3D SIMULATION OF PHOTOELECTRON CLOUD

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Abstract

A 3-dimensional particle simulation code is developed to study the photoelectron cloud in positron rings. The effects of the various magnetic fields in KEKB LER are presented. The distribution and evolution of the electron-cloud are simulated.

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. C-Yoke magnet, which consists of two permanent magnets and a C-shaped iron yoke, was installed in the ring. The effect of C-Yoke magnet was not very clear in suppressing the blow-up for short bunch spacing case, which is required for the physics runs. Then solenoid with total length of 800 m was installed in the LER ring in Sep. 2000 in order to clear the photoelectron near the beam. It was effective on reducing vertical blow-up [4]. Additional 430 m solenoid was installed in Jan. 2001. A 3D simulation code is developed to study the effects of these various kinds of magnetic field on the photoelectron formation, distribution, space charge effect, multipacting, 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:

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

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. A PIC 3D space charge solver has been developed to study the space-charge force [5]. $\mathbf{F}_B$ is the force by magnetic field on the photoelectron. As a preliminary study, the space charge and secondary emission are not included in this study. They will be included one step by one step.

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
Beam line density	n_b	1.5×10^{10} m^{-1}
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.

3.1 Field free region

Figure 1 shows a typical simulation result for a passage of 100 bunches with a bunch spacing of 4 RF buckets and a 480 buckets gap in field free region. In fig. 1(a) the unit of time is bunch spacing, i.e. ~7.86ns(4 RF buckets). The exponential decay time of the electron cloud at the gap is 35 ns. The average volume density of the electron cloud at saturation level is 2.78×10^{11} m^{-3}. The volume density at the central region is 8.83×10^{11} m^{-3}. The central region is defined as a circle with radius of 10 mm at the pipe center. Most electron cloud is confined in the central region of the vertical direction by the positron slices as shown in figure 1(b).

(a)   (b)
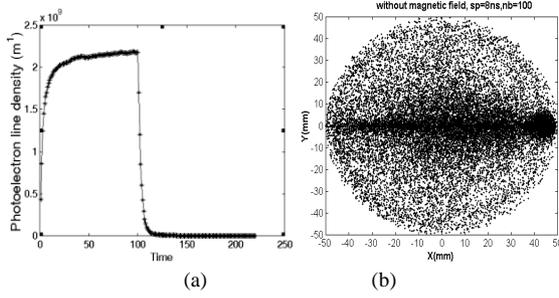
Figure 1   Field Free Case
(a)Electron line density as a function of time
(b)Photoelectron distribution in transverse section. The is integrated longitudinally.

3.2 C-Yoke magnet

The C-Yoke magnet can be arranged in a dipole or quadrupole configuration. For the dipole arrangement of the C yoke magnet configuration, the field can be approximately expressed as

$$B_x = 0 \tag{2}$$

$$B_y = a + b\cos(kz) \tag{3}$$

$$B_z = -bk\sin(kz) \tag{4}$$

where a=141G, b=94G, λ=0.1 m and a=0, b=235 G, λ=0.2 m for the case of adjacent dipoles with equal polarity and alternating polarity, respectively. The distribution of photoelectrons in transverse section for these two fields is shown in figure 2. The average and central volume density are 1.07×10^{11} m^{-3} and 0.75×10^{11} m^{-3} for equal polarity case. They are 0.98×10^{11} m^{-3} and 0.35×10^{11} m^{-3} for alternating polarity case. In alternating polarity case, the volume density is lower and the saturation time is large compared with those in equal polarity case.

(a)   (b)
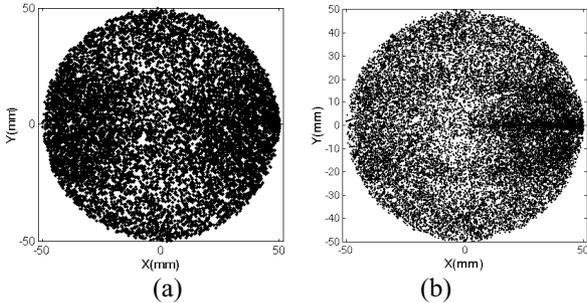
Figure 2   Photoelectron distributions in transverse
section for C yoke dipole field
(a) equal polarity configuration ;
(b) alternating polarity configuration

The C-Yoke magnet can be arranged as a quadrupole magnet with field

$$B_x = (a + b\cos kz)y \tag{5}$$

$$B_y = (a + b\cos kz)x \tag{6}$$

$$B_z = -bk\sin(kz)xy \tag{7}$$

where a=0.3T/m, b=0.2T/m, λ=0.1m and a=0, b=0.5T/m, λ=0.2m for the equal polarity and

alternating polarity, respectively. Figure 3 shows the distribution of photoelectrons in transverse section for these two fields. The average volume density are 1.27×10^{11} m^{-3} and 1.78×10^{11} m^{-3}, respectively. The central volume density are 0.64×10^{11} m^{-3} and 1.59×10^{11} m^{-3}, respectively. The decay time is almost the same in the two cases. The equal polarity configuration is better because the central density is lower.

