SIMULATION OF THE ELECTRON CLOUD INSTABILITY FOR BEPCII*

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Abstract

Electron Cloud Instability (ECI) may take place in positron storage ring when the machine is operated with multi-bunch positron beam. According to the actual shape of the vacuum chamber in the BEPCII, a program has been developed. With the code, we can get the electron density in the chamber with different widths of the antechamber and the different secondary electron yields, respectively. The possibility to put clearing electrodes in the chamber to reduce the electron density in the central region of the chamber is also investigated. Based on the head tail model we simulate the single bunch instability induced by electron cloud in BEPCII. For BEPCII the threshold density is estimated to be ~$10^{12}m^{-3}$ and bunch blow up can be suppressed by increasing chromaticity.

INTRODUCTION

It is clear that the ECI (electron cloud instability), first identified by Izawa et al at Photo Factory [1], can be seriously detrimental for other positive charged, high current, multi-bunch beams. The observation on beam size blow up showed that the electron cloud also causes the single bunch instability [2]. Many restrain methods for suppression, such as antechamber, TiN coating in the vacuum pipe, photon absorber, clearing electrodes, have been suggested. The Beijing Electron Positron Collider will be upgrade to a double-ring machine and enhance the luminosity to $10^{33}cm^{-2}s^{-1}$. The ECI is suspected to occur in positron ring and influence the luminosity performance of the collider. Some restraining methods including antechamber, TiN coating and photon absorber have been adopted in the design. A code has been developed, based on the physical model purposed by K. Ohmi [3], to simulate the ecloud density under different restrain conditions. We also study the possibility of beam blow up in BEPCII based on the head tail model.

Table 1: Parameters of the BEPCII

Variable	BEPCII
Beam energy E(GeV)	1.89
Bunch population $N_b(10^{10})$	4.84
Bunch spacing L_{sep}(m)	2.4
Rms bunch length σ_z(m)	0.015
Rms bunch sizes $\sigma_{x,y}$(mm)	1.18,0.15
Chamber half dimensions $h_{x,y}$(mm)	60,27
Slippage factor η (10^{-3})	22
Synchrotron tune Q_s	0.033
Tune $Q_{x,y}$	6.53,7.58
Circumference C(km)	0.24
Average beta function(m)	10

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ELECTRON CLOUD

We only consider two main sources of electrons, namely: (1) photoelectrons arising from the synchrotron radiation hitting the wall of the vacuum chamber, and (2) secondary emission from electrons hitting the walls. The number of photons due to the synchrotron radiation emitted by a positron per meter is expressed by

$$N_\gamma = \frac{5\pi}{\sqrt{3}\,C}\alpha\gamma \tag{1}$$

where α, γ and C are the fine structure constant, the relativistic factor, and the circumference of the ring, respectively. Because of antechamber, only ~0.5% photons remain inside the chamber. Photoelectrons are produced in the chamber and antechamber by the photons hitting on the wall with a quantum efficiency Y~0.1 and reflectivity R~80%. If there is photo absorber, the Y and R will be much smaller [4], Y~0.02, R~10%. The percentage of photoelectron escaping out of the antechamber depends on the width of antechamber. The beam field is presented by B-E formula [5] and the solver of Poission-Superfish in the central region of $(10\sigma_x, 10\sigma_y)$ and out of the region. Electrons accelerated by the beam field strike the chamber surface and yield the secondary electrons. The SEY (secondary electron yield) depends on the material, electron incident angle and energy. The formula for calculation on SEY can be expressed as,

$$\delta(E,\theta) = \delta_{\max} \cdot 1.11 \cdot \left(\frac{E}{E_{\max}}\right)^{-0.35} \cdot \left\{1 - \exp\left[-2.3 \cdot \left(\frac{E}{E_{\max}}\right)^{1.35}\right]\right\} / \cos\theta \tag{2}$$

where θ, E are incident angle and energy; $\delta_{\max}$ the maximal secondary yield depending on the material; $E_{\max}$ the electron incident energy responding to $\delta_{\max}$, with TiN coating $\delta_{\max} \approx 1.06$, without coating $\delta_{\max} \approx 1.8$.

