COMPUTATIONAL MODELING OF ELECTRON CLOUD FOR MEIC*

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Abstract

This work is the continuation of [4] our earlier studies on electron cloud (EC) simulations for the medium energy electron-ion collider (MEIC) envisioned at Jefferson Lab beyond the 12 GeV upgrade of CEBAF. In this paper, we study the EC saturation density with various MEIC operational parameters. The details of the study shows saturation of line density 1.7 nC/m and tune shift per unit length $4.9{\times}10^{-7}$ m^{-1}.

INTRODUCTION

The medium energy electron-ion collider (MEIC) has been envisioned as a high energy particle accelerator at Jefferson Lab beyond the 12 GeV upgrade of the existing continuous electron beam accelerator facility (CEBAF). A schematic of MEIC is shown in Fig. 1 and the parameters are summarized in Table 1 [1]. A high luminosity of 6×10^{33} cm^{-2} s^{-1} is demanded from MEIC, achieved by considering 3350 short bunches separated by a bunch spacing of 40 cm. At this stage, we have been assessing the performance by analyzing various beam dynamics challenges involved in an accelerator [2] – electron cloud (EC) is one of them which is caused by beam induced multipacting. In an electron-ion collider, the build up of EC is seeded by ionization of residual gas and electrons produced by stray beam particles striking the chamber wall; the photoelectric effect is negligibly small in the case of protons and heavy ions at low energy. In this paper, we have examined the build-up of electron cloud via computer simulations using the code POSINST [3] by exploring the possible parameters. This work is the continuation of a previous parametric study [4] where we could not achieve saturation. In this paper we report our development in achieving saturation and some important conclusions based on the simulation results.

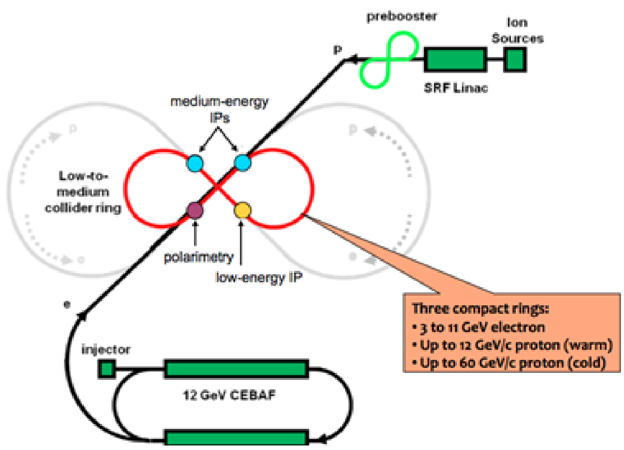

Figure 1: Conceptual layout of MEIC at Jefferson Lab.

Table 1: MEIC Design Parameters for EC Simulations

Parameters	Symbol (Unit)	Value
Beam energy	E_b (GeV)	60
Relativistic beam factor	γ_b	64
Collision frequency	f_c (MHz)	750
Circumference	C (m)	1340
Revolution period	$T_0 (\mu s)$	4.47
Beam pipe cross-section	—	Circular
Beam pipe radius	r_b (mm)	30
Harmonic number	h	3350
Number of bunches	K_B	3350
Bunch spacing	s_b (cm)	40
Bunch population	N_e (10^{10})	0.416
Bunch length	σ_l (mm)	10
Bunch profile	—	Gaussian
Total beam current	I (A)	0.5
Energy spread	σ_E (10^{-4})	3
Norm. horizontal emittance	ϵ_x^n (μm-rad)	0.35
Norm. vertical emittance	ϵ_y^n (μm-rad)	0.07
Horiz. beta function at IP	β_x^* (cm)	10
Vertical beta function at IP	β_y^* (cm)	2
Residual gas pressure	P (nTorr)	5
Temperature	T (K)	300
Ionization cross-section	σ_i (Mbarns)	2
Peak SEY	$\delta_{max} \equiv \delta(E_{max})$	1.6
Energy at peak SEY	E_{max} (eV)	230
Simulation section	—	Dipole magnet
Length of simulated region	L (m)	1.0
Dipole magnetic field	B (T)	1.5

