ISBN: 978-3-95450-217-2 doi:10.18429/JACoW-ERL2019-WEPNEC10

INVESTIGATION ON THE ION CLEARING OF MULTI-PURPOSE ELECTRODES OF BERLINPRO

G. Pöplau*, Universität zu Lübeck, Lübeck, Germany
A. Meseck, HZB, Berlin, and Johannes Gutenberg-Universität, Mainz, Germany

Abstract

High-brightness electron beams provided by modern accelerators require several measures to preserve their high quality and to avoid instabilities. The mitigation of the impact of residual ions is one of these measures. It is particularly important if high bunch charges in combination with high repetition rates are aimed for. This is because ions can be trapped in the strong negative electrical potential of the electron beam causing emittance blow-up, increased beam halo and longitudinal and transverse instabilities. One ion-clearing strategy is the installation of clearing electrodes. Of particular interest in this context is the performance of multi-purpose electrodes, which are designed such that they allow for a simultaneous ion-clearing and beam-position monitoring. Such electrodes will be installed in the bERLinPro facility. In this contribution, we present numerical studies of the performance of multi-purpose clearing-electrodes planned for bERLinPro, i.e. we investigate the behavior of ions generated by electron bunches while passing through the field of the electrodes. Hereby, several ion species and configurations of electrodes are considered.

INTRODUCTION

The Energy Recovery Linac bERLinPro is currently being set up at the Helmholtz-Zentrum Berlin. Based on superconductive RF (SRF) technology, it aims to deliver high current, low emittance cw beams, and to demonstrate energy recovery at unprecedented parameters [1].

In general, Energy Recovery Linacs place very high demands on maintaining beam brightness and reducing beam losses. Ions in vicinity of the electrons have a ruinous impact on the brightness and stability of the beam. This also applies to bERLinPro. Hence counter measures such as clearing electrodes and their performance is of highest importance for the project. For bERLinPro multi-purpose electrodes, that enable simultaneous ion-clearing and beam position monitoring were developed and built at the HZB [2].

They consist of four rectangular electrode-plates, which can in principal be biased independently with a voltage up to 1000V resulting in different voltage-configurations. The different voltage-configurations naturally have different distributions of the electric field. In this paper, we evaluate the performance of the bERLinPro multi-purpose electrodes for four different voltage-configurations. We relate the difference in performance for different voltage-configurations to the motion of the ions within the corresponding clearing fields.

* poeplau@math.uni-luebeck.de

Table 1: Nominal Parameters of bERLinPro.

bERLinPro Bunch	
Nominal Beam Energy	50 MeV
Nominal Beam Charge Q	77 pC
Maximum Repetition Rate	1.3 GHz
Transv. RMS Bunch Size $\sigma_{x,y}$	300 μm
Bunch Length σ_t	2 ps
Vacuum Pressure	$5 \cdot 10^{-10}$mbar

SIMULATION SETUP AND SIMULATION TOOLS

In this section a short introduction to the simulation setup and the simulation tools are provided. Since the applied models and simulation tools coincide with those used for former studies, more details can be found in [2, 3]. The nominal parameters of bERLinPro that are relevant for the simulations are summarized in Table 1.

The Multi-Purpose Electrode

A description of the technical details of the bERLinPro multi-purpose electrode was given in [2]. Here we only provide the information relevant for the presented simulation studies. The multi-purpose electrodes are constructed of four rectangular stripes (electrode-plates) with a size of 10 mm x 38 mm. These stripes are placed pairwise in parallel with a distance of 24.72 mm along the elliptical beam pipe of bERLinPro (70 mm x 40 mm).

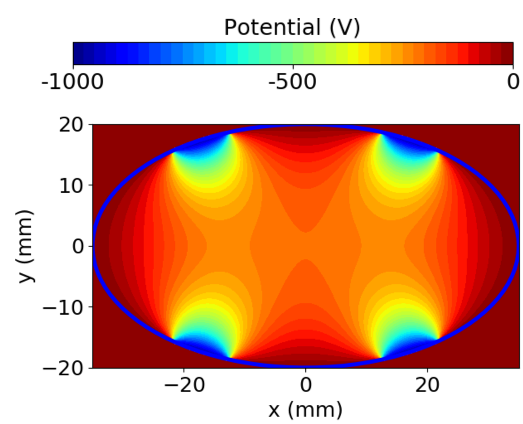

Figure 1: The potential of the bERLinPro multi-purpose electrode with a voltage of −1000 V supplied to all four electrode-plates.

