STUDIES OF ELECTROMAGNETIC SPACE-CHARGE FIELDS IN RF PHOTOCATHODE GUNS *

Chong Shik Park† and Mark Hess, IUCF, Bloomington, IN 47405, USA

Abstract

In high-brightness RF photocathode guns, the effects of space-charge can be important. In an effort to accurately simulate the effects of these space-charge fields without the presence of numerical grid dispersion, a Green's function based code called IRPSS (Indiana Rf Photocathode Source Simulator) was developed. In this paper, we show the results of numerical simulations of the Argonne Wakefield Accelerator photocathode gun using IRPSS, and compare them with the results of an electrostatic based simulation code, PARMELA.

INTRODUCTION

In the RF photocathode gun, the electron beam starts with very low energy, and its speed becomes close to the speed of light at the exit of the first half cell. Therefore, the electromagnetic space-charge effects are very important just after the beam is emitted from the cathode. Various beam dynamics codes are used for designing and optimizing the RF gun. PARMELA, which is an electrostatic PIC code, has typically been the workhose for modeling photoinjectors [1].

We have developed a code for space-charge field solver, IRPSS, to simulate the beam dynamics in the RF photocathode gun. IRPSS calculates the electromagnetic space-charge fields using a Green's function approach [2, 3, 4, 5].

In the next section, we show how to calculate the electromagnetic space-charge fields of the beam, and in the subsequent section, we compare IRPSS simulation results with those from PARMELA. In this paper, we have used the ANL AWA 1.3 GHz gun parameters [6]:

- Cavity radius: $a = 9.08$ cm,
- Peak RF E field: $E_0 = 77$ MV/m,
- Injection phase: $\phi = 65$ degree,
- Beam radius: $r_b = 1$ mm,
- Bunch length: $t_b = 1.2$ ps,
- Beam charge: $Q_b = 1$ nC (10 times greater than ANL gun).

CALCULATIONS OF SPACE-CHARGE FIELDS

The electromagnetic space-charge fields with conductor boundary conditions are calculated using Green's function method [3]. In order to simplify the problem, we assume

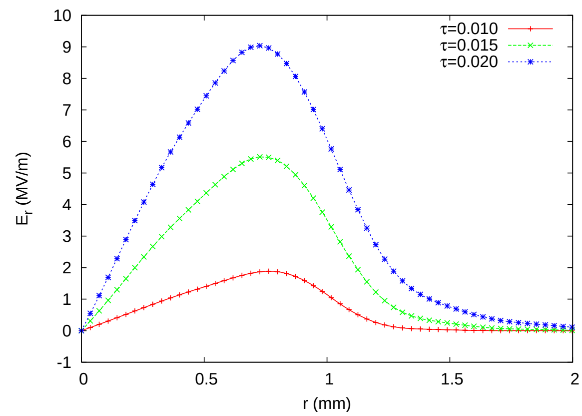


Figure 1: E_r vs. r for different times.

that the gun has no iris and the cavity is cylindrically symmetric. Since the iris does not affect the motion of the first bunch for early times, this assumption is still valid.

In a previous paper, we showed the computational requirements for IRPSS, such as minimum eigen mode numbers and minimum numerical integration time steps [5]. Since the bunched beam has a finite size in the longitudinal direction, the multi-sliced bunch model is used to generate the finite size bunch [4]. In the space-charge field calculation, 41 slices, which is adequate for 1.2 ps bunch, form a bunch in the simulation.

Fig. 1 shows E_r vs. r at the center of the bunch for 3 different times. At $\tau(= ct/a) = 0.02$, the beam has moved approximately 0.1 mm. Between $\tau = 0.005$ and $\tau = 0.02$, E_r increases by a factor of 9. The increase is large due to the presence of image charges on the cathode.

The RF field for the beam accelerating in the gun is calculated using Superfish. In order to examine the effect of the space-charge fields only, the solenoidal fields for the emittance compensation and other external fields are excluded.

