ELECTRON CLOUD BUILD UP AND INSTABILITY IN THE CLIC DAMPING RINGS *

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Abstract

Electron cloud can be formed in the CLIC positron damping ring and cause intolerable tune shift and beam instability. Build up simulations with the Faktor2 code, developed at CERN, have been done to predict the cloud formation in the arcs and wigglers of the damping rings. HEADTAIL simulations have been used to study the effect of this electron cloud on the beam and assess the thresholds above which the electron cloud instability would set in

INTRODUCTION

The CLIC design relies on the presence of pre-damping and damping rings in the transport of electron/positron beams from the source to the interaction point, which are needed to “cool” the beams to the desired emittances through synchrotron radiation. A positron damping ring stores the positron beam during several damping times, so that the beam can be extracted from it with a very low emittance (the equilibrium emittance of the ring, depending on the optics). The beam is later sent to the main linac, which will provide the beam with the right energy for collision. The damping rings usually accumulate many densely populated positron bunches with a narrow spacing. Therefore, electron cloud could be an issue. The positron beam emits synchrotron radiation photons, which create a large number of photoelectrons at the inner chamber wall surface. Though antechambers are used to absorb a large percentage of the produced synchrotron radiation and thus reduce the number of photoelectrons, still a considerable rate of photoelectrons are scattered inside the vacuum chamber and they can multiply through secondary emission. This causes electrons to be accumulated in the chamber in large amounts with a possible destabilizing effect on the circulating beam. A study of the electron cloud effect in the positron damping ring is one of the most important subjects to assess the feasibility of the linear collider with some given parameters. Some works on the electron cloud effect in the damping rings or linear colliders have been published throughout the years (CLIC, NLC, TESLA, JLC, ILC) [1, 2]. In this paper, studies of electron cloud build-up and single bunch instabilities with the Faktor2 and HEADTAIL codes are reviewed for the latest CLIC damping ring design parameters. The set of the CLIC damping ring parameters is shown in Table 1 [3].

THE FAKTOR2 CODE

Faktor2 is a new code developed at CERN, which can simulate electron cloud build up around positron or hadron beams, or ion accumulation around electron beams. Primary generation of electrons can come both from residual gas ionization and from photoemission. Then the electrons are tracked in the beam field (or in field-free region between bunches) and in their own space charge field and, when they hit the beam pipe inner wall, they can cause secondary emission or be elastically reflected. The models for these surface mechanisms are essentially the same as those used in the ECLOUD code [4]. A semianalytical solution for particle tracking inside a strong dipole field is used to significantly increase the tracking speed. The main strength of Faktor2 lies in the quick and efficient algorithm for the accurate solution of the Poisson equation for the electromagnetic field with boundary conditions applicable on a pipe of arbitrary shape. Perfectly conducting wall boundary conditions can be applied or different potentials can be given to different parts of the boundary in order to simulate clearing electrodes. Besides, more complicated geometries (e.g., antechambers) can be simulated. It has to be noted that in the Faktor2 model the beam is rigid and does not feel the effect of the electron or ion cloud.

Table 1: Damping Ring parameters used in our study

Energy	E_0 (GeV)	2.424
Norm. transv. emitt.	$\epsilon_{x,y}$ (nm)	386, 4.1
Bunch length	σ_z (mm)	1.53
Momentum spread	$\delta p/p_0$	1.43 $\times 10^{-3}$
Bunch spacing	ΔT_b (ns)	0.5
Bunch population	N	4.1×10^9
Circumference	C (m)	365.2
Mom. compaction	α	8×10^{-5}
Number of bunches	N_b	312
Tunes	$Q_{x,y,s}$ (m)	69.82, 33.80
Bend length	L_{bend} (m)	0.545
Bend chamb. rad.	R_{bend} (cm)	2
Number of bends	N_{bend} (m)	96
Aver. beta in bends	$\bar{\beta}_{x,y,arc}$ (m)	0.5
Wiggler length	L_w (m)	2
Wiggler field	B_w (T)	2.5
Number of wigglers	N_w (m)	76
Wigg. chamb. rad.	r_w (mm)	9
Aver. beta in wigg.	$\bar{\beta}_{x,y,w}$ (m)	4
Photoem. yield	Y_{eff}	0.01
Number e^- in bends	n_{e^-}/n_{e^+}/m	0.0576
Number e^- in wigg.	n_{e^-}/n_{e^+}/m	0.109

Simulations Without Antechamber

In a first approximation, we considered elliptical beam pipes and disregarded the presence of the antechamber. However, the effect was taken into account by scaling down the number of photoelectrons (uniformly produced

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around the chamber) by the amount of radiation not absorbed by the antechamber.
In the dipoles, the electron cloud formation as simulated by the Faktor2 code appeared to be largely dominated by the photoemission up to maximum secondary emission yields of 1.8. Figures 1 show the electron central densities (i.e., within a region of $5\sigma_x \times 5\sigma_y$ around the beam center) for three different values of photoemission yield (modeling antechambers absorptions of 90, 99% or 99.9%) and maximum SEY of 1.3 and 1.8. It is evident that for the lower value of maximum SEY, the electron density is basically proportional to the photoemission yield. For the higher value, a sign of electron cloud saturation is visible at the highest value of photoemission yield considered. Electron cloud central densities in the range of $10^{11} - 10^{13}$ m^{-3} can be reached in the dipole regions.