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RESULTS AND DISCUSSION

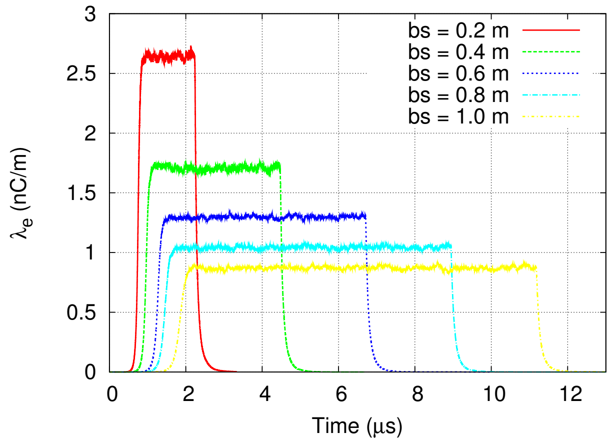

Figure 2: Time variation of electron cloud build-up (line density) for different bunch spacing. Simulations have been run for 3350 consecutive bunches.

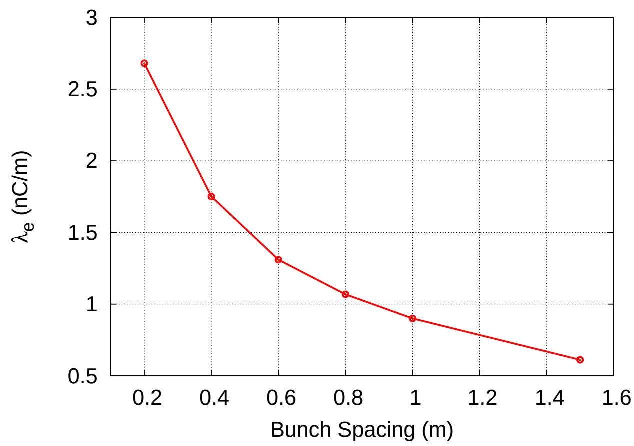

Figure 3: Variation of saturated line density with bunch spacing. Simulations have been run for 3350 consecutive bunches.

To start simulations, we have considered material properties of the beam pipe, peak secondary yields (SEY) etc. consistent with the similar machine [5]. We have explored the parameter space affecting the electron cloud development. The effect of bunch separation is illustrated in Fig. 2. The time evolution of EC line density clearly demonstrates exponential growth followed by saturation where the space charge due to EC stops further emission of secondaries. The cloud density decreases and the time to reach saturation increases with the increase of bunch spacing. This is due to the increase of mean free path. The saturation density decays exponentially with bunch spacings – see Fig. 3. Fig. 4 shows the variation of linear density of cloud electrons with the pipe radius. Clearly, the density decreases with the increase of beam pipe radius – showing a trend that the time to reach saturation increases with the increase

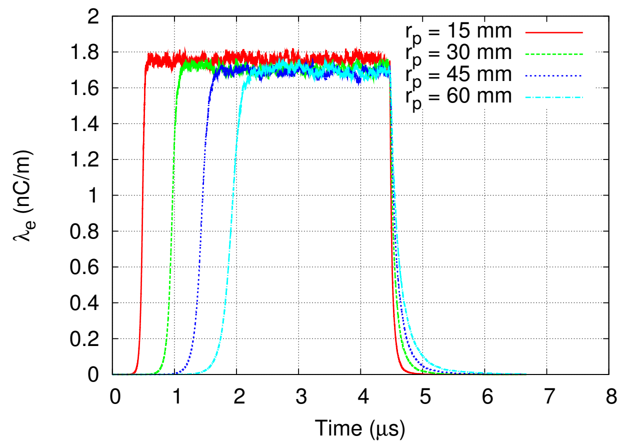

Figure 4: Time evolution of electron cloud for beam pipe with different radii. Simulations are run for 3350 consecutive bunches.