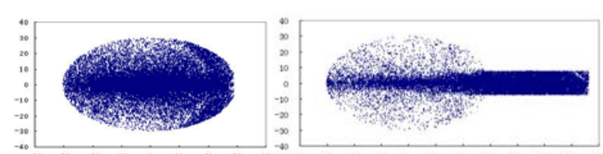

Figure 1: Ecloud distribution in the chamber.
(left: elliptic chamber, right: antechamber)

The electron cloud distribution is much different with or without antechamber and the central ecloud density can differ about 5 times.

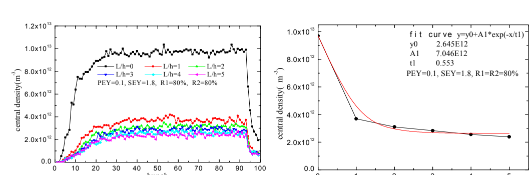

Figure 2: Ecloud density with different width of antechamber.

The simulation for the effect on SEY shows that secondary electrons multipacting is serious in BEPCII. After $\delta_{max} > 1.6$, ecloud density increases quickly. Thus TiN coating is necessary for reducing ecloud density.

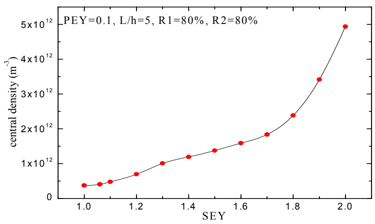

Figure 3: Ecloud density with different secondary yield.

Placing two electrodes at the entrance of the antechamber can attract more electrons to the edge of the chamber and reducing the central density. The simulation shows the relations between clearing voltage with ecloud central density in Fig. 4. We also simulated the ecloud density in different restraining methods and the results were summarized in table 2.

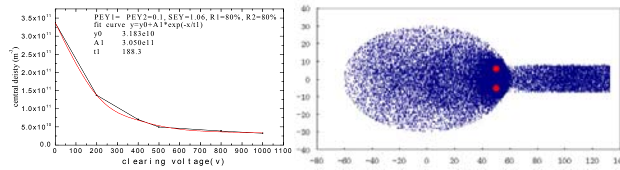

Figure 4: Ecloud density in different clearing voltage.

Table 2: Summary of the ecloud density in different restraining methods

Restraining methods	L/h	PEY(Y)	R	SEY(δ_{max})	ρ (m^{-3})
none	0	0.1	80%	1.8	1.035×10^{13}
Antechamber only	5	0.1	80%	1.8	2.220×10^{12}
TiN coating only	0	0.1	80%	1.06	1.856×10^{12}
antechamber and TiN coating	5	0.1	80%	1.06	3.261×10^{11}
antechamber and photon absorber	5	0.02	10%	1.8	7.188×10^{11}
antechamber, photon absorber and TiN	5	0.02	10%	1.06	1.355×10^{11}
antechamber and clearing electrodes	5	0.1	80%	1.8	3.748×10^{11}
antechamber, clearing electrodes and TiN	5	0.1	80%	1.06	3.334×10^{10}

COUPLED BUNCH INSTABILITY

The coupled bunch instability may occur in BEPCII. Based on the ecloud density calculated in part two, we use tracking method to simulate the motion of 93 bunches in a train and in every turn their positions were recorded. The growth time can be obtained by fitting the amplitude of the oscillation, $\tau_x \approx 0.4ms, \tau_y \approx 0.08ms$ .The coupled bunch oscillation obtained by tracking is transferred to the spectrum with FFT. In the simulation the ecloud density is about 1.03×10^{13}m^{-3}.

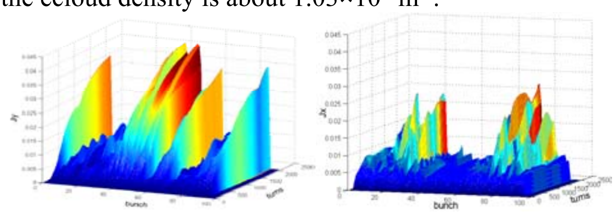

Figure 5: Growth behavior of coupled-bunch oscillation.