Figure 1 shows the potential of the electrodes with the typical voltage-configuration, where a voltage of −1000 V is

ISBN: 978-3-95450-217-2 doi:10.18429/JACoW-ERL2019-WEPNEC10

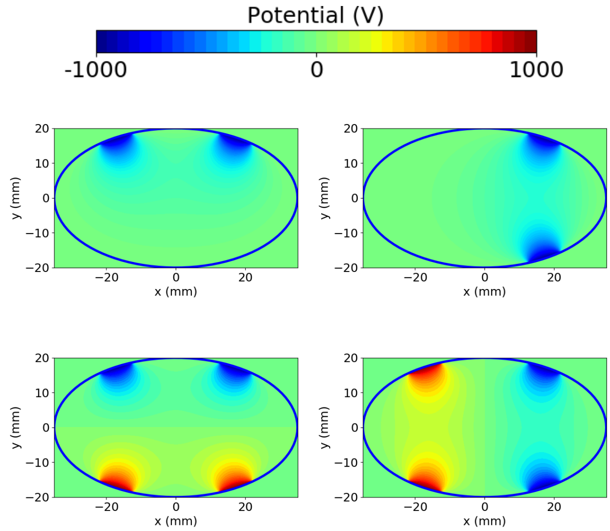

Figure 2: Potential of the bERLinPro multi-purpose electrode in transversal cross-section: voltage-configuration 1 (top, left), voltage-configuration 2 (top, right), voltage-configuration 3 (bottom, left) and voltage-configuration 4 (bottom, right).

supplied to all four electrode-plates. In [2] it was shown that this voltage-configuration has a poor clearing performance, because in this case the strength of the electric field at the position of the electron beam is rather low.

In this paper we investigate the clearing performance of voltage-configurations that provide a high field gradient at the pipe centre, i.e. at the position of the electron beam. The clearing performance and rates in the case of the bERLinPro multi-purpose electrodes were examined for the following voltage-configurations:

- *voltage-configuration 1*: the negative voltage is supplied to the two upper stripes and zero voltage to the two lower stripes of the clearing electrode.
- *voltage-configuration 2*: the negative voltage is supplied to the two right stripes and zero voltage to the two left stripes of the clearing electrode.
- *voltage-configuration 3*: the negative voltage is supplied to the two upper stripes and the positive voltage to the two lower stripes of the clearing electrode.
- *voltage-configuration 4*: the negative voltage is supplied to the two right stripes and the positive voltage to the two left stripes of the clearing electrode.

Figure 2 shows the potentials in transversal cross-section with a voltage of +/-1000 V applied to the electrodes. It has to be mentioned that the voltage-configurations 1 and 3 were already studied in [2] with a voltage of 1000 V. We repeat these results here in order to give a direct comparison to the voltage-configurations 2 and 4.

The Ion Model

In order to allow the comparison of the simulation results presented in this paper to former results we apply two different mixtures of residual gas introduced in [3]. Both mixtures are compositions of H_2^+, CH_4^+ and CO^+, where Gas A consists mainly of the light H_2^+-ions and gas B consists roughly of 50% H_2^+-ions and 50% of the much heavier CH_4^+- and CO^+-ions. Within the present simulations the ions are generated due to collisions with the electrons of the bunch, where the production rate R_j of ion j is described by the following model [4]:

$$R_j = cN_e\sigma_j\frac{P}{k_BT}. \tag{1}$$

Hereby c denotes the speed of light, N_e the number of electrons in the bunch, σ_j the ionization cross-section of ion species j (see [5]), P the vacuum pressure, k_B the Boltzmann constant and T the temperature.

