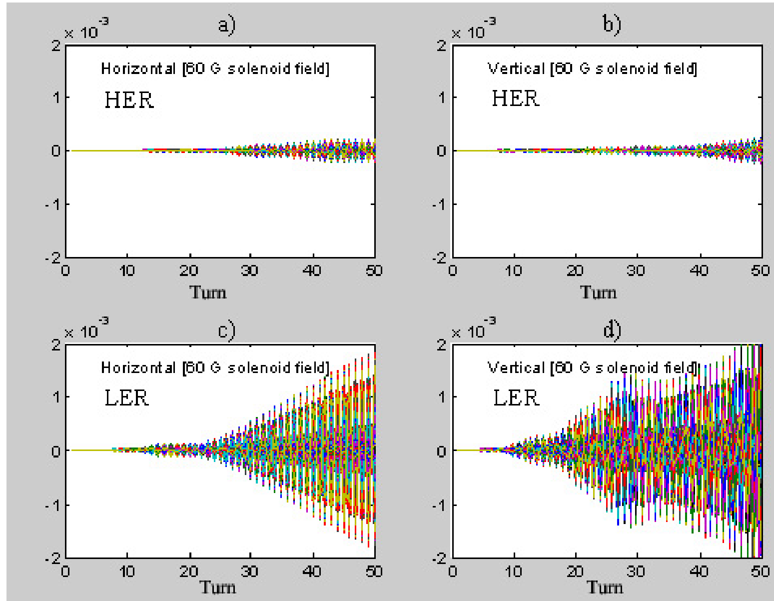


Figure 4: Positron bunch oscillations in 60 G solenoid field; a) in horizontal plane at 8.0 GeV, b) in vertical plane at 8.0 GeV, c) in horizontal plane at 3.5 GeV, and d) in vertical plane at 3.5 GeV. (Y-axis of the figures show the amplitude of oscillation in m)

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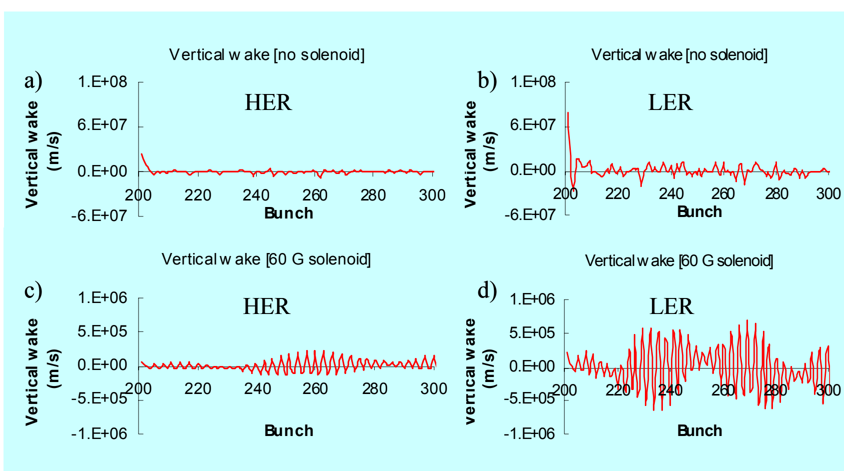


Figure 5: Vertical wake force; a) at 8.0 GeV without solenoid field, b) at 3.5 GeV without solenoid field, c) at 8.0 GeV in 60 G solenoid field, and d) at 3.5 GeV in 60 G solenoid field.