CLIC-DR ELECTRON CLOUD BUILD UP SIMULATIONS

F. Yaman[*], İzmir Institute of Technology, İzmir, Turkey
G. Iadarola, D. Schulte, CERN, Geneva, Switzerland

Abstract

This study investigates impact of beam pipe material and external magnetic field on electron cloud build up mechanism. The machine parameters are in the scope of CLIC damping rings. Two different filling schemes for 0.5 and 1 ns bunch spacings are considered. VSim Plasma Discharges and Plasma Acceleration package is employed to perform 2D electrostatic particle in cell simulations such that the space charge effect and Furman-Pivi secondary emission yield model are included in the computations. It is illustrated that the build up time varies due to bunch spacing while the external magnetic field influences the number of electrons generated by initial seeds. The evolution of generated secondary electrons due to bunch passes and the corresponding energy levels are presented in details.

INTRODUCTION

CLIC damping rings reduce the emittance of particle beams to achieve design considerations of the e^- and e^+ main linacs. Smaller emittance for a sufficiently short damping time can be obtained via long wiggler magnet sections. Accordingly, quantification of magnetic field on the electron build-up is of interest. Initial studies for CLIC-DR simulations with ECLOUD 2.4 and PyECLOUD are presented in [1,2], respectively. Both studies predict electron cloud formations for certain secondary emission yields and scenarios, i.e. including residual gas and photoemission mechanisms. Within this framework, the present study employs alternatively VSim package [3] and Furman-Pivi secondary emission yield model [4] for the CLIC damping ring simulations by modifying machine/beam parameters slightly compared to the former works. Here a similar simulation set-up presented in [5] is used for two dimensional case. However, not only stainless steel but also copper as a beam pipe material is investigated. Additionally the external magnetic field variations are examined in this study.

MACHINE & SIMULATION PARAMETERS

The circumference of the damping ring is 427.5 m such that an elliptical beam pipe with the horizontal and vertical radii 40 and 6 mm, respectively is considered. The energy of the beam is 2.86 GeV given for the bunch population 4.1×10^9 positrons per bunch. The beam is elliptical with the transverse horizontal and vertical emittances $\epsilon_x = 500$ and $\epsilon_y = 5$ nm. Two filling patterns for 2 batches per beam i.e. 312 bunches per batch with 0.5 ns bunch spacing and 156 bunches per batch with 1 ns bunch space are studied. The Gaussian shaped bunches with the length of 1.8 mm in the longitudinal direction are used. Initial electron density is chosen as 5×10^{12} m^{-3}, based on the results in [6]. Furthermore it is assumed that initial electrons having Gaussian distribution on the transversal plane are confined at a circular cross section of radius $\approx$ 4 mm in the beam pipe at time zero. Afterwards the Poisson's equation is computed at each time step $\approx 3.23 \times 10^{-12}$ sec. via the SuperLU direct solver on a uniform two dimensional cartesian grid. More than 4.4 M of time steps are calculated in a parallel manner via a desktop-type workstation using 4 cores to simulate a single revolution period. The accuracy and the convergence of the solution are evaluated by considering the number of macro particles and grid cells. Throughout the paper, Furman-Pivi model is employed for copper, with max(SEY) = 2.1 at a primary energy of E_{max} = 271.0 eV and for stainless steel with max(SEY) = 2.05 at of E_{max} = 292.0 eV, see [4].

NUMERICAL RESULTS

Firstly, quantifications of electron densities for 0.5 ns and 1 ns bunch spacings for copper and stainless steel beam pipes are illustrated in Fig. 1. As it is expected the shorter bunch spacing increases the number of generated electrons. Additionally, one can conclude that the impact of steel beam pipe on electron generations is more significant compared to shorter bunch spacing, i.e. electron density for 1 ns steel is larger than 0.5 ns copper. Furthermore, for the case 1 ns copper the lowest density and the longest build-up time is obtained.

