SIMULATION OF THE BEHAVIOR OF IONIZED RESIDUAL GAS IN THE FIELD OF ELECTRODES *

G. Pöplau†, U. van Rienen, University of Rostock, 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 small emittance over time. Instabilities caused by ionized residual gas have to be avoided. In this paper we present simulations of the behavior of ionized residual gas in the field of clearing electrodes and investigate e. g. clearing times. For these simulations we apply MOEVE PIC Tracking developed at the University of Rostock. We demonstrate numerical results with parameters planned for the ERL B*ERL*inPro.

INTRODUCTION

To ensure the optimum performance, Energy Recovering Linacs (ERL) require minimal beam losses and small emittance in all intended operation modes. Thus, the instabilities and emittance growth caused by the ionized residual gas have to be avoided.

Different scenarios for the impact of the ionized residual gas on the beam delivered by an ERL was theoretically investigated using the Cornell X-Ray ERL as an example [1]. Most of these scenarios are critical with respect to ions. Hence counter measures such as clearing electrodes have to be designed carefully. Accordingly, simulation studies of the ion impact which take into account the clearing electrodes as well as the particle beam are most desirable.

In this paper we introduce a newly implemented method for the study of the behavior of ionized residual gas in the field of electrodes including the passages of the bunch. It allows the 3D tracking of different particle species including the computation of full 3D space charge fields. Thus, we are now not only able to estimate clearing times but also to undertake detailed studies of the behavior of the ions under the influence of the field of the electrodes as well as the bunch. Starting point for this implementation was the software package MOEVE PIC Tracking [3] developed in Rostock originally for the simulation of single bunch instabilities caused by an electron cloud [4].

Within our numerical simulations we have taken into account the parameter settings planned for B*ERL*inPro as described in [5]. The parameters that are relevant for the simulations in this paper are given in Table 1. Since with exception of the beam energy, these parameters are very close to those of the Cornell X-ray ERL, also in this case ions will be a critical issue. In [1] it was shown that for settings similar to those given in the Table 1, all ions will be trapped in the potential of the bunch. Hence, detailed analytical and numerical investigations are very important for the design of B*ERL*inPro.

Table 1: Main Parameters of B*ERL*inPro

maximum beam energy	50 MeV
maximum beam current I	100 mA
nominal beam charge Q	77 pC
maximum repetition rate	1.3 GHz
normalized emittance	10^{-6} m
bunch length σ_t	2 ps
vacuum pressure	10^{-10} mbar

CLEARING ELECTRODES

To avoid the accumulation of the ions in the potential of the electron beam, B*ERL*inPro utilizes clearing electrodes positioned at locations where ion accumulation is expected. The electric force generated by the static fields of these electrodes pulls the ions out of the beam's potential. For this purpose, the voltage of the electrodes has to be sufficiently large. For the computation of the potential U in the centre of the bunch we consider the formula given in [6]:

$$U = \frac{I}{2\pi\varepsilon_0 \beta c}\left(\ln\left(\frac{r_c}{a}\right) - \frac{1}{2}\right). \qquad (1)$$

Here, I denotes the current, ε_0 the vacuum permittivity, β the ratio of the velocity and the velocity of light c, r_c the radius of the vacuum chamber and a the rms radius of the beam, respectively. Note that we use the peak current instead of the average current originally intended in [6]. The reason is that the extremely short and narrow beam of B*ERL*inPro generates a very steep potential, which seems to be much better described with peak (bunch) current than with the average current. Our simulations verify this approach.

With the parameters given in Table 1, we obtain for the peak current of the bunch $I_{peak} = Q/(\sqrt{2\pi}\sigma_t) \approx 15.36$ A. Hence, the voltage yields $U \approx -2625$ V assuming $a = 0.7$ mm and $r_c = 2$ cm.

SIMULATION OF THE ION'S BEHAVIOR

For the presented study, the behavior of the ion cloud in the fields of electrodes and electron beam has been simulated with a further development of the software package MOEVE PIC Tracking [4]. It tracks particles, where the space charge fields are taken into account in each time

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

ISBN 978-3-95450-115-1

step of the tracking procedure. The space charge forces are computed in 3D using the particle-mesh method, i. e. the particles are transformed to the rest frame, where Poisson's equation is solved for the potential (see [2] and citations therein). Hereby, the multigrid Poisson solver MOEVE enables the efficient solution of Poisson's equation [2, 3].

