ELECTRON TRAPPING IN WIGGLER AND QUADRUPOLE MAGNETS OF CESRTA *

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Abstract

The Cornell Electron Storage Ring (CESR) has been reconfigured as an ultra low emittance damping ring for use as a test accelerator (CesrTA) for International Linear Collider (ILC) damping ring R&D [1]. One of the primary goals of the CesrTA program is to investigate the interaction of the electron cloud with low emittance positron beam to explore methods to suppress the electron cloud, develop suitable advanced instrumentation required for these experimental studies and benchmark predictions by simulation codes. This paper reports the simulation of the electron-cloud formation in the wiggler and quadrupole magnets using the 3D code CLOUDLAND. We found that electrons can be trapped with long lifetime in a quadrupole magnet due to the mirror field trapping mechanism and photoelectrons produced in the wiggler zero field zone have long lifetime due to their complicated trajectory.

INTRODUCTION

The development of an electron cloud in magnets is the main concern where a weak solenoid field is not effective. There are long wiggler sections in the ILC damping ring where the electron cloud is expected to develop with large density. Quadrupole and sextupole magnets have mirror field configurations which may trap electrons by the mirror field trapping mechanism [2]. This paper reports the simulation of electron cloud in CESRTA wiggler and quadrupole magnets. Table 1 shows the main parameters used in the simulation.

Table 1: Main simulation parameters for CESRTA ring

Description	Value
Beam energy	5.289 GeV
Circumference	768.43m
Bunch length	15.0/17.24mm
Beam size	1.56/0.15 mm
Bunch spacing	14ns
Bunch number per train	45
Bunch intensity	$0.75 \sim 1.6\times10^{10}$

LONG LIFETIME ELECTRON IN WIGGLER NULL

In the simulation, a 3D field from the measurement is used. Here we describe the field in more detail in order to better understand the electron dynamics. According to the Halbach formulae [3] the magnetic field of wiggler can be expressed as

$$\begin{aligned} B_x &= \frac{k_x}{k_y} B_0 \sinh(k_x x)\sinh(k_y y)\cos(kz) \\ B_y &= B_0 \cosh(k_x x)\cosh(k_y y)\cos(kz), \\ B_z &= -\frac{k}{k_y} B_0 \cosh(k_x x)\sin(k_y y)\sin(kz) \end{aligned} \quad (1)$$

where $k_{x,y}$ and k satisfy

$$k_{x,n}^2 + k_{y.n}^2 = (nk)^2 = (n2\pi/\lambda)^2 \quad (2)$$

The total field is the summation of all components.

$$\vec{B} = \sum_n B_n \vec{f}_n (k_{x,n}, k_{x,n}, nk, x, y, z)\,, \quad (3)$$

Here we consider only the fundamental component n=1. K_x=0 is assumed, which is a good approximation at small |x| where multipacting occurs. When K_x=0, B_y and B_z are independent of the horizontal position, and B_x vanishes. The wiggler field has a peak field of 2T with a period of 0.4 m.

Figure 1 shows the wiggler magnetic field line and strength in the vertical-longitudinal plane. In the y-z plane, it is quadrupole type field. Therefore, it is a mirror field like, which may trap electrons due to the mirror field trapping mechanism. The field has a minimum at (y=0, z=0) because *cosh* and *sin* functions are zero there.

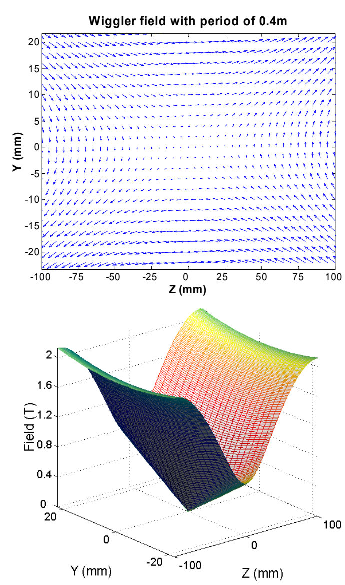

Figure 1: Wiggler field distribution (top) and field strength in vertical-longitudinal plane.

