SIMULATIONS FOR ION CLEARING IN AN ERL *

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

Abstract

Light sources of the next generation such as ERLs (Energy Recovering Linacs) require very high quality bunches in order to achieve the research objectives they are designed for. It is essential to avoid sources of instabilities such as ionized residual gas. In order to enable detailed numerical studies the tracking code MOEVE PIC tracking developed by the research group at the University of Rostock was expanded to simulations of the behavior of an ion cloud in the environment of electromagnetic fields. In this paper we take further steps to study possible designs of clearing electrodes - a common countermeasure for the clearing of ions. We present simulations with different compositions of the residual gas. The numerical results taking into account the design of the ERL B*ERL*inPro show how the clearing time depends on the percentage of heavy ions in the ion cloud.

INTRODUCTION

Energy Recovery Linacs (ERLs) being the most promising candidates for next-generation light sources put very high demands on preservation of beam brightness and reduction of beam losses. Thus, it is mandatory to avoid the impact of ionized residual gas considered as a source for instabilities in accelerators [1].

Recently, we have presented simulations for the clearing of ionized residual gas with electrodes performed with an upgraded version of software package MOEVE PIC Tracking. It has been currently further developed to model the interaction of the ions with the electron beam in presence of external electromagnetic potentials such as the field of clearing electrodes [2, 3]. The tracking code allows for studies on clearing times for electrodes with different voltage as well as detailed studies of the behavior of the ions in the environment of the electrodes.

In this paper, we especially consider the influence of different compositions of the residual gas on the clearing times. For our numerical studies, we have chosen two different compositions of ion species in the residual gas due to [1] and [4], respectively. The numerical results indicate that the essential influence on the clearing time for the special composition is caused by the varying percentage of ions much heavier than H_2^+. Furthermore, the parameters for the bunch are taken from the design of B*ERL*inPro due to [5].

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

MOEVE PIC TRACKING FOR THE SIMULATION OF ION CLOUDS

The new version of the software package MOEVE PIC Tracking presented in [3] allows for the computation of the interaction of the ion cloud with the bunch and includes the field generated by the clearing electrodes. All simulations take into account the 3D space charge fields of both bunch and ion cloud. Hence, this approach allows for very detailed numerical studies of the dynamics of ion clouds beyond established theoretical results [6, 7]. For a more detailed description of the upgrade of MOEVE PIC Tracking we refer to [3] and references therein.

Further, the clearing times for different voltages of the electrodes are studied in [3]. The simulations with parameters of B*ERL*inPro confirmed the consideration of the peak current of the bunch rather than the average current in order to assign the voltage of the electrodes. We restricted the ion species in the cloud to H_2^+ ions.

In this paper we present simulations for ion clouds with different compositions of ion species. For the first test case (mixture 1) the residual gas consists of H_2^+ ions (98%), CH_4^+ (1%) and CO^+ ions (1%) due to the studies for the Cornell X-ray ERL [1]. Mixture 2 was taken with H_2^+ ions (48%), CH_4^+ (16%), CO_2^+ (18%), CO^+ (14%) and CO_2^+ (17%) ions due to measurements at SPEAR3 [4]. The main difference of these two compositions lies in the percentage of the ions much heavier than H_2^+: for mixture 1 it is 2% and in mixture 2 it is 52%. The data of these residual gas compositions are summarized in Table 2. Beam pipe and electrodes are modelled as in [3], i. e. we set a circular beam pipe with a radius of 2 cm and button-like electrodes with a diameter of 16 mm. The electrodes are located on opposite sides of the beam pipe and the voltage of each is set to the same value of -2700 V due to the observations in [3].

The ion clouds are modelled with a total number of 1 million ions with the mixtures specified in Table 2. The ions are distributed over the whole pipe's cross-section

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

ISBN 978-3-95450-116-8

Table 2: Mixtures of Ionized Residual Gas Used for the Simulations

	ion species	percentage	mass number
mixture 1	H_2^+	98 %	2
	CH_4^+	1 %	16
	CO^+	1 %	28
mixture 2	H_2^+	48 %	2
	CH_4^+	5 %	16
	H_2O^+	16 %	18
	CO^+	14 %	28
	CO_2^+	17 %	44

along a length of 1 cm. The bunch was generated by the program *generator* of ASTRA [8] with 100,000 macro electrons uniformly distributed in a cylinder due to the parameters given in Table 1.