BEAM TRACKING SIMULATION

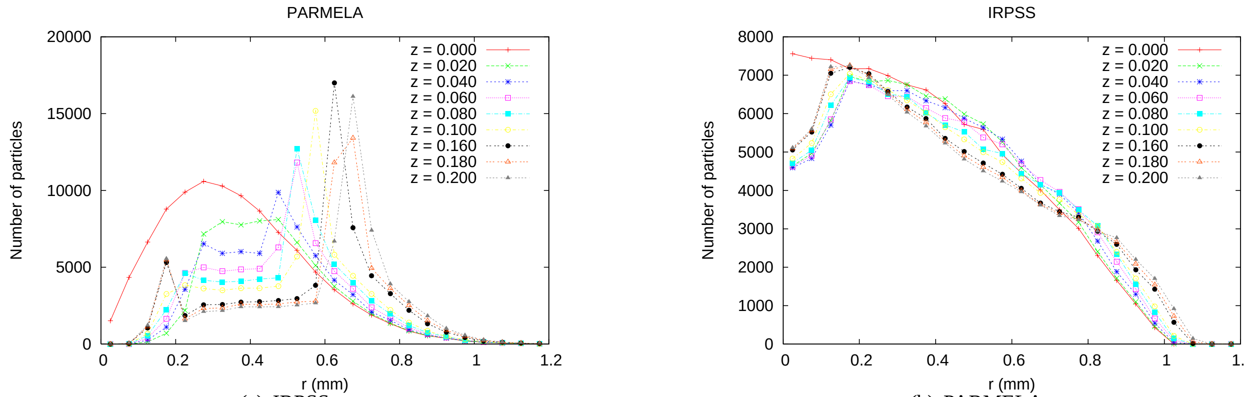
Change of the Beam Distribution

When the first few time steps in the PARMELA simulation, we see in Fig.2(a) that nearly 40% of the beam is lost to the cathode. The majority of that loss occurs close to the radial center of the bunch. In Fig. 2(b), we see that 6% of the beam near the center is lost to the cathode.

The disparity between the two simulations is most likely the result of the electrostatic PARMELA $\vec{E}$ fields being an overestimate compared to the electromagnetic IRPSS $\vec{E}$ fields. After that, the shape of the beam distribution in

* Work supported by in part by the Department of Energy under grant DEFG0292ER40747 and in part by the National Science Foundation under grant PHY-0552389

† chspark@indiana.edu



(a) IRPSS (b) PARMELA

Figure 2: Evolution of the beam distribution along the radial direction.

IRPSS does not change significantly, however, the beam distribution continues to vary with time in PARMELA compared to IRPSS.

Comparison of the Emittance

In the ANL RF gun, the transverse emittance of the electron beam increases from 0 to 5 mm-mrad within 1 mm. Without space-charge fields (only with RF fields), it is only the order of 10^{-3} mm. The dramatic increase of the emittance is due to the space-charge effect.

As we have seen from Fig. 3, PARMELA overestimates the space-charge fields and hence the emittance can be overestimated as well. Fig. 3 shows plot of normalized rms emittance vs. z and the overestimate of the emittance by PARMELA.

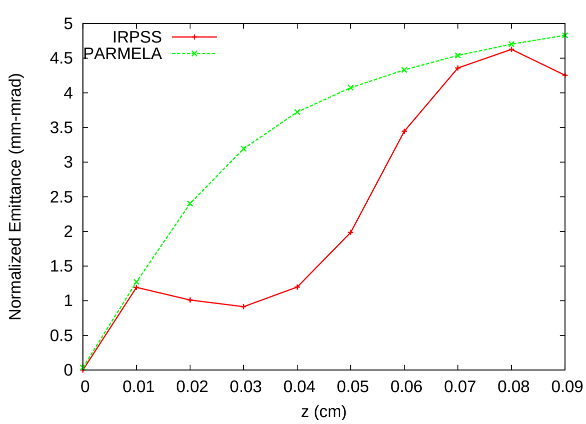


Figure 3: Normalized rms Emittance vs. z.

Phasespace Plots

At the cathode, all particles are starting with zero momentum, hence they are on the $x(y)$ axis on the transverse phasespace plots. However, even for z-values close to the cathode (i.e., $z = 0.010$ cm), the space-charge forces are so strong that they have a significant effect on the phasespace.

Fig. 4 shows transverse phasespace plots for two different z locations. At $z = 0.01$ cm, the two codes have the same emittance, but the phasespace plots have very different. And at $z = 0.05$ cm, the difference in emittances are large compared to phasespaces. At a farther distance, both the emittance and phasespace plots are different.

CONCLUSION

In this paper, we present the space-charge effects in the ANL RF photocathode gun for early times by comparing the beam distribution, emittance, and phasespace between IRPSS and PARMELA. The beam distribution in IRPSS does not change significantly unlike PARMELA. We have found that although PARMELA and IRPSS emittances may agree in certain locations, their phasespace plots may be very different.