Unlike dipole magnet, the wiggler field varies longitudinally. Therefore, the distribution of electron

*Work supported by the U.S. Department of Energy under contract DE-AC02-76SF00515 and DE-FC02-08ER41538
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cloud is not uniform in longitudinal direction. Figure 2 shows the electron flux at the top surface of the beam pipe in different longitudinal locations: maximum (position A) and zero (position B) vertical magnetic field regions, and a region in between (position C). There is a similar electron cloud in position A and C, while there is very low electron flux at position B because of the presence of a longitudinal field there as shown in figure 1. The longitudinal field confines the photoelectrons near the chamber surface and suppresses the electron multipacting. Meanwhile, the electrons inside the beam chamber near z=0 can't penetrate the field line and hit the surface of the wall.

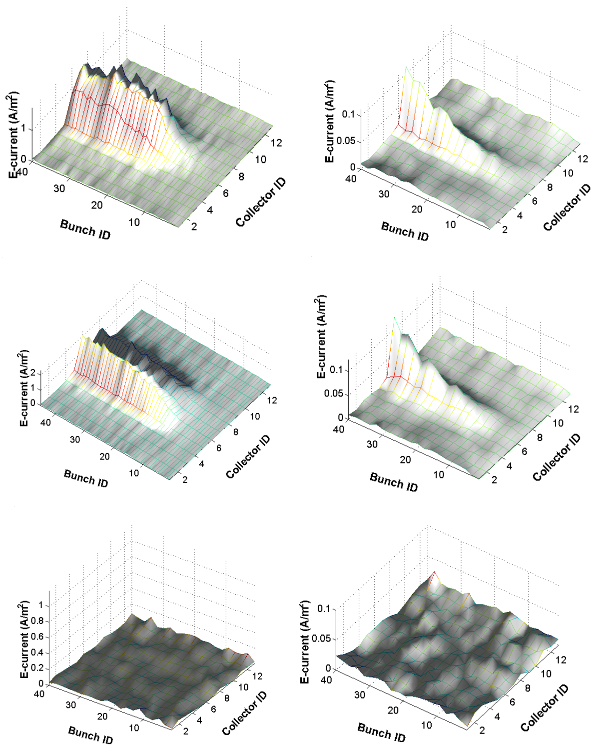

Figure 2: Simulated electron flux in RFAs of CESRTA wiggler: peak field region (top), zero vertical field region (bottom) and the region in between (middle) for a bunch current 1.5mA (Left) and 0.45mA (Right). The collector is installed on the top of the beam chamber and the collector ID shows the horizontal position, collector 7th is the central collector.

Figure 3 shows the distribution of the electron cloud inside the wiggler chamber for different photon reflectivity: 10% and 0%. Similar as in a dipole magnet, multi-pacting in a wiggler occurs only for electrons emitted from the top and bottom of the beam pipe. When a reflectivity of 10% is used, one stripe of multipacting electrons (when |x| is close to zero) is clearly seen in Figure 3. However, there is no multipacting in the zero vertical field region (z=0). The direct photoelectrons emitted from the zero magnetic field region (y=0, z=0 in Figure 1) cross the beam chamber in horizontal direction and forms a horizontal stripe there as shown in Figure 3. It becomes clearer in the case of 0% reflectivity. In this case, there are no multipacing electrons because there are no initial photons hitting on the top and bottom of the beam chamber. Only the direct photoelectrons from the zero vertical field region can cross the beam pipe horizontally, direct photoelectrons (near y=0) from other area can't enter the chamber due to the strong magnetic field shown in Figure 1.

Electrons in the zero vertical field region are originating from direct photoelectrons. Therefore, their number/density is proportional to the direct photon in that special area. A weak solenoid field doesn't suppress the electron multipaction there. Electron dynamics in that area is quite complicated due to E×B effect, field gradient effect, mirror field effect and beam field. Figure 4 shows an extreme case of the trajectory of an electron which has long lifetime. Typically, these electrons are not deeply trapped, but they do have long life-time due to their complex trajectory. Electrons in wiggler move in the three dimensions, but most electrons move effectively in the horizontal direction and form the horizontal stripe shown in Figure 3.