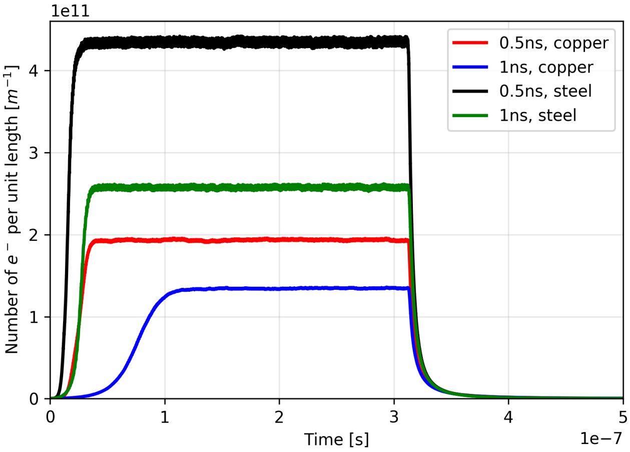


Figure 1: Ecloud build up for two types of bunch spacings and beam pipe materials.

Next, the dependence of electron cloud build up for externally applied magnetic field in the transverse direction is examined. The beam pipe material is chosen as copper and bunch spacing is 0.5 ns. The maximum value of the magnetic field in Fig. 2 is limited by considering a possi-

---

[*] fatihyaman@iyte.edu.tr

ble choice of the wiggler field, see [7]. Here the effect of magnetic field on the reduction of the secondarily generated electrons is confirmed. This nonlinear effect slightly shortens the dissipation time of the existing electrons in the chamber.

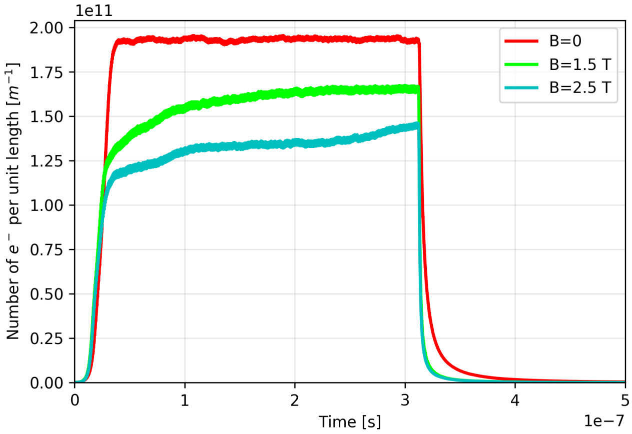
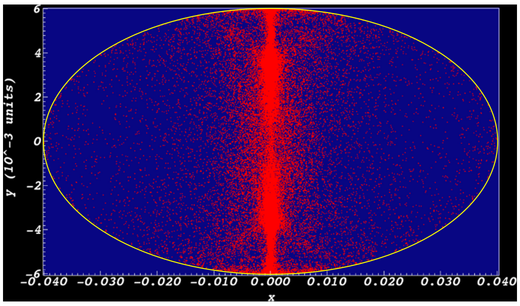
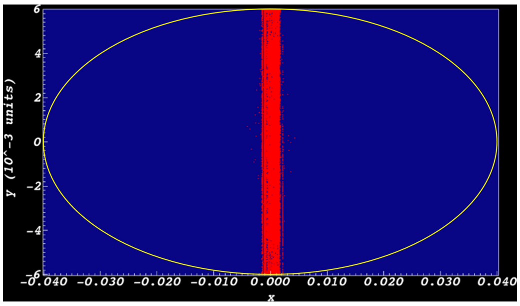


Figure 2: Effect of magnetic field on the Ecloud build up for 0.5 ns bunches, copper beam pipe.

Additionally, the external magnetic squeezes the electrons in a regular form at the center of the beam pipe and decreases the interaction of the electrons with the pipe surface, see Fig.3. A similar distribution as in Fig.3b is presented in [2] for the simulations of CLIC-DR wiggler magnets with PyECLOUD.



(a) B = 0



(b) B = 2.5 T

Figure 3: Electron distribution w.r.t external magnetic field for 0.5 ns copper pipe @21.376 ns.

The impact of the magnetic field for different bunch spacings and materials can be seen by comparing Fig. 1 and Fig. 4. In all cases the number of electrons is reduced and the decrease rate depends non-linearly on the material type. Furthermore, rapid electron generations in the build-up regime is observed. Particularly for the stainless steel beam pipe material the magnitude of the oscillations is increased.

