SIMULATION STUDY OF THE ELECTRON CLOUD INSTABILITY IN SUPERKEKB

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Abstract

A simulation of a build-up of an electron cloud in SuperKEKB was done by a program CLOUDLAND. Average electron density and electron density at the center of a vacuum chamber were calculated in a drift space and in various magnetic fields. The result shows that a solenoid field is very effective in reducing the electron density and the simulated electron density is below the threshold electron density of the strong head-tail instability by the electron cloud if solenoids are installed in the drift space.

INTRODUCTION

Photoelectrons produced by synchrotron radiation and secondary electrons produced by impinging electrons on a chamber wall form an electron cloud in positron storage rings. The interaction between the electron cloud and a beam leads to the single- and multi-bunch instability named the electron-cloud instability(ECI). Above all a beam blowup caused by the strong head-tail instability is one of the most important issues faced at existing B factories. In SuperKEKB[1] which is an upgrade plan of the KEK B factory, so called an energy switch where a positron beam will be stored not in the low energy ring(LER) but in the high energy ring(HER) is considered after LINAC upgrade to mitigate the ECI. Ante-chambers to be installed will be also effective to reduce the number of electrons because the synchrotron radiation which creates the photoelectrons hits photon-stops away from the beam. Nevertheless the ECI might be an issue of SuperKEKB because large beam current of 4.1A will be stored with a short bunch-to-bunch interval of 2ns. It is important to study the electron cloud build-up not only in a drift space but also in magnetic fields because the motion of the electrons is greatly affected by the magnetic fields. In this paper we will present the result of a simulation of the electron cloud build-up especially in magnetic fields and its effect on the beam blowup.

SIMULATION

Since the build-up of the electron cloud is very complicated process it has been studied mainly by numerical simulations. To evaluate the electron cloud in SuperKEKB we used a simulation program CLOUDLAND[2]. Table 1 shows parameters used in the simulation. We assumed that the positron beam is stored in the HER and primary electrons are generated uniformly around a chamber wall supposing that the ante-chambers work well to reduce the number of the photoelectrons. Since we have no reliable way to estimate how many primary electrons are produced on the chamber wall of the ante-chamber, we provisionally assume that the number of the primary electrons is 1% of the number of photons which are emitted by the synchrotron radiation. A secondary electron yield for elastically reflected electrons is assumed to be 0. Figure 1 displays the electron distribution in a drift space and in various magnets at the end of a bunch train. In the drift space the electron density at the center of the vacuum chamber is very high. In a quadrupole magnet some electrons are trapped by mirror fields as shown in Fig. 2. Most trapped electrons are away from the center of the chamber. In a dipole magnet strong multipacting which produces two strips of the electrons is seen and average electron density in the chamber amounts to 2×10^{13} m^{-3} though the electron density at the center of the chamber is as small as 6×10^{11} m^{-3}. In a solenoid magnet most electrons stay near the chamber wall. Figure 3 shows the average electron density in the chamber and the electron density at the center of the chamber along the

Table 1: Parameters used in a simulation of electron cloud build-up.

Beam energy(GeV)	8
Bunch spacing(ns)	2
Number of particles in a bunch	$5.2 \; 10^{11}$
Chamber radius(mm)	37
Maximum secondary emission yield	1.5
Energy at maximum secondary yield(eV)	250
Number of bunches	200
Number of train	1
Primary electron yield	0.01
rms bunch length(mm)	3
Horizontal emittance(m)	$2.4 \; 10^{-8}$
Vertical emittance(m)	$4.8 \; 10^{-10}$
Average horizontal beta function (m)	10
Average vertical beta function (m)	10

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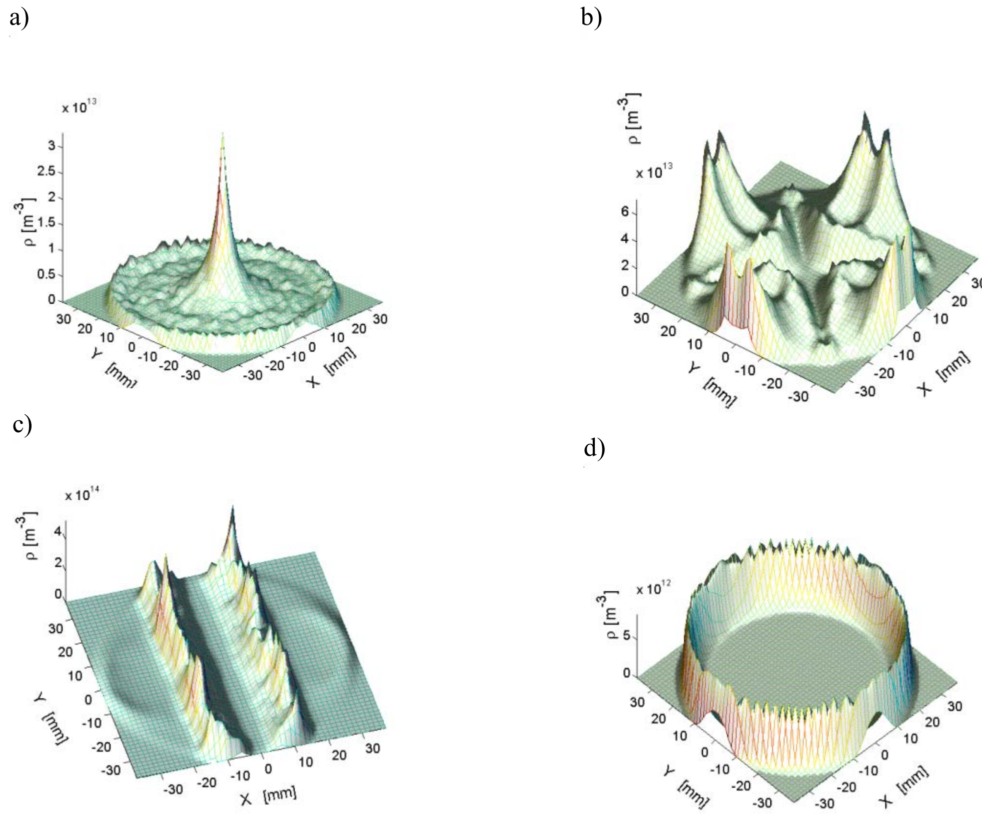