We propose here to install photon absorbers in the zero field region shown in Figure 1 to reduce the number of photons and suppress the formation of high electron density there. Since we only need to reduce the photons near the field null, it should be straightforward to include a proper photon absorber.

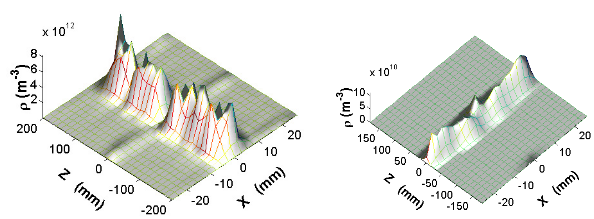

Figure 3: Electron cloud distribution in horizontal and longitudinal plane for 10% (left) and 0% (right) photon reflectivity.

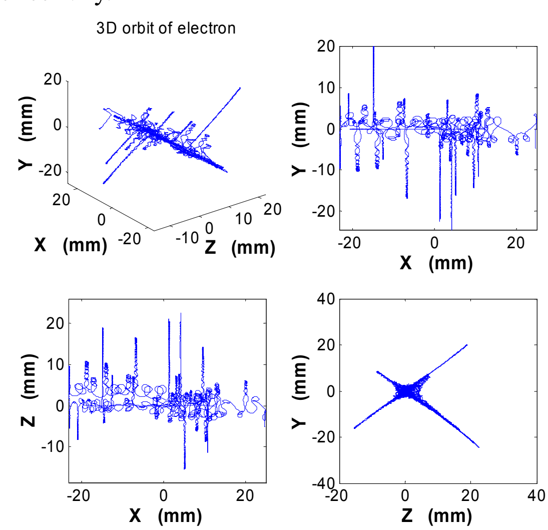

Figure 4: Example of an electron trajectory, which shows how the electron passes through the beam chamber horizontally.

MIRROR FIELD TRAPPING IN QUADRUPOLE

In principle, electron cloud can be trapped in a quadrupole magnet due to the mirror field trapping. However, certain conditions are required for deep trapping [4]. Electron cloud in a quadrupole magnet is sensitive to other parameters besides secondary emission, bunch current and beam filling pattern. Figure 5 shows the build-up of the electron cloud in a quadrupole magnet. The beam has one bunch train consisting of 45 bunches followed by a long train gap of 1.93μs. The electron cloud reaches saturation level after 10 turns (25μs). In contrast to the dipole magnet case, where electrons can't survive such long train gap, the electrons in quadrupole magnets surviving from the long train gap are trapped electrons.

Figure 6 and 7 shows the evolution of an electron cloud during the train gap for two different sets of parameters. The 1st picture in Fig 6-7 is the electron cloud just after the passage of the last bunch. We can clearly see the quadrupole pattern: electrons moving along the magnetic field lines. The survived electrons shown in Figure 6 are located at the minimum field region of the mirror field, which clearly shows mirror field trapping. Similar phenomenon is shown in Figure 7. Differently in this case, the trapped electrons are closer to the beam. Therefore, these trapped electrons can be important for the beam dynamics.

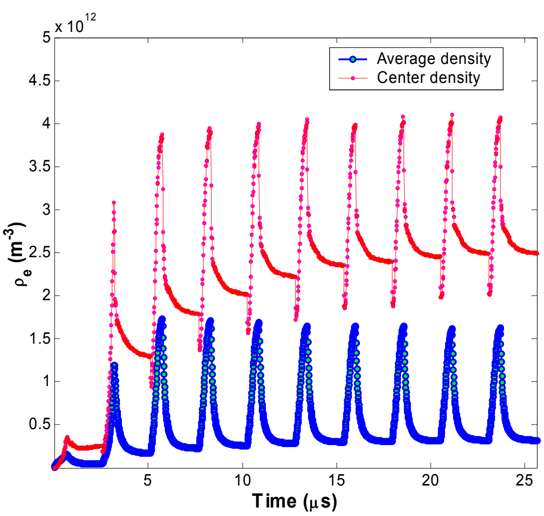

Figure 5: Electron build-up in the quadrupole magnet with a field gradient of 9.*2T/m*.

