SIMULATION OF THE INTERACTION OF AN ELECTRON BEAM WITH IONIZED RESIDUAL GAS*

G. Pöplau†, U. van Rienen, Rostock University, Rostock, Germany
A. Meseck, HZB, Berlin, Germany

Abstract

Light sources of the next generation such as ERLs require minimal beam losses as well as a stable beam position and emittance over the time. Instabilities caused by ion accumulation have to be avoided. In Rostock the tracking code MOEVE PIC Tracking has been developed for the simulation of space charge influenced beam dynamics, which is recently applied for simulations of the interaction beam - e-cloud. In this paper we apply MOEVE PIC Tracking for simulations of the interaction of the ionized residual gas with an electron bunch. We demonstrate numerical results with parameters planned for the ERL B*ERL*inPro.

INTRODUCTION

Energy Recovering Linacs (ERL) require minimal beam losses and stable emittance during operation time. Instabilities caused by the ionized residual gas have to be avoided.

The effect of ions in an ERL was theoretically investigated with different scenarios for the X-Ray ERL planned at Cornell University [5]. Most of these scenarios are critical with respect to ions. Hence counter measures like clearing electrodes have to be planned carefully.

In this paper we investigated the interaction between an electron bunch and an ion cloud by numerical tracking of the particles. We computed the fields of the ions and the electron bunch and applied them to the particles of the bunch as well as to the ions. For this purpose we adapted the software package MOEVE PIC Tracking. MOEVE PIC Tracking has been developed in Rostock for the simulation of single bunch instabilities caused by an electron cloud [6].

Within our numerical simulations we have taken into account the parameter settings that are planned for B*ERL*inPro and described in [2]. The parameters that are relevant for the simulations in this paper are given in Table 1. Since these parameters are very close to those of the ERL at Cornell University ions will be a critical issue. In [5] it was theoretically shown that for the settings given in Table 1 all ions will be trapped in the potential of the bunch. Hence, detailed theoretical and numerical investigations are very important for the design of B*ERL*inPro. The numerical simulations presented in this paper confirm the theoretical results and allow for a further analysis of the behavior of the ions and of the bunch.

* Work supported by BMBF under contract number 05K10HRC
† gisela.poeplau@uni-rostock.de

Table 1: Main parameters of B*ERL*inPro.

maximum beam energy	$100\ \mathrm{MeV}$
maximum beam current	$100\ \mathrm{mA}$
nominal beam charge	$77\ \mathrm{pC}$
maximum repetition rate	$1.3\ \mathrm{GHz}$
normalized emittance	$10^{-6}\ \mathrm{m}$

SIMULATION OF THE INTERACTION

Simulation Method

The interaction of the electron bunch and the ions is simulated with the tools of MOEVE PIC Tracking [6]. MOEVE PIC Tracking tracks particles, where the space charge fields are taken into account in each time step of the tracking procedure. The space charge forces are computed with the particle-mesh method, i. e. the particles are transformed to the rest frame, where Poisson's equation is solved for the potential [4]. The multigrid Poisson solver of MOEVE is applied for the efficient solution of Poisson's equation [7, 8]. Furthermore it has to be mentioned that we used the adaptive mesh refinement for the discretization that is based on multigrid. This method was introduced in [9].

The Poisson equation was solved separately for each particle species. For the superposition the resulting fields were interpolated at the position of the particles - the ions and the (macro) electrons. After the interaction the ions were tracked further until the next bunch arrived and the interaction was computed again.

Simulation Parameters

The parameters for the simulation were chosen from the design of B*ERL*inPro published in [2] (Table 1). Further parameters necessary for the simulations but not yet fixed were taken according to the investigations for the X-Ray ERL at Cornell University [5].

The electron bunch was modelled with 10,000 macro particles with uniform distribution of a cylindrical shape. For the generation of the distribution the program *generator* of the tracking code ASTRA was used [3]. Since the maximum energy planned for B*ERL*inPro is $100\ \mathrm{MeV}$ we investigated here two cases for the energy of the bunch: $50\ \mathrm{MeV}$ and $100\ \mathrm{MeV}$, respectively. The bunch length was taken with $\sigma_t = 2\ \mathrm{ps}$, the average beta function with $\beta = 50\ \mathrm{m}$. The bunches were separated by a distance of $0.25\ \mathrm{m}$.

The ion cloud was modelled with 1,000 particles, where it contained H_2^+ (98 %), CO^+ (1 %) and CH_4^+ (1 %) ions. These ions have a relative atomic mass of $A = 2$ (H_2^+), $A = 16$ (CH_4^+) and $A = 28$ (CO^+), respectively.