RESULTS

The first question we considered was how many ions we have to take into account for the simulations. Assuming that all molecules of the residual gas are ionized a pipe with a radius of 2 cm is filled with 31 million ions per cm at a vacuum pressure of 10^{-10} mbar. Simulation results for these parameters were presented in [3]. Since in practice we expect rather a vacuum pressure of 10^{-8} mbar related simulations would require 3,100 million ions per cm which is impossible to run on a normal PC. Hence, the question is what could be concluded from a simulation with e. g. 1 million ions for the dynamics of 31 million ions and more.

As a test case we compared the results from simulations with ion clouds - consisting of H_2^+ only - of 1 million, 31 million (vacuum pressure of 10^{-10} mbar) and 150 million ions (vacuum pressure of ca. $5 \cdot 10^{-10}$ mbar), respectively. Figure 1 represents the clearing time for these ion clouds scaled up to 150 million in order to make the results comparable. It turns out that independently of the number of ions most of the ions are cleared after 1 µs. Furthermore the dynamics of the ions at different densities is quite similar as shown in Figure 2. As a consequence we performed the simulations with mixed ions only with a total number of 1 million ions.

Figure 3 shows the clearing time for ionized residual gas with compositions due to Table 2. As expected the clearing time increases for increasing percentage of heavier ions in the ionized residual gas. Figure 4 represents the transversal dynamics of the different ion clouds. Furthermore, Figure 5 shows the evolution of the ion cloud with mixture 1 within the first µs, where only H_2^+ (dark blue) and CH_4^+ (light blue) are plotted. The originally uniformly distributed ion species are separated due to their different mass and consequently different velocity.

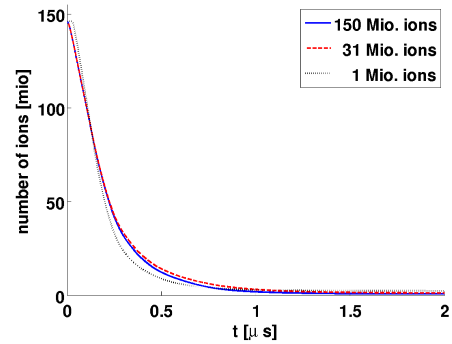

Figure 1: Clearing times of ion clouds with H_2^+ ions cleared by the field of electrodes with a voltage of -2700 V.

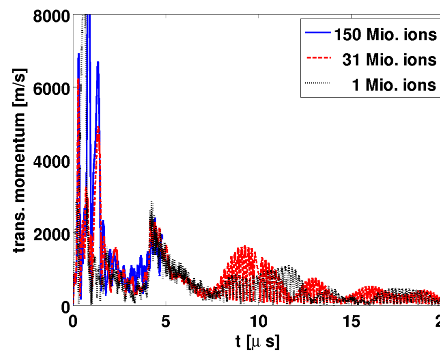

Figure 2: Transversal momentum of ion clouds with H_2^+ ions in the field of electrodes with a voltage of -2700 V.

CONCLUSION

In this paper we presented a simulation study on the behavior of an ion cloud in the potentials of clearing electrodes and electron beam. The simulations are performed for different compositions of ions in the residual gas. The software package MOEVE PIC Tracking allows for a detailed analysis of the dynamics of an ion cloud which

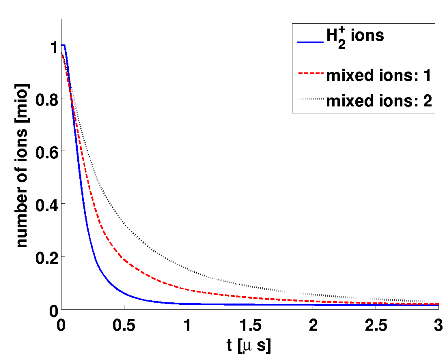

Figure 3: Clearing times of clouds with different compositions of ions compared to H_2^+ ions cleared by the field of electrodes with a voltage of -2700 V.