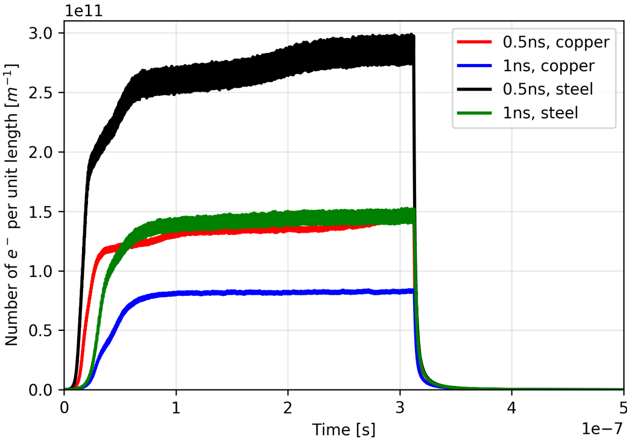


Figure 4: Ecloud build up for two types of bunch spacings and beam pipe materials with 2.5 T magnetic field.

The energy of the electrons for the copper beam pipe for 0.5 and 1 ns bunch spacings is illustrated in Fig. 5. Certain ranges from build-up, saturation and dissipation regions are zoomed as well. The increase in the energy is consistent with the bunch spacing which indicates the energy gains due to bunch passes. The maximum energy 3.95 μJ is observed in 30 ns for the 0.5 ns bunches while 2.1 μJ is reached after 50 ns using 1 ns bunch spacing. Afterwards, electrons oscillate in the saturation region and gain energy up to $\approx$ 1.62 μJ during 275 ns and $\approx$ 1 μJ during 255 ns for the 0.5 and 1 ns, respectively. Finally, electron cloud formation dissipates exponentially in 20 ns after the bunch passes, for both bunch spacing scenarios. The time needed to vanish electrons from the computational domain does not change significantly with respect to pipe material. Furthermore, similar energy plots but for the different values are obtained using stainless steel pipe. For instance, electrons reach 7.1 and 3.6 μJ maximums in 20 and 40 ns for 0.5 and 1 ns bunches, respectively. The saturation is also longer for the 0.5 ns case compared to 1 ns bunch spacing, i.e. 285 and 265 ns. The behaviours of the energy patterns agree well with the number of generated electrons for the investigated scenarios. The number of electrons reaches largest values consistently with the computed maximum energy gains for shorter bunch spacing using steel pipe, see Fig. 1 and Fig. 4. In particular, similar number of electrons for the 0.5 ns copper and 1 ns steel is obtained in saturation, see Fig. 4, from the similar number of energy gains, i.e. 3.4 μJ . Furthermore it is noted that the behaviours of the CLIC-DR simulation results for copper and steel pipes agree with those presented in [8] by considering the FNAL recycler machine for the parameters, pipe radii: (22, 47) mm, energy: 8 GeV, proton bunch population: 5.25×10^{10}, bunch length: 60 cm, beam radius: 3 mm and bunch spacing: 18.94 ns.