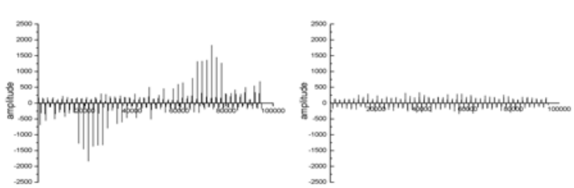

Figure 6: Sidebands.

SINGLE BUNCH INSTABILITY

The electron cloud can act as a short range wake field, and drive single bunch instability. Based on the head tail model [6], a code was developed to simulate bunch blow up. In the model, transverse distribution of the electron cloud and the bunch are represented by N_e and N_p macro particles. We use 2 dimension vectors (x_e, x'_e, y_e, y'_e) to describe the transverse motion of electron. Including the synchrotron oscillation, the motion of bunch macro particles is described by 3 dimension vector, $(x_p, x'_p, y_p, y'_p, z, \frac{\Delta P}{P})$. The bunch is divided into N_s slices, which interact with the ecloud one another and cause the distortion of the cloud distribution. The macro particles in different slices can change position because of synchrotron oscillation.

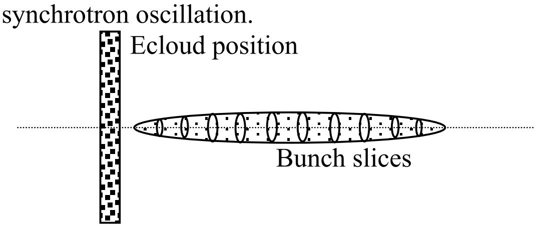

Figure 7: Schematic of the simulation recipe.

The motion of electrons and bunch particles can be expressed as,

$$\frac{d^2 \boldsymbol{X}_{p,i}}{ds^2} + K(s)\boldsymbol{X}_{p,i} = \left(\frac{2r_e}{\gamma}\right)\cdot\sum_{j=1}^{n_e} \boldsymbol{F}(\boldsymbol{X}_{p,i} - \boldsymbol{X}_{e,j}) \tag{3}$$

$$\frac{d^2 \boldsymbol{X}_{e,i}}{dt^2} = -2r_e c^2 \cdot \sum_{i=1}^{n_b} \boldsymbol{F}(\boldsymbol{X}_{p,i} - \boldsymbol{X}_{e,j}) \tag{4}$$

$$\boldsymbol{F} = -\frac{\boldsymbol{X}}{|X|}\delta(s) \tag{5}$$

$$K(s) = \begin{pmatrix} \cos(2\pi\nu_{x,y}) & \bar{\beta}\sin(2\pi\nu_{x,y}) \\ \dfrac{\sin(2\pi\nu_{x,y})}{\bar{\beta}} & \cos(2\pi\nu_{x,y}) \end{pmatrix} \tag{6}$$

where $F(X_{pi}-X_{ej})$ and $K(s)$ are the force between the bunch particles and the electrons and transfer matrix of the ring. $\delta(s)$ is the Delta function, which means to the interaction between the bunch and the electron cloud only occurred when the bunch passing through the position where the electrons were concentrated. We simulate the wake field caused by displacement of the head particle. The ecloud wake can be expressed by the formula,

$$W(z_j,z_i)=\frac{N_p\gamma}{N_b r_e}\frac{\delta y'_{p,j}}{\Delta y_{p,i}} \tag{7}$$

where N_b, $\Delta y_{p,i}$ and r_e are the particle number in a bunch, electron classic radius and displacement of the head particles, respectively. Simulation shows that the wake is linearization to the ecloud density, Fig. 8. It is consistent with eq. (7).

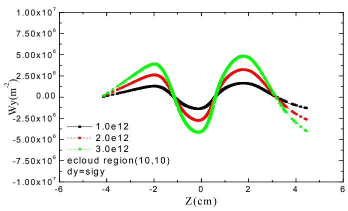

Figure 8: Ecloud short wake.