The Poisson equation is solved separately for each particle species. Additionally, the potential of the electrodes is modelled as boundary condition to solve for the potential of the ion cloud. For the superposition the resulting fields are interpolated at the position of the particles - the ions and the (macro) electrons. After the passage of one bunch the ions are tracked further together with the field of the electrodes until the next bunch arrives and the interaction is computed again. The recent version of MOEVE PIC Tracking allows electrodes in beam pipes with rectangular and elliptical cross-sections. The simulations for this paper are performed for a beam pipe with circular cross-section, assuming a radius of 2 cm. The electrodes are modelled as button-like shapes with a diameter of 16 mm. In our model they are located on the opposite sides of the pipe in y-direction and have the same voltage with the same sign.

The electron beam parameters for the simulations are chosen according to the nominal B*ERL*inPro parameters published in [5]. The electron bunch is modelled with 100,000 macro particles using a uniform distribution of a cylindrical shape. For the generation of the distribution the program *generator* of the tracking code ASTRA was applied [7].

In this study we restrict the model of the ion cloud to H_2^+ ions with a relative atomic mass of $A = 2$. Since the residual gas consists mainly of H_2 (98 %) these ions are the most relevant species for investigations of ion effects in B*ERL*inPro. The density of the ions cloud was taken with $2.4{\cdot}10^6$ cm^{-3} according to a vacuum pressure of 10^{-10} mbar. Hence, the number of ions in a circular beam pipe with 2 cm radius is ca. 31 million ions per cm.

RESULTS

The simulations are performed with an ion cloud of 31 million H_2^+ ions distributed over the whole cross-section of the pipe on a length of 1 cm. Additionally, a cloud with only 1 million ions is considered as a proof of principle simulation. The choice of the voltages for the electrodes is with -1600 V below and with -2700 V above the minimum value expected from equation (1).

Figure 1 shows the number of remaining ions as a function of time indicating the clearing times. As expected the clearing with the electrodes of -2700 V (red curves) is much faster than with the lower voltage (blue curves). Whereas most of the ions are cleared quite fast a small rest remains over a long time as shown clearly for the case of 1 million ions in Figure 1 (left). These are ions that are located around the centre of the bunch. In the case of -1600 V the voltage is not high enough to enable full clearing. The electrodes with -2700 V attract the ions also from the bunch centre but it is a very slow process. Hence, a higher voltage has to be chosen for a faster clearing. Figure 2 represents how the ions are attracted by the electrodes (left). Later in time it can be observed that the ions in the vicinity of the beam centre are attracted by the bunch (right) while the ions farther seem to repel each other.

A more detailed analysis of ion oscillations is shown in Figure 3 with the componentwise average momentum. Generally we expect (and observe in our simulations) an oscillation in transversal direction caused by the bunch. With the clearing electrodes included, the remaining ions oscillate around the centre of the bunch, after most of the ions are cleared. For the higher clearing voltage (right) ions can still escape the bunch potential if the amplitude of the oscillation becomes large enough. While the oscillation in the y-direction is strongly disturbed by the clearing voltage, the horizontal oscillation of ions shows less disturbance due to the electrodes, furthermore we observe an oscillation in longitudinal direction caused by the low voltage electrodes, which seems to indicate how the arriving bunch pulls the ions away from the electrodes in cases where the electrode-voltage is not high enough.

CONCLUSION

In this paper we present a simulation study on the behavior of an ion cloud in the potentials of clearing electrodes and electron beam. The simulations are performed with the software package MOEVE PIC Tracking with newly implemented features for ion's simulations. The parameters planned for the ERL facility B*ERL*inPro are chosen for the simulations. We show that a minimum clearing voltage of -2700 V is needed to fully clear the B*ERL*inPro beam from the ions in less than one microsecond. For a faster clearing the clearing voltage has to be higher.

REFERENCES

[1] G. H. Hoffstaetter and M. Liepe. Ion clearing in an ERL. Nuclear Instruments and Methods in Physics Research Section A, 557(1), 205– 212, 2006.

[2] 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 Computational Accelerator Physics 2002, 281–288, Bristol, 2005.

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

[4] A. Markoviḱ, 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, Kyoto, Japan, 1928–1930, 2010.

[5] A. Jankowiak and et al. B*ERL*inPro - a compact demonstrator ERL for high current and low emittance beams. In Proceedings of LINAC 2010, Tsukuba, Japan, 407–409, 2010.

[6] Y. Baconnier. Neutralization of accelerator beams by ionization of the residual gas. CERN-PS-84-24-PSR-REV-2, CERN, 1985.