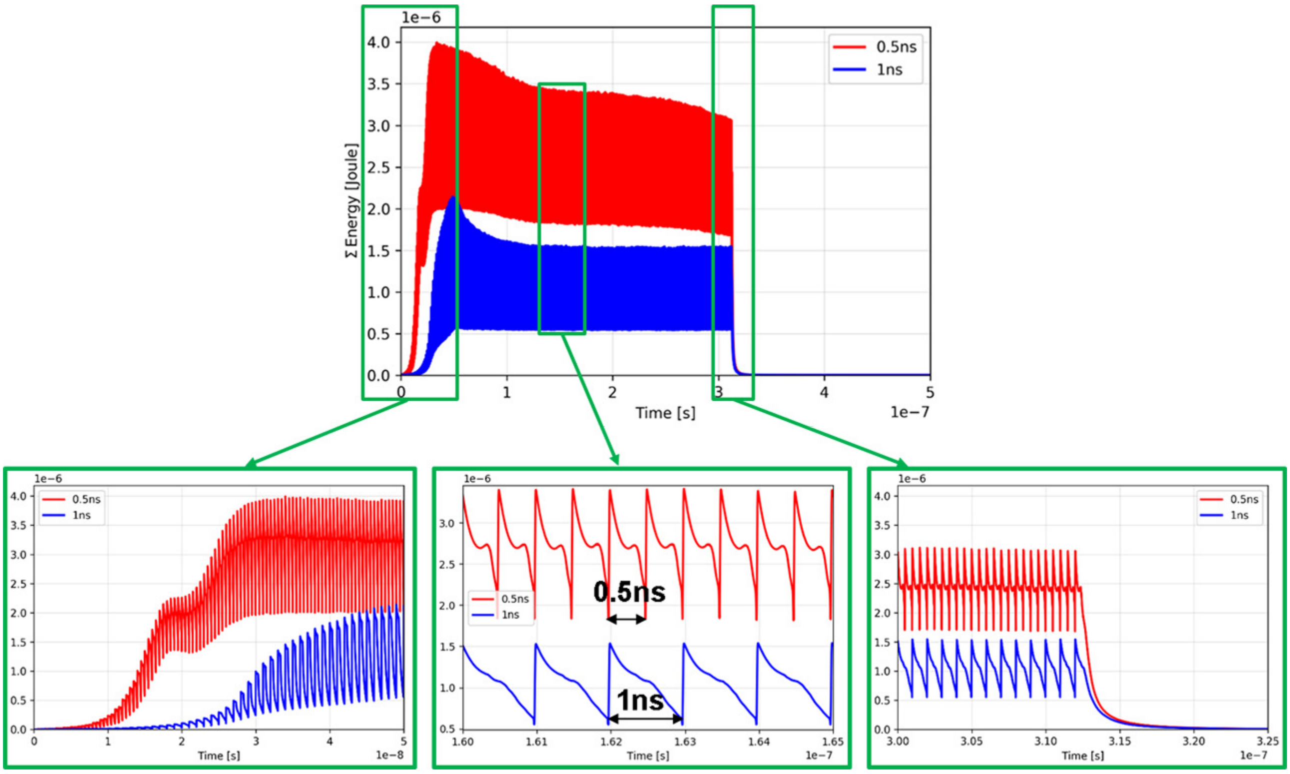


Figure 5: Energy of the electrons for two types of bunch spacings with copper beam pipe.

CONCLUSION

In this study, effects of external magnetic field and copper/stainless steel pipe materials on the number of electrons and corresponding energies are quantified via VSim for the CLIC-DR machine for positron beam parameters. The computational domain is loaded with initial electrons as seeds of the secondaries generated according to Furman-Pivi secondary emission yield model. The collisions of the positron beam with the residual gases and photoemission mechanisms are omitted in simulations in order to focus on magnetic field and pipe material effects. It is confirmed that applying external dipole magnetic field and increasing bunch spacing reduces the electron cloud density. Furthermore, stainless steel has a significantly higher capability to emit electrons as compared to copper. External magnetic field aligns electrons at the center of the beam pipe in a narrow region as a stripe and reduces the interaction area of the pipe surface for the electrons. Moreover, magnetic field decreases number of secondaries in different ratios for steel and copper pipes.

ACKNOWLEDGEMENTS

We would like to thank S.A. Veitzer and J. Smith for their help on VSim.

REFERENCES

[1] D. Schulte, R. Wanzenberg and F. Zimmermann, "Electron-Cloud Effects in the TESLA and CLIC Positron Damping Rings", Proc. ECLOUD04, Napa, 2004, CERN-2005-001 (2005)

[2] G. Iadarola, G. Rumolo and H. Bartosik, "Electron Cloud Build up Studies for the CLIC Positron Damping Ring", presented in TWIICE2014 (2014), `https://indico.cern.ch/event/277919/`

[3] VSim, Powered by Vorpal; Empowered by Tech-X Corp.

[4] M.A. Furman and M.T.F. Pivi, "Probabilistic Model for the Simulation of Secondary Electron Emission", PRST-AB, 5, 124404, (2002)

[5] S. A. Veitzer and P. H. Stoltz, "Electron Cloud Buildup and Dissipation Models For PIP-II", IPAC2015, Richmond, VA, USA, MOPMA037, (2015)

[6] G. Rumolo, W. Bruns and Y. Papaphilippou, "Electron Cloud Build up and Instability in the CLIC Damping Rings", Proc. EPAC08, Genoa, Italy, MOPP050, (2008)

[7] E. K. Platia, "High Frequency Effects of Impedances and Coatings in the CLIC Damping Rings", PhD Thesis EPFL, CERN-THESIS-2015-152, (2015).

[8] F. Yaman, "A Numerical Investigation for the Electron Cloud Build-up Mechanism" Proc. HEZARFEN, İzmir, Turkey, (2019).