Based on the strong head tail instability theory, there is a criterion to calculate the threshold. It is expressed as,

$$\Gamma=\frac{N_b r_e|W_y|\bar{\beta}_y}{16\gamma\nu_s} \tag{8}$$

where ν_s is synchrotron tune. Thus the wake field threshold is $1.47\times10^6\mathrm{m}^{-2}$ corresponding to the ecloud density about $9.2\times10^{11}\mathrm{m}^{-3}$. After tracking the bunch for 4096 turns in different ecloud density, we find the threshold by simulation is constant with the formula results, Fig. 9.

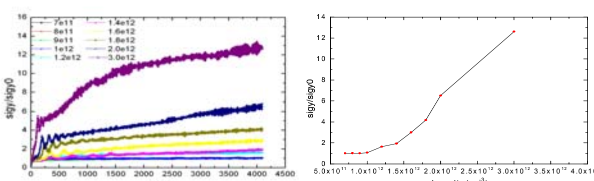

Figure 9: Bunch size in different ecloud density.

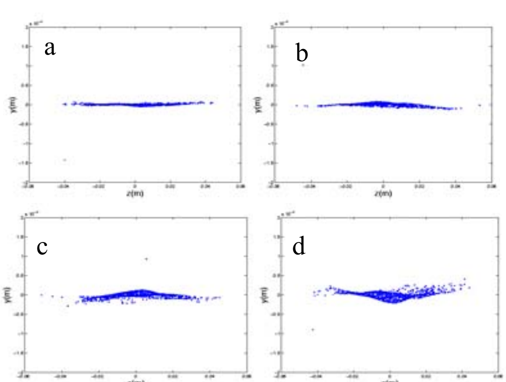

Figure 10: Bunch shape.
(a: 145th circle, b:150th circle, c:155th circle, d: 160th)

For the energy error, the tune change in different particles. The betatron and synchrotron motions are coupled by chromaticity that can restrain beam blow up.

$$\nu_{x,y}=\nu_{0x,0y}+\xi_{x,y}\left(\frac{\Delta P}{P}\right)_{x,y} \tag{9}$$

$$\varphi_{x,y}=\varphi_{0x,0y}+\frac{\omega_0\xi_{x,y}}{c}\int_C\left(\frac{\Delta P}{P}\right)_{x,y}ds \tag{10}$$

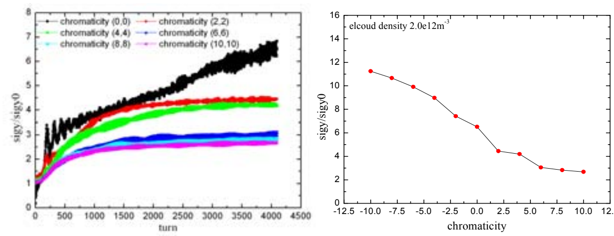

Figure 11: The bunch size versus chromaticity.

DISCUSSION

The electron cloud instability including the ecloud density, single bunch instability and couple bunch instability has been studied in detail in BEPCII under the conditions of the different restraining methods. The simulation results show that we can use antechamber, TiN coating and clearing electrodes to reduce the central ecloud density. The methods, antechamber, TiN coating and photo absorber will be used in BEPCII.

The single bunch instability, causing the bunch blow up, may occur in BEPCII if the ecloud density exceed the threshold, $1.0\times10^{12}\mathrm{m}^{-3}$. With the positive chromaticity the bunch blow up can be restrained.

The coupled bunch instability will be serious if there are no any methods to reduce the ecloud density. The simulation results are meaningful for the project of BEPCII.

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REFERENCES

[1] M. Izawa, et al., Phys. Rev. Lett. 74, 5044 (1995).
[2] H. Fukuma et al., EPAC2000, Vienna (2000).
[3] K. Ohmi, Phys. Rev. Lett. 75, 1526 (1995).
[4] Y. Ssetsugu et al., Journal of Vacuum Science Technology A., Vol.21, 2003.
[5] M. Bassetti and Erskine, Report No CERN ISR Th/80-06, 1980.
[6] A. Chao, Physics of Collective Instability in High Energy Accelerators (J. Wiley, New York, 1993).