

NUMERICAL STUDY OF PHOTOELECTRON CLOUD IN KEK LER

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Abstract

A 3-dimension particle in cell simulation code is developed to study the photoelectron cloud instabilities in KEK LER. The photoelectron motion in various kinds of magnetic field is studied in detail, especially for solenoid field. Special solenoid has been installed in KEK LER in order to reduce the photoelectron effect. Simulation shows solenoid is very effective to confine the photoelectron to the vicinity of the vacuum chamber wall and make a photoelectron free region at the vacuum pipe center. The more uniform the solenoid field is, the more effective the field is.

1 INTRODUCTION

A blow-up of the vertical beam size is observed in the KEKB positron ring (LER)[1] and it is one of the serious problems limiting the luminosity of KEKB. F. Zimmerman and K. Ohmi [2-3] explained the blow-up as a single-bunch instability of a positron bunch due to electron cloud generated by photoemission and secondary emission. The blow-up depends on the electron cloud density near the beam. Solenoid with total length of 1270m was installed in the LER ring in order to clear the photoelectron near the beam. It was effective on reducing vertical blow-up [4]. A 3D simulation code is developed to study the effects of these various magnetic field on the photoelectron formation, distribution, space charge effect, and so on.

2 COMPUTER PROGRAM

The positron bunch is longitudinally divided into a number of slices according to Gaussian distribution. Photoelectrons are emitted when positron slices pass through a beam pipe with length L , which is usually chosen as 1 or 2 m. A photoelectron yield of 0.1 is assumed in simulation and 30% of the photoelectrons are produced by the reflective photons. The center of photoelectron energy distribution is 5 eV with rms (root mean square) energy spread of 5 eV. In our simulation, the photoelectrons are represented by macro-particles, which move in 3-dimensional space under the force:

$$\mathbf{F}_e = \mathbf{F}_p + \mathbf{F}_{space} + \mathbf{F}_B \quad (1)$$

where \mathbf{F}_p is the force by positron beam which is given by the Bassetti Formula and \mathbf{F}_{space} is the space charge force of the photoelectron. \mathbf{F}_B is the force by magnetic field on the photoelectron. The result for without space charge force case has been shown in Ref. [5]. A PIC 3D space charge solver has been developed recently to study the space-charge force [6]. The 3D space charge force is

included in this study.

The parameters used in the simulation are shown in table 1.

Variable	Symbol	Value
Ring circumference	C	3016.26 m
RF bucket length	s_{rf}	0.589 m
Bunch spacing	s_b	4 RF buckets
Bunch population	N	3.3×10^{10}
Average vertical betatron function	β_y	10 m
Average horizontal betatron function	β_x	10 m
Horizontal emittance	ϵ_x	1.8×10^{-8} m
Vertical emittance	ϵ_y	3.6×10^{-10} m
Betatron tune	ν_x/ν_y	45.52/44.09
Rms bunch length	σ_l	4 mm
Chamber diameter	$2R$	100 mm

Table 1: Parameters assumed for the simulation

3 ELECTRON -CLOUD IN VARIOUS MAGNETIC FIELD

The build up and the distribution of electron cloud (e-cloud) in various magnetic fields are discussed in this section. Figure 1 shows a typical distribution of the e-cloud in various magnetic fields. Figure 2 and 3 shows the average and center volume density in different magnet field as a function of time for a train with 100 bunches spaced by 7.86 ns and followed by a gap of 120 missing bunches.

In free case, the average volume density of the electron cloud at saturation level is $3.2 \times 10^{11} \text{ m}^{-3}$. The volume density at the central region is $9.0 \times 10^{11} \text{ m}^{-3}$. Most electron cloud is confined in the central region of the vertical direction by the positron slices as shown in figure 1a.

Figure 1b shows the distribution of electron cloud in transverse plane for uniform longitudinal magnetic field with strength 10 Gauss. The uniform solenoid field is very effective to confine the photoelectron. All of the photoelectrons are confined to the vicinity of the vacuum chamber wall. Therefore, 10 Gauss uniform field is enough. The average volume density is $6.7 \times 10^{11} \text{ m}^{-3}$. The most important is that there is a large photoelectron free region at pipe center.

The C-Yoke magnet can be arranged in a dipole or quadrupole configuration with equal polarity(EP) or alternating polarity(AP). For the C-yoke dipole, the field can be approximately expressed as

$$B_x = 0 \quad (2)$$

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$$B_y = a + b \cos(kz) \quad (3)$$

$$B_z = -bk \sin(kz) \quad (4)$$

where $a=141\text{G}$, $b=94\text{G}$, $\lambda=0.1\text{m}$ and $a=0$, $b=235\text{G}$, $\lambda=0.2\text{m}$ for the case of adjacent dipoles with equal polarity and alternating polarity, respectively. The magnet field in a C-yoke quadrupole is

$$B_x = (a + b \cos kz)y \quad (5)$$

$$B_y = (a + b \cos kz)x \quad (6)$$

$$B_z = -bk \sin(kz)xy \quad (7)$$

where $a=0.3\text{T/m}$, $b=0.2\text{T/m}$, $\lambda=0.1\text{m}$ and $a=0$, $b=0.5\text{T/m}$, $\lambda=0.2\text{m}$ for the equal polarity and alternating polarity, respectively. The photoelectron density at pipe center is about 10 times smaller than that of field free cases for all C-yoke magnet configurations. It is interesting that the central density in equal quadrupole case decays very slowly during the train gap comparing with other cases.