RESULTS

In this section we present the results that we obtained with the simulation of 100 interactions. The interactions were computed by the method described above and during the gap the further evolution of the ion was computed. The simulations demonstrated that all ions are attracted by the potential of the bunch (both the 50 MeV and 100 MeV bunch) and get trapped. These results confirm the theoretical investigations in [5].

Figure 1 shows the second interaction between ion cloud and electron bunch. It can be observed how the force of the passing bunch attracts the ions and increases their momentum. Furthermore, the increase of the momentum is much higher after the interaction with the 100 MeV bunch than after the interaction with the 50 MeV bunch.

Figure 2 represents the distribution of the ions after 100 interactions. In addition Figure 3 shows the mass of the ions such that the different species can be recognized. It can be observed that the 100 MeV bunch has focussed the ions much more to the transversal centre of the bunch than the 50 MeV bunch. Furthermore, if we compare the Figures 2 and 3 it turns out that the CO^+ and CH_4^+ ions have gained much less energy than the much lighter H_2^+ ions. For the 100 MeV bunch the heavier ions are not that close to the transversal bunch centre.

It has to be mentioned that the plots in the Figures 1 – 3 were generated with Paraview [1]. In the plots of Figure 1 the number of particles in the bunch was restricted to 5,000 to make the plot more clear. However, the simulations were performed with 10,000 macro particles.

CONCLUSION

In this paper we simulated the interaction of an electron beam with an ion cloud. The simulations were performed with the software package MOEVE PIC Tracking with an adaptive meshing technique for the computation of the space charge fields. The parameters planned for the ERL facility B*ERL*inPro and the ERL at Cornell University were chosen for the simulations.

The numerical investigations confirm theoretical results from case studies for the ERL at Cornell University. Furthermore, the tracking simulations allow for a more detailed analysis of the behavior of the ion cloud and the bunch. In this sense our numerical investigations are a starting point for continuing studies for B*ERL*inPro.

REFERENCES

[1] ParaView. `www.paraview.org`, release 3.8.1 and 3.10.1, 2011.

[2] A. Jankowiak et al. "B*ERL*inPro - a compact demonstrator ERL for high current and low emittance beams." In Proceedings of LINAC 2010 (Linear Accelerator Conference), Tsukuba, Japan, pages 407–409, 2010.

[3] K. Flöttmann. "ASTRA." DESY, Hamburg, `www.desy.de/~mpyflo`, 2000.

[4] R.W. Hockney and J.W. Eastwood. " Computer Simulation Using Particles." Institut of Physics Publishing, Bristol, 1992.

[5] Georg H. Hoffstaetter and Matthias Liepe. "Ion clearing in an ERL." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 557(1):205 – 212, 2006.

[6] A. Markovik, G. Pöplau, and U. van Rienen. "3D PIC computation of a transversal tune shift caused by an electron cloud in a positron storage ring." In Proceedings of IPAC 2010 (1st International Particle Accelerator Conference), Kyoto, Japan, pages 1928–1930, 2010.

[7] G. Pöplau. "MOEVE: Multigrid Poisson Solver for Non-Equidistant Tensor Product Meshes." Universität Rostock, 2003.

[8] G. Pöplau, U. van Rienen, S.B. van der Geer, and M.J. de Loos. "A multigrid based 3D space-charge routine in the tracking code GPT." In M. Berz and K. Makino, editors, Computational Accelerator Physics 2002 (Proceedings of the 7th International Computational Accelerator Physics Conference, East Lansing, Michigan, USA), number 175 in Institute of Physics Conference Series, pages 281–288, Bristol and Philadelphia, 2005. Institute of Physics Publishing.

[9] S.B. van der Geer, M.J. de Loos, G. Pöplau, and U. van Rienen. "Adaptive space-charge meshing in the general particle tracer code." In Proceedings of PAC 2011 (11th Particle Accelerator Conference), New York, USA, 2011.