In future, we will study how electromagnetic space-charge fields can affect the designs of magnetic focusing schemes for photocathode gun, such as emittance compensation.

ACKNOWLEDGMENT

Authors of this paper would like to thank to DRs. Wei Gai and John Power of ANL for the great support in this work.

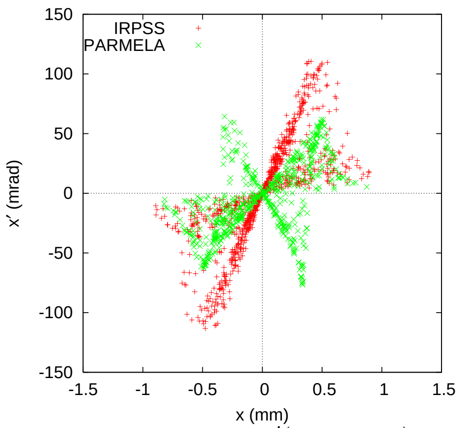
REFERENCES

[1] L.M. Young (documentation by J.H. Billen), PARMELA, report LA-UR-96-1835, Los Alamos, 1996 (rev. 2004).

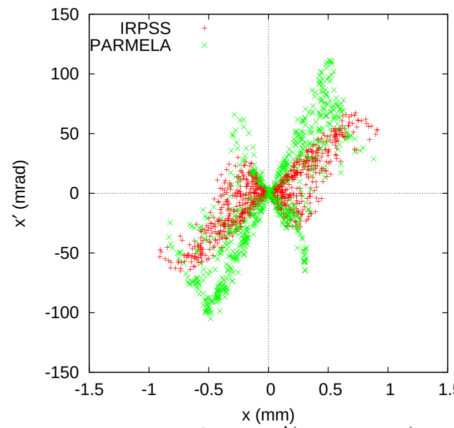
[2] M. Hess and C.S. Park, "Advanced Electromagnetic Analysis of Electron Source Geometries," PAC'05, Knoxville, May 2005, p. 2815.

[3] M. Hess, C.S. Park and D. Bolton, Phys. Rev. ST Accel Beams **10**, 054201 (2007).

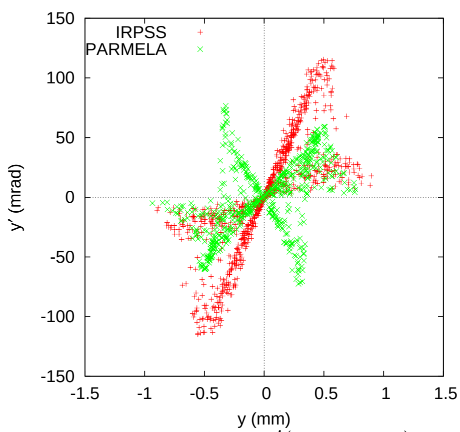
[4] M. Hess and C.S. Park, "A Multislice Approach for Electromagnetic Green's Function Based Beam Simulations," in PAC'07 proceedings.



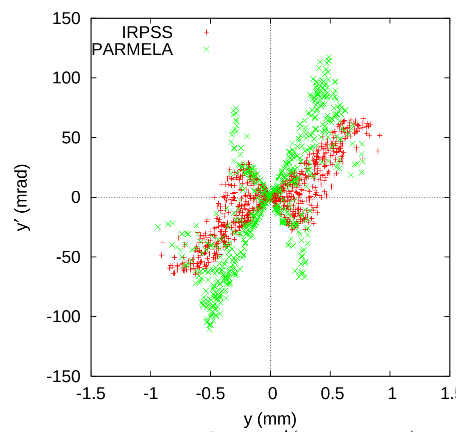
(a) $x - x'(z = 0.01cm)$



(b) $x - x'(z = 0.05cm)$



(c) $y - y'(z = 0.01cm)$



(d) $y - y'(z = 0.05cm)$

Figure 4: Phasespace plots for two different z locations, $z = 0.01cm$ and $z = 0.05cm$: (top) $x - x'$, (bottom) $y - y'$

[5] C.S. Park and M. Hess, "Computational Requirements for Green's Function Based Photocathode Source Simulations," in PAC'07 proceedings.

[6] P. Schoessow, et al, The Argonne Wakefield Accelerator Overview and Status, Proceedings of PAC'03, Washington, D.C., p. 2596.