The resulting number of bunch passages after which a new ion per cm is generated is given in Table 2 for the bERLinPro case. Furthermore, within the simulations the ions are generated at a length of 4 cm. This is approximately the length of the electrode-plates. For a more detailed picture also the total number of ions generated after a simulation time of 10 ms (1.3 million bunch passages) at a length of 4 cm is added to Table 2.

Table 2: Mixtures of Ionized Residual Gas and the Corresponding Ionization Process for the bERLinPro Case

ion species	**%**	**ion gener. after bunch no.**	**total no. of ions** (10 ms) **4 cm**
Gas A			
H_2^+	98	18,500	2,812
CH_4^+	1	282,500	188
CO^+	1	330,000	160
Gas B			
H_2^+	48	37,000	1,388
CH_4^+	26	11,000	4,728
CO^+	26	13,000	4,000

Simulation Tools

The ions once generated are tracked further due to the equations of motion under the influence of the attracting field of the passing bunches and the field of the multi-purpose electrode. Once an ion hits the electrode or wall of the beam pipe the ion is neutralized and will be tracked no longer. This approach enables a detailed study of the built-up of the ion cloud (accumulation) and the level of the established equilibrium.

The tracking and the generation of ions was performed with the code CORMORAN [3]. Here also the potential of the bunch is computed. The potential of the multi-purpose electrode is pre-computed by means of the Python Poisson

ISBN: 978-3-95450-217-2 doi:10.18429/JACoW-ERL2019-WEPNEC10

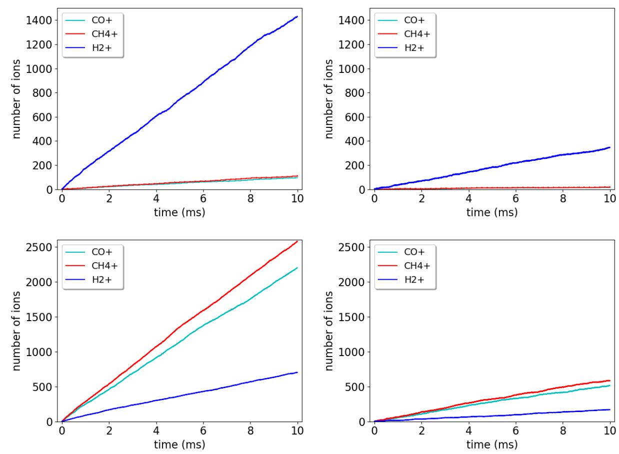

Figure 3: Comparison of electrode 1 (left) and 2 (right) at a voltage of 1000 V: the number of remaining ions is shown as a function of clearing time for gas mixture A (top) and B (bottom).

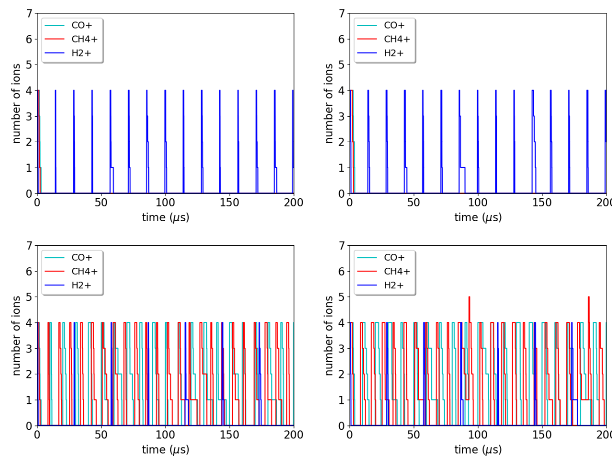

Figure 4: Comparison of electrode 3 (left) and 4 (right) at a voltage of 1000 V: the number of remaining ions is shown as a function of clearing time for gas mixture A (top) and B (bottom).

Solver [6]. More details about the simulation model and parameters can be found in [3, 6].

The time for a bunch passage was set to 200 ps due to an interaction region of 4 cm with a step size of 2 ps. The remaining time between two bunches was discretized by 10 equal time steps.