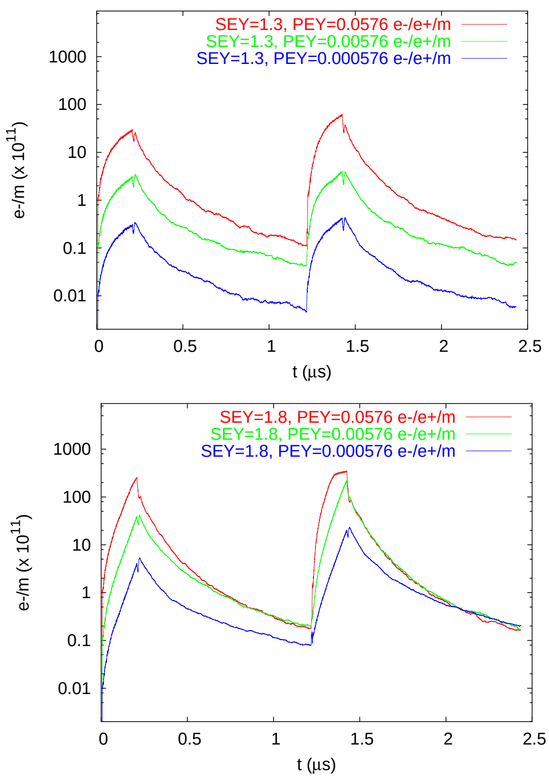

Figure 1: Electron central densities in the dipole chamber of the CLIC DRs for different values of photoemission yields (as labelled), and $\delta_{max} = 1.3$ (top) and $\delta_{max} = 1.8$ (bottom).

In the wigglers, the situation is more critical because of the smaller pipe radius. The electron cloud build up starts to be dominated by secondary emission for maximum SEY's around 1.5. Figures 2 (similar parameters to those considered in the dipole chambers) show that, independently of the initial seed of photoelectrons, extremely high central densities of electrons can be reached for $\delta_{max} = 1.8$, in the order of 10^{14} m^{-3}. For $\delta_{max} = 1.3$, the electron central density would still be very high ($10^{12} - 10^{13}$) if the antechamber absorbs less than 99.9% of the emitted synchrotron radiation. Therefore, for maximum SEY below 1.3, the photoelectrons can still be present in large numbers in the wiggler beam pipe, if the antechamber does not absorb a sufficiently high fraction of the emitted radiation.

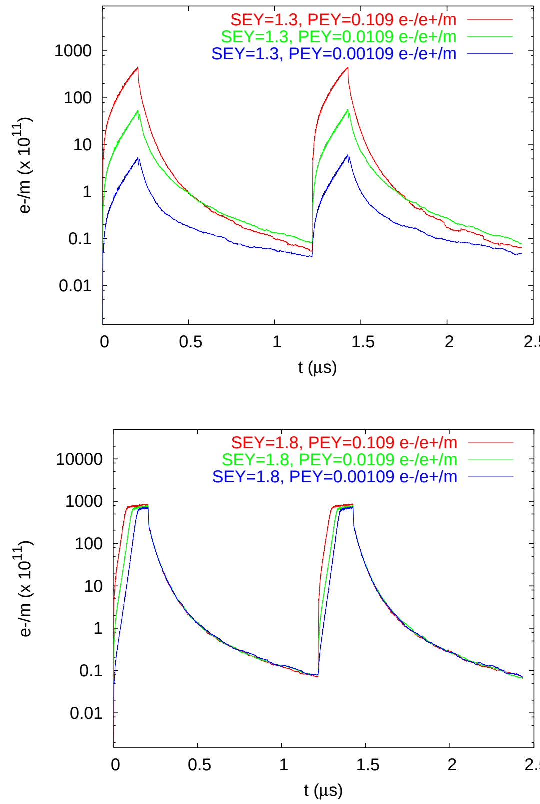

Figure 2: Electron central densities in the wiggler chamber of the CLIC DRs for different values of photoemission yields (as labelled), and $\delta_{max} = 1.3$ (top) and $\delta_{max} = 1.8$ (bottom).

Simulations With Antechamber

All these e-cloud build up simulations have been re-run using the correct chamber geometry, i.e. including the antechamber, Figs. 3. In the new configuration, the correct electromagnetic boundary conditions were applied, and also the electrons generated outside of the main chamber were tracked to exclude any possible mechanism that could feed them back to the main beam pipe. Both simulations in the arc chambers and in the wigglers showed that actually, while the electrons of the antechamber contribute to the line density of electrons (due to the high percent of radiation absorbed), they do not change the density of electrons around the center of the main chamber. In fact, electrons central densities obtained from simulations with and without antechamber are hardly distinguishible, as is displayed in Fig.4 for the wigglers. This confirms both that the electric fields are not significantly changed by the presence of the antechamber, and that electrons generated in it are sufficiently screened as not to have any interaction with those generated around the beam in the main chamber.