When the periodic solenoids are arranged with the same current direction in the coil, we call this kind of arrangement equal polarity configuration. In this case, the magnetic field can be approximately expressed as

$$B_z(x, y, z) = B_0 + B_0 \sin kz, \quad (8)$$

$$B_x(x, y, z) = -0.5B_0 kx \cos kz, \quad (9)$$

$$B_y(x, y, z) = -0.5B_0 ky \cos kz. \quad (10)$$

When the solenoids current takes alternating direction, which is called alternating polarity configuration, the longitudinal field is expressed as

$$B_z(x, y, z) = B_0 \sin kz \quad (11)$$

The transverse field components are the same as equal polarity case. Simulation shows equal polarity configuration is better. There is an electron free region at the pipe center. There is a same conclusion in the without space charge force case[7]. The more uniform the longitudinal field becomes, the larger the central electron free region is. The solenoid field increases the decay time during the train gap. The average density is 5% smaller than without space cases and the longitudinal distribution of the cloud becomes more uniform due to the longitudinal space charge force.

Most of bending magnets in LER are normal bending magnets with $B=0.848\text{T}$. There is a low density region with $|x|<10\text{mm}$ as shown in fig1(i). The preliminary photoelectrons have been cleared up by the magnetic force. Therefore, they don't contribute to the cloud in this case. There is the same conclusion for normal quadrupole and sextupole. The photoelectron distribution in transverse plane is quite similar to the field pattern and the central density is low for both normal quadrupole and sextupole as shown in figure 1(j-k). The average density increase linearly during the bunch train in normal dipole, quadrupole and sextupole as shown in figure 2, which suggests short train is better to reduce the average density in these magnets.

Figure 4 is the photoelectron energy distribution at the end of a train with 100 bunches spaced by 7.86 ns for

different magnets cases. It shows that the energy distribution strongly depends on the magnetic field.

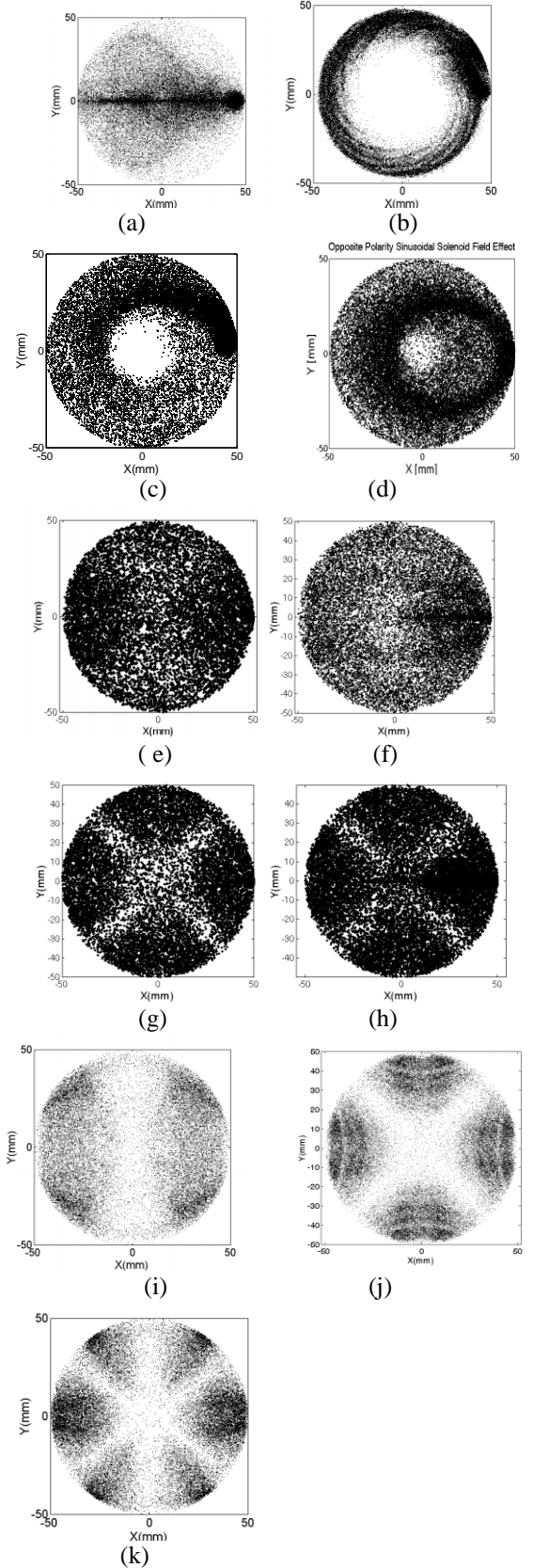


Figure 1 Photoelectron distribution in transverse section. Field free case (a); uniform longitudinal magnetic

field($B=10G$) (b); Solenoid with equal/alternating polarity configuration(c)/(d); C-Yoke dipole with equal/alternating polarity configuration(e)/(f); C-Yoke quadrupole with equal/alternating polarity configuration(g)/(h); Normal dipole(i); Normal quadrupole(j); Normal sextupole(k).