SIMULATION RESULTS

First, let us examine the four voltage-configurations with a voltage of 1000 V. The corresponding potentials are depicted in Figure 2. Figure 3 presents the results for voltage-configuration 1 and 2. It can be observed, that in both cases the ions accumulate, but the accumulation rate for voltage-configuration 2 is four times less than for voltage-configuration 1. With voltage-configuration 2 nearly 90%

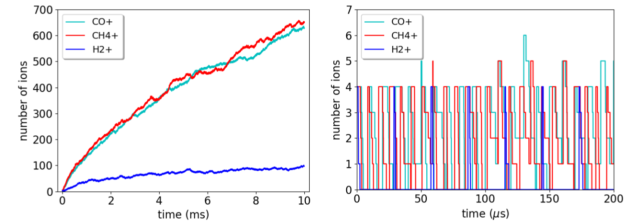

Figure 5: Comparison of electrode 3 (left) and 4 (right) at a voltage of 600 V: the number of remaining ions is shown as a function of clearing time for gas mixture B.

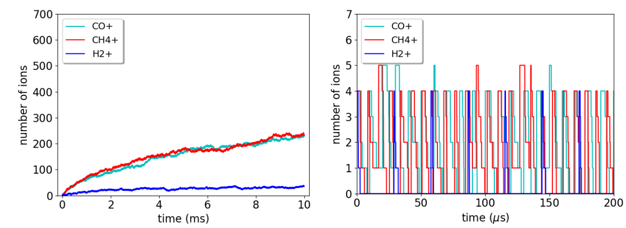

Figure 6: Comparison of electrode 3 (left) and 4 (right) at a voltage of 700 V: the number of remaining ions is shown as a function of clearing time for gas mixture B.

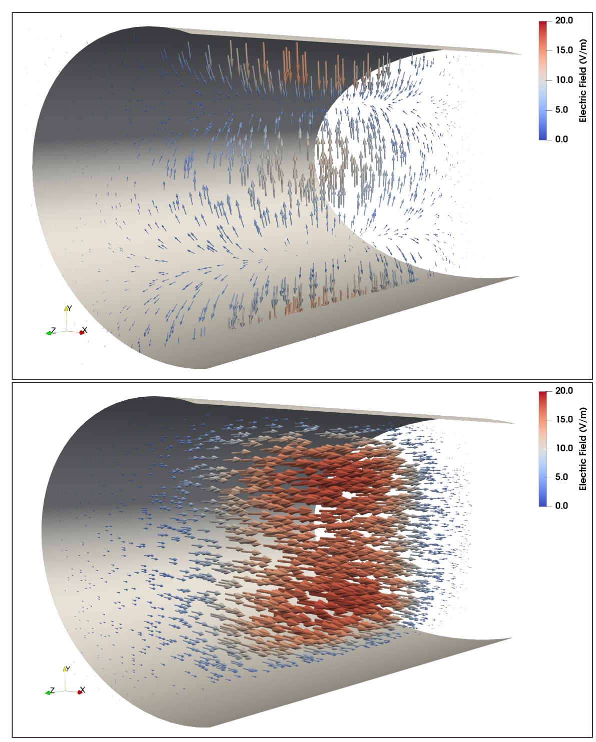

Figure 7: Electric field of the multi-purpose electrode: voltage-configuration 3 with a voltage of 1000 V (top) compared to voltage-configuration 4 (bottom); the longitudinal cross-sections at $x = 0$ are shown.