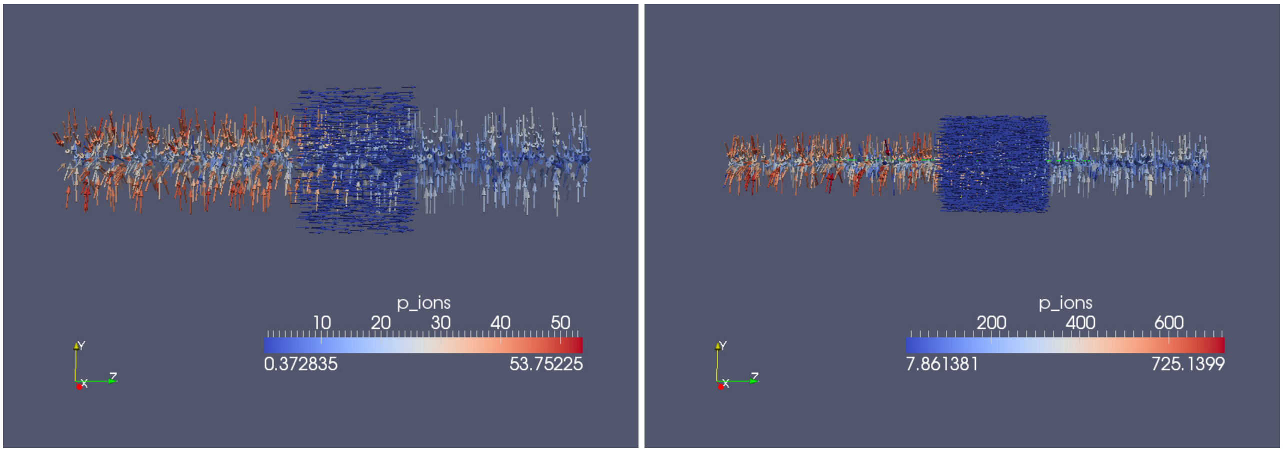

Figure 1: Second interaction between an ion cloud and an electron bunch (plotted in blue) with an energy of 50 MeV (left) and 100 MeV (right), respectively.

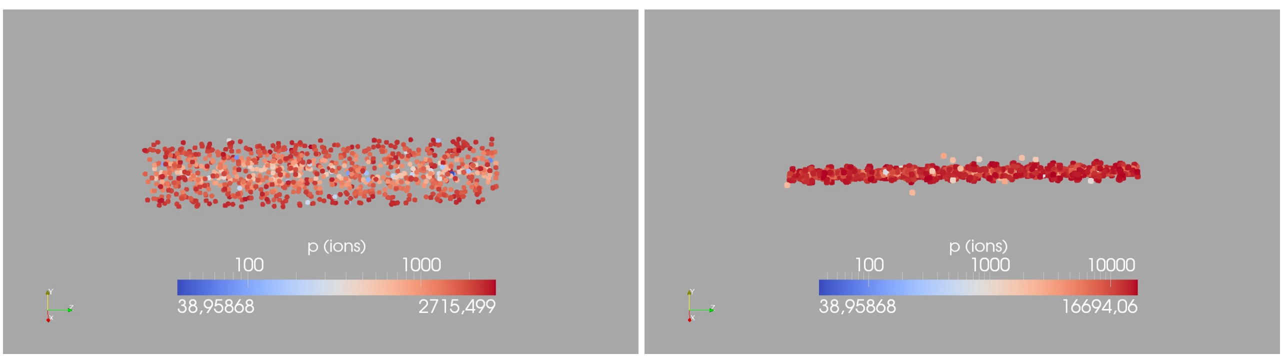

Figure 2: Ion cloud after 100 interactions with an electron bunch with an energy of 50 MeV (left) and 100 MeV (right), respectively.

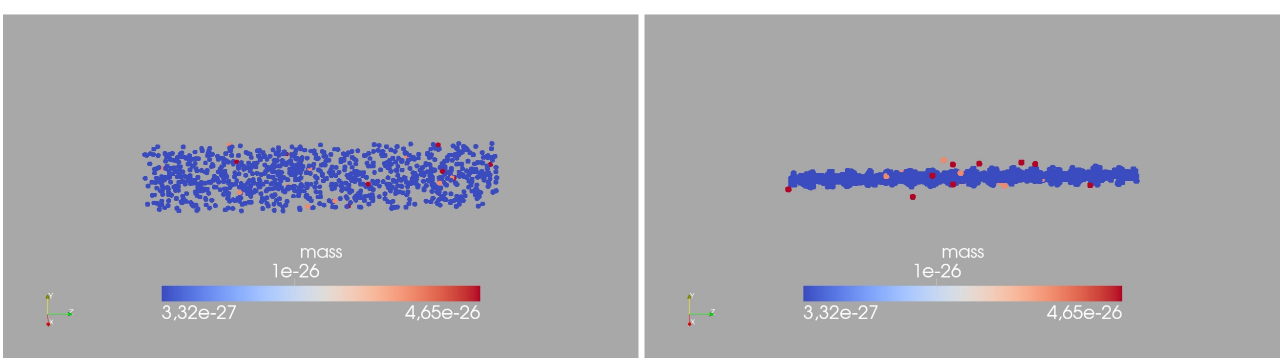

Figure 3: Mass of the ions. Ion cloud after 100 interactions with an electron bunch with an energy of 50 MeV (left) and 100 MeV (right), respectively.