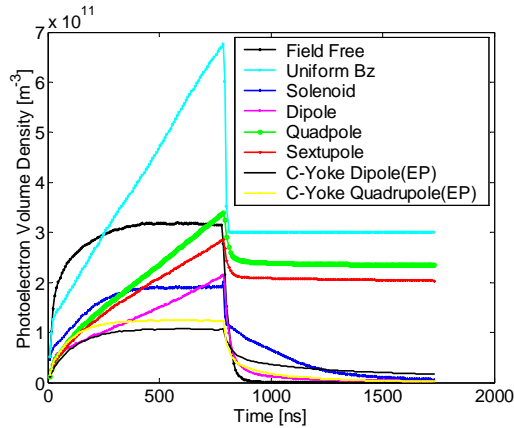


Figure 2 Photoelectron average volume density in different magnet field as a function of time for a train with 100 bunches spaced by 7.86 ns and followed by a gap of 120 missing bunches.

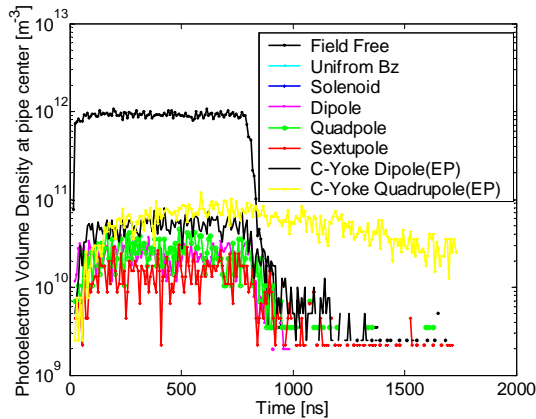


Figure 3 Photoelectron volume density at pipe center for different magnet field cases as a function of time for a train with 100 bunches spaced by 7.86 ns and followed by a gap of 120 missing bunches.

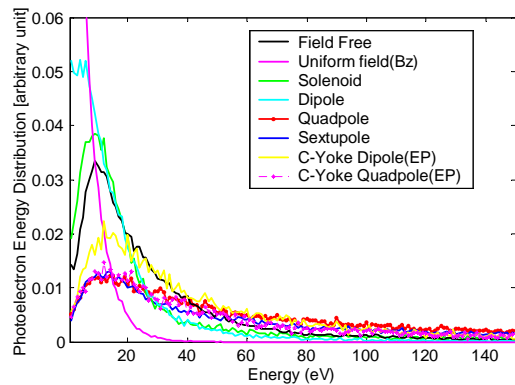


Figure 4 Photoelectron energy distribution at the end of a train with 100 bunches spaced by 7.86 ns for different magnets cases.

It is very interesting that more than 50% of the photoelectrons can be strongly trapped by quadrupole and sextupole magnetic field during the train gap. Figure 5 shows one typical trapped electron orbit in normal quadrupole field during the train gap. The drift time is about 960ns. The trapped electron spirals in an ever-tighter orbit along the magnetic field line when the field becomes stronger, converting more and more translational energy into energy of rotation until its velocity along the field line vanish. Then the electron turns around, still spiraling in the same sense, and move back along the field line.

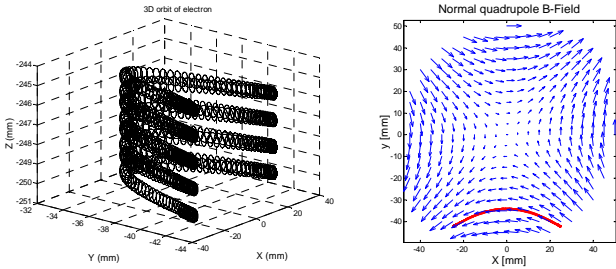


Figure 5 Photoelectron Trapping in Quadrupole Magnetic Field During the Train Gap. Left: 3D orbit; right: 2D orbit (red line) and quadrupole field (blue arrow)

4 SUMMARY AND CONCLUSIONS

The simulation shows that the magnetic field can reduce the electron density at the pipe center. However, it has little effect on reducing the electron average density. Uniform solenoid field is the most effective field to confine the photoelectron to the vicinity of the vacuum chamber wall and solenoid is better than other kind of magnets. A strong electron-trapping phenomenon during the train gap has been found in normal quadrupole and sextupole. The space charge force is not important when the secondary emission is not included.

5 REFERENCE

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