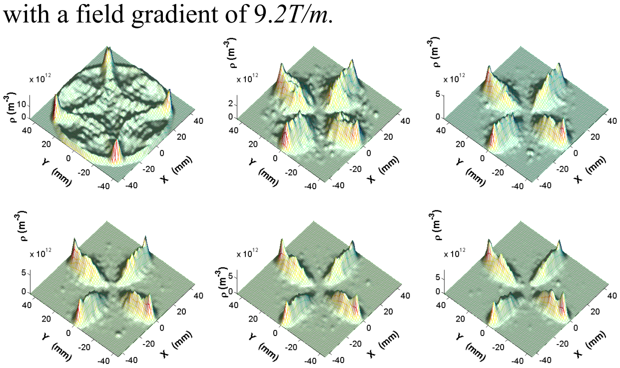

Figure 6: Evolution of electron cloud during the train gap; subsequent frames are separated by Δt=70 *ns*. Parameters used for simulation: bunch length 15mm, bunch current 1.3 *mA*, bunch spacing 14 *ns*, field gradient 0.517 *T/m*, peak SEY 2.0, energy at peak SEY 276 *eV*.

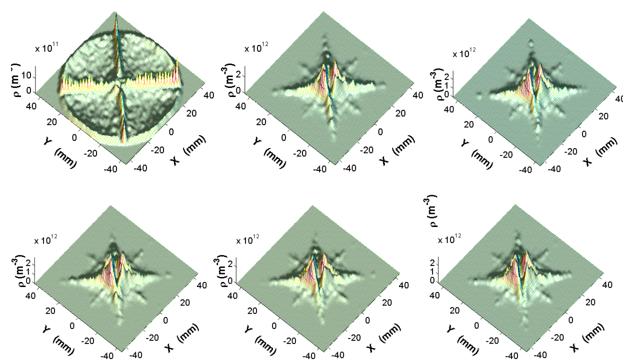

Figure 7: Evolution of electron cloud during the train gap, frames separated by Δt=70 *ns*. Parameters used for simulation: Bunch length 17.24 *mm*, bunch current 1.0 *mA*, bunch spacing 14 *ns*, field gradient 9.2 *T/m*, peak SEY 2.0, energy at peak SEY 310 *eV*, photon flux 0.21 photons/m/particle, reflectivity 20%.

CONCLUSION

We have simulated the electron cloud build-up in wiggler, quadrupole and sextupole regions of CesrTA. The transverse distribution of an electron cloud in a wiggler magnet is similar to a dipole magnet except in the zero vertical field regions where the electrons have complicated trajectories and therefore a longer lifetime. Fortunately, these electrons are direct photoelectrons dominant and emitted from a small zone (radius smaller than 20*mm*). We propose to arrange photon absorbers or blocks to reduce the number of photo-electrons there. As long as there are no direct photons near that area (y=0, z=0 in Figure 1), there will be no long lifetime electrons. Simulations show that the electron cloud in a quadrupole magnet can be deeply trapped by the mirror field. The trapped electrons can survive the long train gaps gap of 1.93μs. The distribution of trapped electrons strongly depends on the field and beam parameters. Simulations show that there is a larger electron density near the beam with a stronger quadrupole field. When the electrons are near the beam, the effect on the positron beam can be significant.

ACKNOWLEDGMENTS

We thank J. Calvey for helpful discussions and providing the input data.

REFERENCES

[1] M. Palmer, et al. this proceedings.
[2] D. Jackson, Classical Electrodynamics.
[3] K. Halbach, Nucl.Inst. and meth. Vol 78 pp265, 1970.
[4]L. Wang, H. Fukuma, S. Kurokawa, K. Oide, Physical Review E, 66, 036502(2002)