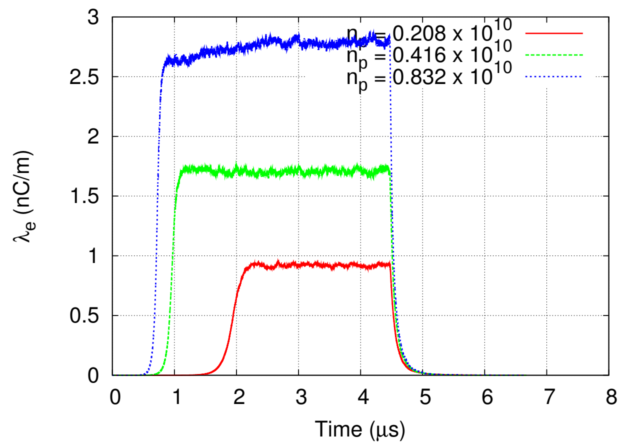

Figure 5: Time evolution of electron cloud linear density for different bunch population. Simulations are run for 3350 consecutive bunches.

of pipe radius.

The effect of bunch population is shown in Fig. 5. Increasing the bunch population increases the density of cloud build-up. The space charge effect speed up the saturation which is indeed seen in the simulations. Fig. 6 shows the effect of variation in the residual gas pressure. We see that the growth time decreases with the increase of pressure due to the faster rate of ionization.

The straightforward consequence of EC density is a tune shift owing to the focusing effect of the electrons on the beam. Assuming that the EC density distribution is round in the transverse plane, the tune shift per unit length of beam traversal through the cloud is given by [6]

$$\Delta\nu/L = \frac{r_p\bar{\beta}\rho_e}{2\gamma_b} \quad (1)$$

where the classical proton radius $r_p = 1.535 \times 10^{-18}$ m and $\rho_e = 3.75 \times 10^{12}$ m^{-3} is the EC density, $\bar{\beta}$ = 11 m, γ_b

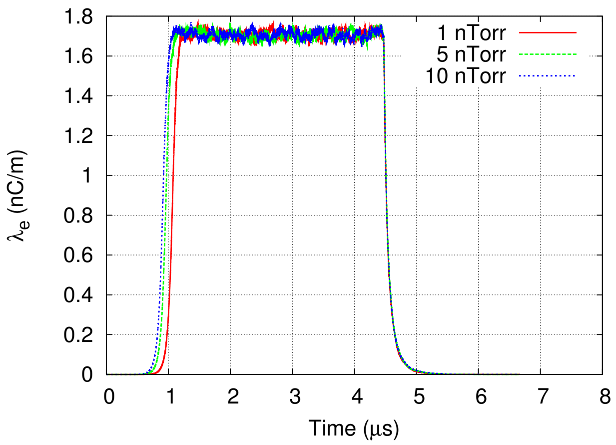

Figure 6: Evolution of electron cloud density with time for 3350 consecutive bunches at residual gas pressure 1, 5 and 10 nTorr.

= 64. We obtain $\Delta\nu/L = 4.9\times10^{-7}$ m^{-1}; taking $L = C$ = 1340 m gives an idea of the magnitude of $\Delta\nu$ = 6.6×10^{-4}.

CONCLUSION

The electron cloud build up for MEIC has been explored for the possible parameter space such as bunch spacing, intensity, beam pipe radius, magnetic fields and the ambient gas pressure etc. This study shows the saturation for closely spaced (40 cm) 3350 bunches confirming that the space charge effect stops the further build up of electron density. The direct consequence of EC is the tune shift per unit length which is 4.9×10^{-7} m^{-1}. The dynamic effects of EC on beam such as emittance growth and instabilities will be reported separately.

ACKNOWLEDGEMENT

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