Figure 1: Distribution of the electrons in various places in the ring; a) drift space, b) qadrupole magnet, c) dipole magnet, d) solenoid.

train in the solenoid magnet. Some electrons are trapped in the solenoid field, but most trapped electrons are near the chamber wall. Table 2 summarizes the simulated average electron density in the chamber and the electron density at the center of the chamber in various places in the ring. The results are summarized as

1) the solenoid field of 60G is very effective to reduce the electron density at the center of the chamber in the drift space where very large numbers of electrons are seen in the absence of the solenoid field,
2) a considerable number of the electrons stay inside the dipole and the quadrupole magnet on average over the volume of the chamber and
3) the electron density at the center of the chamber is less than 6 x 10^{11} m^{-3} in the magnetic fields considered here.

DISCUSSION

A theory by K. Ohmi and F. Zimmermann[3] shows that the strong head-tail instability occurs if a condition

$$\int_0^L \rho \cdot ds > \frac{2\gamma\nu_s}{\pi r_e \beta_y} \qquad (1)$$

is satisfied, where ρ is the electron cloud density, s the obit length, ν_s the synchrotron tune, β_y the average vertical beta function, L the total length of the ring and γ is the Lorenz factor of the beam. The right side of the Eq.(1) is estimated to be 4.5 x 10^{15}m^{-2} from beam parameters of SuperKEKB. Using ρ's in Table 2, $\int_0^L \rho \cdot ds$ is calculated to be 0.6 x 10^{15}m^{-2} which is below the threshold integrated electron density of the strong head-tail instability.

A betatron tune shift by the electron cloud is given by[4]

$$\Delta\nu_{x,y} = \frac{r_e \cdot \beta_{x,y} \cdot \int_0^L \rho \cdot ds}{2\gamma}. \qquad (2)$$

Using 0.6 x 10^{15}m^{-2} for $\int_0^L \rho \cdot ds$, $\Delta\nu_{x,y}$ is estimated to be as small as 0.0005.

In the simulation several uncertain assumptions were used about the electron distribution on the chamber wall in the ante-chamber, the amount of the primary electrons in the ante-chamber and elastically reflected electrons. We need refinements to the above-mentioned input parameters to obtain more reliable estimations. Moreover behavior of the electron cloud inside the magnets is not studied much experimentally for the positron beam. Further experimental study is necessary to justify the result of the simulations.

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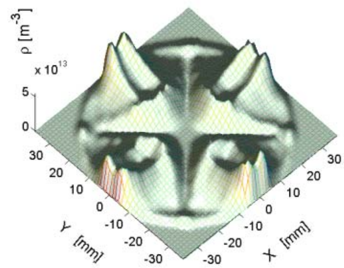

Figure 2: Distribution of the electrons in the quadrupole at 40ns after the last bunch in the train passed the electron cloud.

The simulation shows that a substantial number of the electrons stay inside the dipole and quadrupole magnets. Though these electrons will not contribute to the blow-up because of small electron density at the center of the chamber, they may cause the coupled bunch instability(CBI)[5]. The estimation of the strength of the CBI will be also studied in future. The simulation study of the electron cloud build-up, the strong head-tail instability and the CBI in the LER is also necessary to justify the energy switch of the SuperKEKB[6].

As the simulation shows that the solenoids are very effective to reduce the electrons, the vacuum chambers in the drift space of the SuperKEKB will be covered by solenoid winding. Table 3 shows tentative parameters of a solenoid system. The solenoids will be installed both in the LER and the HER because the positron beam will be stored in the LER at the early stage of the operation then stored in the HER after LINAC upgrade.

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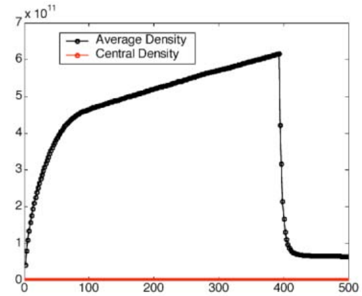

Figure 3: Average electron density and the electron density at the center of the chamber inside the solenoid in m^{-3}. Horizontal axis is time along the train in unit of ns. Even 400ns after the train passed the electron cloud some electrons are trapped.

[6] K. Ohmi, "RECENT DEVELOPMENTS IN DESIGNS FOR e^+e^- COLLIDERS", PAC'03, Portland, May 2003, p. 345.

Table 2: Average electron density in the vacuum chamber and electron density at the center of the vacuum chamber in drift space and in various magnetic fields.

	Field strength	average ($10^{12}m^{-3}$)	at chamber center ($10^{12}m^{-3}$)
Drift space	-	1.0	-
Bend	0.25(T)	20.0	0.6
Quad	10.3(T/m)	8.4	0.46
Solenoid	60(G)	0.61	0.0

Table 3: Main parameters of solenoid system.

	LER	HER
Field strength(G)	60	60
Current(A)	3.8	3.8
Diameter of wire(mm)	1.6	1.6
Layers of winding	2	2
Total length of solenoid(m)	2470	1850
Total turns of winding(10^6)	3.09	2.31
Resistance of wire(kΩ)	13.1	9.1
Dissipated power(kW)	189	131