ISBN: 978-3-95450-217-2 doi:10.18429/JACoW-ERL2019-WEPNEC10

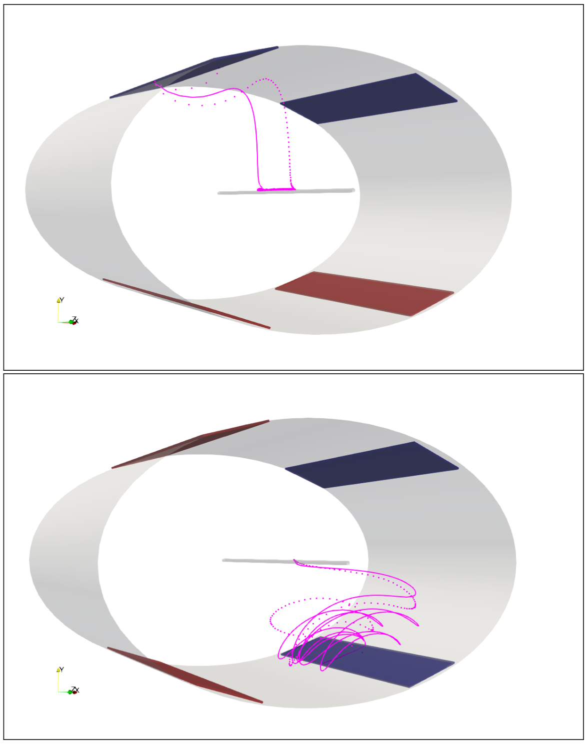

Figure 8: Path of an ion in the field of the multi-purpose electrode with a voltage of 700 V (solid line) and with a voltage of 1000 V (dashed line): voltage-configuration 3 (top) compared to voltage-configuration 4 (bottom).

of the generated ions are cleared after 10 ms, whereas only around 50% are cleared with voltage-configuration 1.

In the case of the voltage-configuration 3 and 4 all ions are cleared almost immediately after the generation, see Figure 4. Therefore, we investigated these two voltage-configurations with lower voltages of 600 V and 700 V. The simulation results for gas mixture B are presented in the Figures 5 and 6, respectively. It turns out that the ions are immediately cleared for voltage-configuration 4. This happens even at lower voltages. This is not the case with voltage-configuration 3, where the ions accumulate more as the voltage decreases. The reason seems to be that the electric field at the centre of the pipe is much higher for voltage-configuration 4 than for voltage-configuration 3 as shown in Figure 7. As a consequence an ion lingers much longer in the vicinity of the beam in the case of voltage-configuration 3, whereas it is kicked out from the centre of the pipe with voltage-configuration 4, see Figure 8. Similar considerations can be made for the difference between voltage-configuration 1 and 2.

CONCLUSIONS

Using numerical codes we have evaluated the performance of the bERLinPro multi-purpose clearing electrodes for four different voltage-configurations. We have observed that voltage-configurations that have the stripes biased with the same voltage on the left and right side perform far better than voltage-configurations that have the stripes biased with the same voltage on top and bottom. Although the stripes may be in principal independently biased, configurations 2 and 4 may not be possible at bERLinPro for a technical reason. This needs to be checked.

REFERENCES

[1] M. Abo-Bakr *et al.*, "Status report of the berlin energy recovery linac project bERLinPro," in *Proc. IPAC'18*, Vancouver, BC, Canada, Apr. 4,, pp. 4127–4130, `doi:10.18429/JACoW-IPAC2018-THPMF034`

[2] G. Pöplau, M. Meseck, F. Falkenstern, M. Markert, and J. Bartilla, "Investigation on the ion motion towards clearing electrodes in high-brightness electron accelerators," `arXiv:1910.04025`, 2019.

[3] G. Pöplau and M. Meseck, "Investigation on the ion motion towards clearing electrodes in an accelerator," in *Proc. IPAC2017*, Copenhagen, Denmark, May 2017, paper THPAB016, pp. 3723–3726. `doi:10.18429/JACoW-IPAC2017-THPAB016`

[4] A. Poncet, "Ions and neutralization," in *Frontiers of Particle Beams: Intensity Limitations* (M. Dienes, M. Month, and S. Turner, eds.), vol. 400 of *Lecture Notes in Physics*, pp. 488–508, Springer Berlin / Heidelberg, 1992. `doi:10.1007/3-540-55250-2_41`

[5] F. F. Rieke and W. Prepejchal, "Ionization cross sections of gaseous atoms and molecules for high-energy electrons and positrons," *Phys. Rev. A*, vol. 6, pp. 1507–1519, Oct 1972. `doi:10.1103/PhysRevA.6.1507`

[6] G. Pöplau and C. Potratz, "A python poisson solver for 3D space charge computations in structures with arbitrary shaped boundaries," in *Proc. IPAC 2014* (5th International Particle Accelerator Conference), Dresden, Germany, pp. 406–408, 2014. `doi:10.18429/JACoW-IPAC2014-MOPME013`