The results of the simulated electron cloud central densities for several combinations of photoemission and secondary emission yields are summarized below in Table 2.

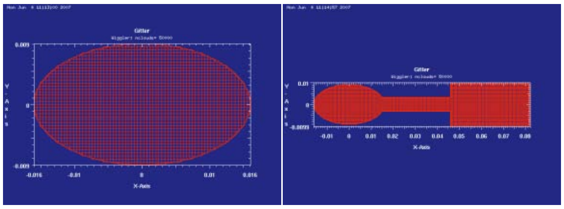

Figure 3: Simulated geometries and grids for the Faktor2 calculations. Ellipse (left) and geometry with antechamber (right).

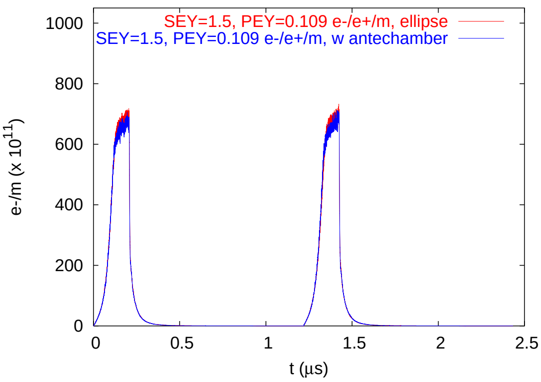

Figure 4: Electron central densities in the wiggler chamber of the CLIC DRs for the labelled value of photoemission yield, and $\delta_{max} = 1.5$ (simulations with and wihout the antechamber).

Low values of electron cloud density can only be reached with a maximum SEY of 1.3 and 99.9% of the synchrotron radiation absorbed by the antechamber. All other values are very high, and the highest ones are only dependent on the δ_{max}, because they are due to multipacting, which is not influenced by the initial seed (photoemission in this case). The next step is to check what is the threshold for beam instability in terms of electron cloud density, and thus determine which surface requirements have to be applied to have margin against electron cloud.

ELECTRON CLOUD INSTABILITY IN THE CLIC-DRS

The single bunch electron cloud instability has been studied by means of HEADTAIL [5] simulations. The first step was to plug in some of the density values from the build up simulations and see how that would potentially affect the positron beam circulating in the ring. The density values given in the Table above had to be scaled by the "filling" factors both of dipoles and wigglers (i.e., the fractions they cover the ring), which amouint to about 0.143 for the dipoles and 0.41 for the wigglers. The first scaled values used in the simulations were in the order of few units 10^{11} for the dipoles and few tens 10^{12} for the wigglers, which correspond to electron cloud densities moderately high (see Table above) resulting from a combination of low maximum SEY and high photoemission or higher maximum SEY and lower photoemission. The results showed a strongly unstable bunch (see Fig. 5).

Table 2: Electron cloud densities from simulations

PEY	SEY	ρ_e ($\times 10^{12}$ e$^-$/m^3)
0.000576	1.3	0.04
0.000576	1.8	2
0.0576	1.3	7
0.0576	1.8	40
0.00109	1.3	0.6
0.109	1.3	45
0.109	1.5	70
0.109	1.8	80

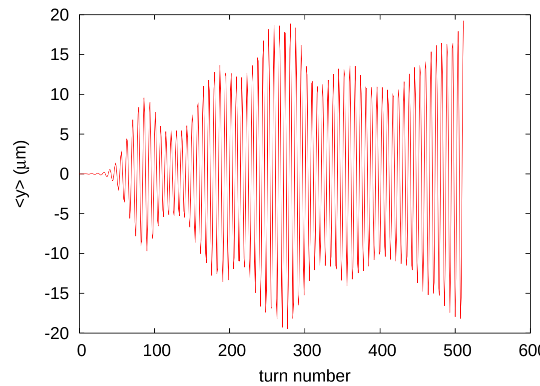

Figure 5: Bunch centroid motion with an electron cloud of 3×10^{11} m^{-3} in the dipoles and 2×10^{13} m^{-3} in the wigglers.

We therefore lowered the electron cloud density values in order to look for the threshold for the onset of the instability. An intense simulation campaign showed that the threshold value for the e-cloud density lies at about 5×10^{12} m^{-3} in the wigglers, independently of the electron density value in the dipoles. This means that countermeasures are needed to prevent electron accumulation in the wigglers, because when the electron cloud forms it reaches very quickly the critical values to make the beam unstable.

CONCLUSIONS

Build up and instability simulations show that the electron cloud is a very serious bottle neck for the CLIC damping rings. An antechamber absorbing 99.9% of the synchrotron radiation and a maximum SEY of the surface below 1.3 could ensure stable operation because it would prevent electron cloud formation and its detrimental effect on the positron beam.

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