(a)   (b)
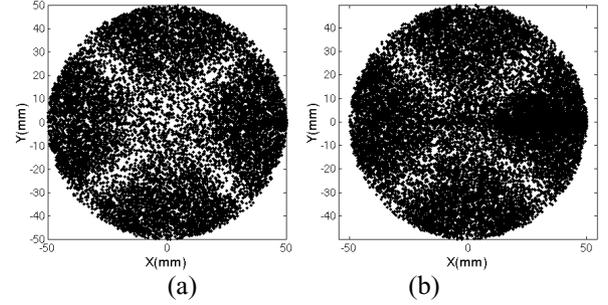
Figure 3 Photoelectron distribution in transverse
section for C yoke quadrupole field
(a) equal polarity configuration
(b) alternating polarity configuration

3.3 Uniform longitudinal field

Figure 4 shows the distribution of electron cloud in transverse plane for uniform longitudinal magnetic field with strength 10 Gauss and 20 Gauss, respectively. The uniform solenoid field is very effective to confine the photoelectron. 20 Gauss uniform field is enough. Most of the photoelectrons are confined to the vicinity of the vacuum chamber wall. The average volume density is 2.99×10^{11} m^{-3} and 1.08×10^{11} m^{-3} for B=10G and B=20G, respectively. The most important is that there is a large photoelectron free region at pipe center. The photoelectron takes about 10ns to drift few mm in the vacuum chamber to reach the pipe wall under such magnet field.
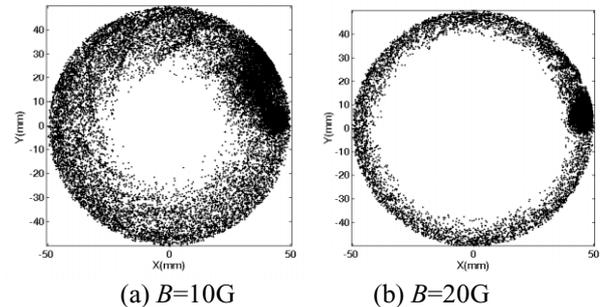
(a) B=10G   (b) B=20G
Figure 4   Photoelectron distributions in transverse
section in uniform longitudinal magnetic field

3.4 Solenoid field

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

$$B_z(x,y,z) = B_{z0} + B_0 \sin kz, \tag{8}$$

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

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

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

$$B_z(x,y,z) = B_0 \sin kz. \tag{11}$$

The transverse field components are the same as equal polarity case. The simulated electron cloud distribution with B_{z0}=30 Gauss, B_0=20 Gauss, λ=1 m and B_0=50 Gauss, λ=2 m for equal and opposite polarity case is shown in figure 5. The volume densities in equal polarity and opposite polarity case are 2.21×10^{11} m^{-3} and 2.61×10^{11} m^{-1}, respectively. The decay time in the train gap is 290 ns and 245 ns, respectively. There is an electron free region and a low electron density of 0.25×10^{11} m^{-3} region at the pipe center for the equal and opposite polarity case, respectively. Another paper[6] discusses the calculation in more details.
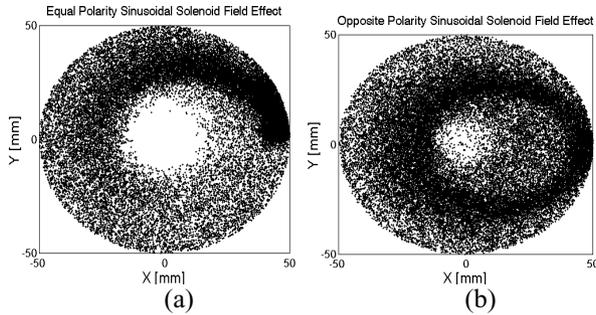
Figure 5 Photoelectron distributions in transverse section in periodic solenoid field (a: equal polarity configuration; b: alternating polarity configuration)

3.5 *Normal dipole and quadrupole magnet*

Most of bending magnets in LER are normal bending magnets with B=0.848T. A gradient of 10.3T/m is assumed for the normal quadrupole in simulation. Figure 6 shows the photoelectron distribution in these two kinds of magnets. The e-cloud distribution in normal dipole magnet is different from that in the dipole C-Yoke because the field pattern and strength is different. The average and central volume density in normal dipole magnet are 0.98×10^{11} m^{-3} and 0.28×10^{11} m^{-3}. The pattern of the e-cloud in a normal quadrupole is quite similar with that in the C-Yoke quadrupole magnet. The average volume density is 1.78×10^{11} m^{-3}, which is same as C-Yoke alternating polarity case. However, the volume density at pipe center, 0.14×10^{11} m^{-3}, is few times lower than that of C-Yoke case. The density of photoelectron in various kinds of magnet fields is summarized in table 2.
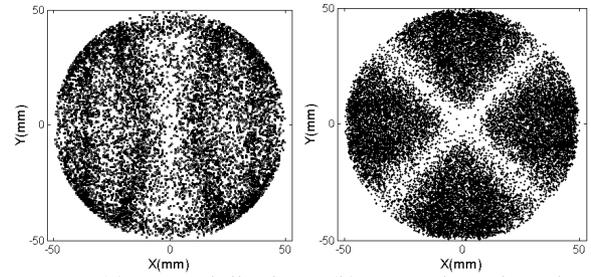
(a) Normal dipole   (b) Normal quadrupole

Figure 6 Photoelectron distributions in transverse section in normal dipole and quadrupole magnet

Table 2 Photoelectron density in various magnet

Magnet Field	ρ_a ($\times10^{11}$ m^{-3})	ρ_c ($\times10^{11}$ m^{-3})
Field Free	2.78	8.83
C-Yoke Dipole (EP)	1.07	0.75
C-Yoke Dipole (AP)	0.98	0.35
C-Yoke Quadrupole (EP)	1.27	0.64
C-Yoke Quadrupole(AP)	1.78	1.59
Uniform B=10G	2.99	<2.5×10^{-4}
Uniform B=20G	1.08	<2.5×10^{-4}
Solenoid (EP)	2.21	<2.5×10^{-4}
Solenoid(AP)	2.61	0.25
Normal Dipole	0.98	0.28
Normal Quadrupole	1.78	0.14

Symbol in table: ρ_a : Average volume density; ρ_c : Centra volume density, **EP**: equal polarity, **AP**: alternating polarity.

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 C-Yoke magnet.

5 REFERENCES

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