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

ISBN 978-3-95450-115-1

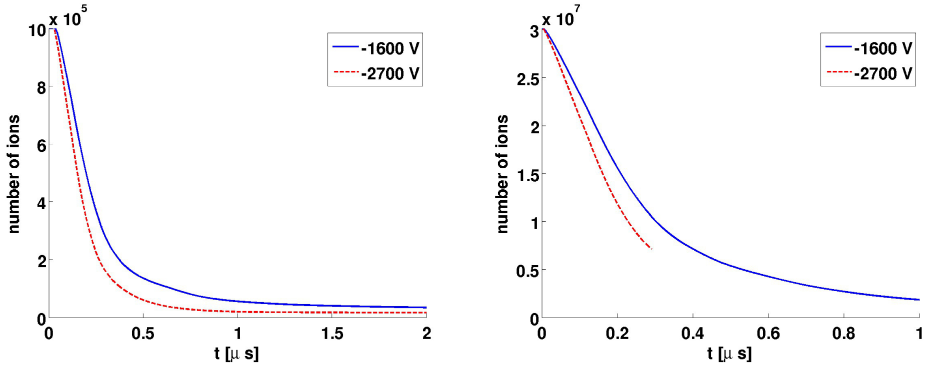

Figure 1: Clearing times of H_2^+ ions with electrodes of different voltage starting with a cloud of 1 million ions (left) and 31 million ions (right) distributed in the whole beam pipe.

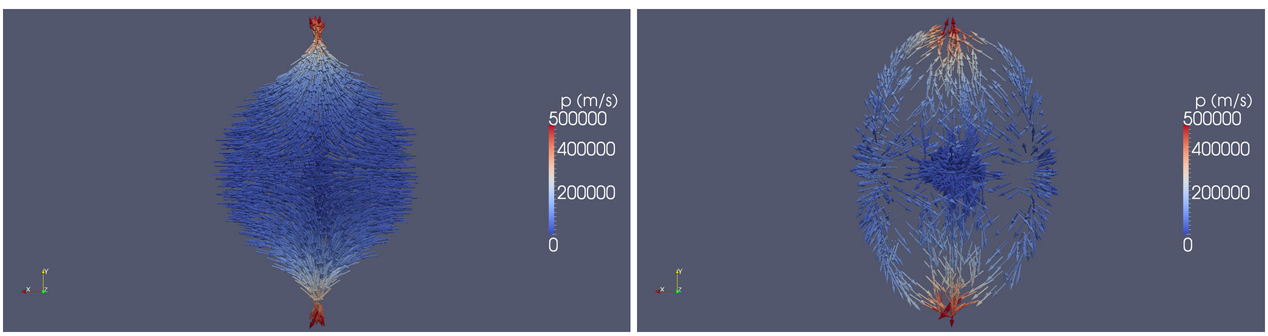

Figure 2: Ion cloud initially located in the whole beam pipe represented along the cross-section of the beam pipe ((x, y)-plane): distribution in the field of electrodes after 50 bunch passages (left) and after 1000 bunch passages (right). Starting with an ion cloud of 1 milion ions and applying electrodes with -2700 V, there are ca. 969,000 ions left after 50 passages and 26,000 ions after 1000 passages of the bunch, respectively.

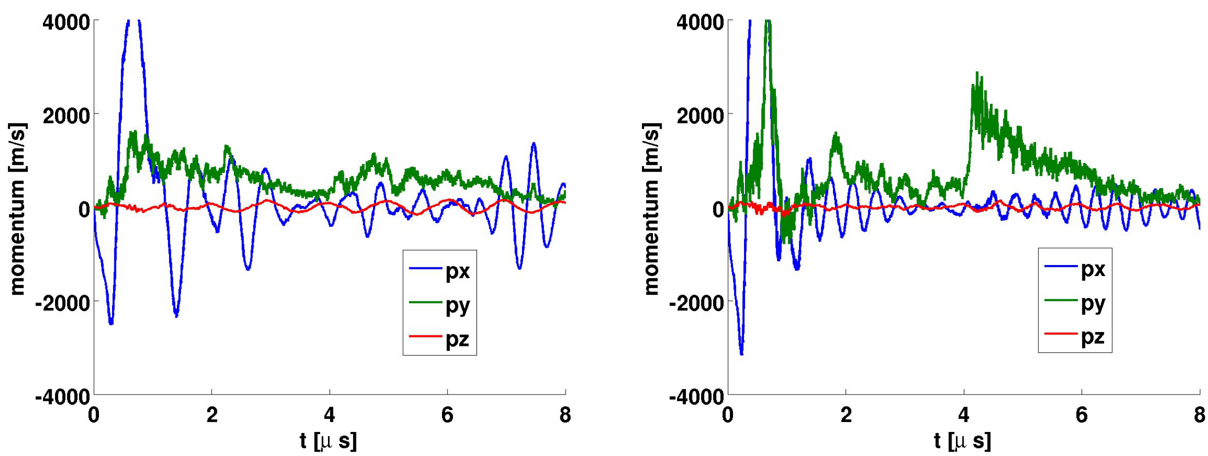

Figure 3: Average momentum of the ion cloud in the field of the bunch and the electrodes with a voltage of -1600 V (left) and -2700 V (right).

ISBN 978-3-95450-115-1