ISBN 978-3-95450-116-8

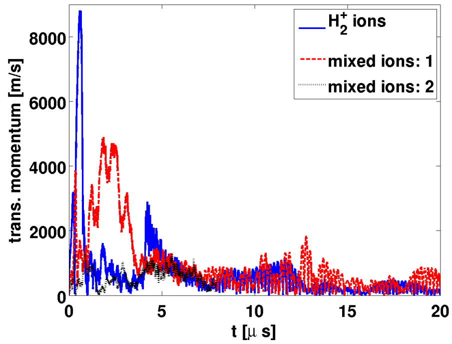

Figure 4: Transversal momentum of ion clouds with different compositions of ions compared to H_2^+ ions in the field of electrodes with a voltage of -2700 V.

undergoes the potentials of the electron beam and clearing electrodes simultaneously. The deep understanding of this dynamics is important for further design studies for B*ERL*inPro. The simulation results indicate that the percentage of the ions with much heavier mass than H_2^+ ions have a significant impact on the clearing time. The higher the percentage of the heavy ions the longer the clearing time.

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. Multigrid algorithms for the fast calculation of space-charge effects in accelerator design. *IEEE Transactions on Magnetics*, 40(2):714–717, 2004.

[3] G. Pöplau, A. Meseck, and U. van Rienen. Simulation of the behavior of ionized residual gas in the field of electrodes. In *Proceedings of IPAC 2012, New Orleans, USA*, 283–285, 2012.

[4] L. Wang, Y. Cai, T. O. Raubenheimer, and H. Fukuma. Suppression of beam-ion instability in electron rings with multibunch train beam fillings. *Phys. Rev. ST Accel. Beams*, 14:084401, Aug 2011.

[5] A. Knobloch and et al. Status of the B*ERL*inPro Energy Recovery Linac Project. In *Proceedings of IPAC 2012, New Orleans, USA*, 601–603, 2012.

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

[7] A. Poncet. Ions and neutralization. In M. Dienes, M. Month, and S. Turner, editors, *Frontiers of Particle Beams: Intensity Limitations*, volume 400 of *Lecture Notes in Physics*, Springer Berlin / Heidelberg, 488–508, 1992.

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

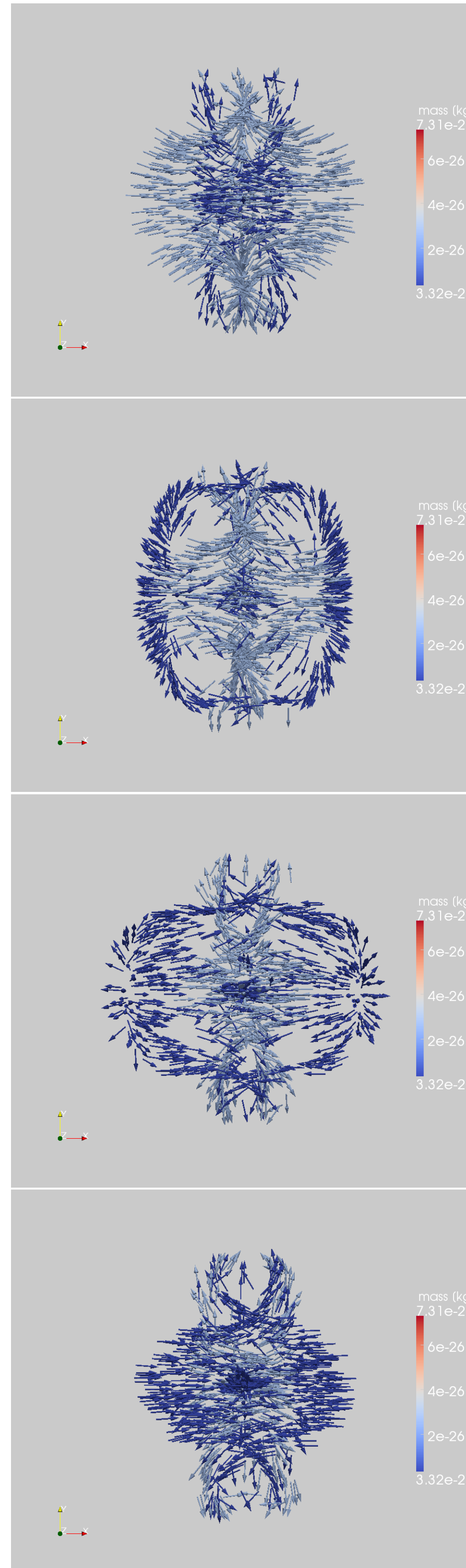

Figure 5: Evolution of an ion cloud (dark blue: H_2^+, light blue: CH_4^+) in the field of electrodes with a voltage of -2700 V after 0.23 μs, 0.38 μs, 0.54 μs and 0.69 μs (from top).

ISBN 978-3-95450-116-8