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ELECTRON CLOUD STUDIES IN FCC-ee

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Abstract

Electron cloud effects are one of the most critical aspects for the LHC and the future circular colliders. In the frame of the electron-positron collider FCC-ee, an estimation of the electron cloud build up in the machine will be discussed in this paper. A preliminary evaluation of the heat load in the arc components and interaction region magnets will be presented, together with possible mitigation strategies.

INTRODUCTION

FCC-ee is a high luminosity electron-positron collider foreseen to operate at four different centre-of-mass energies from 91 GeV to 365 GeV to study the properties of the Z resonance, the W and top pair thresholds and the Higgs boson with unprecedent precision. It is part of the Future Circular Collider project at CERN [1] and has been designed as a possible first step towards the 100 TeV hadron collider FCC-hh that will be built in the same tunnel of 97.75 km. One important limitation for such a kind of machine is represented by the electron cloud (EC) that can interact with the pipe walls, causing the heating of the vacuum chamber and vacuum and diagnostics degradation, or with the beam itself, inducing transverse instabilities, emittance growth, tune shift and spread and beam losses. This paper presents EC studies for the lepton collider FCC-ee at 45.6 GeV. The electron cloud build up has been analyzed in the drift space and in all the magnets of the machine (dipoles and quadrupoles in the arcs and final focusing quadrupoles in the interaction region) and the multipacting threshold has been evaluated for each component by scanning the Secondary Electron Yield (SEY) of the surface. Numerical simulations have been performed with the PyECLOUD code [2] to study the effects of the bunch spacing on the build up.

ELECTRON CLOUD STUDIES

The arcs of FCC-ee are based on FODO cells, each of which contains two main dipoles with lengths 23.44m and 21.94m and twin-aperture focusing and defocusing quadrupoles with the same length of 3.1m. Dipoles occupy about 81.8% of the total length of the collider. In these studies, we used the realistic shape of the vacuum chamber, modelled as a circular pipe with 35mm radius and two rectangular antechambers on both sides for synchrotron radiation (SR) absorbers installation. On the other hand, for the final focusing quadrupoles of the interaction region (IR) the beam pipe is circular with 15mm radius for the quadrupole QC1 and 20mm radius for the quadrupole QC2. For the beam optics in the arcs and around the interaction point one can refer to [3]. PyECLOUD simulations have been performed for all the magnetic elements and drift sections of the ring.

Table 1: Magnet Parameters used for Simulations at 45.6 GeV

Element	Length [m]	Magnetic field
Arc dipole	23.44	0.01415 T
Arc quadrupole	3.1	± 5.65 T/m
Arc drift	-	-
QC1L1	1.2	-96.3 T/m
QC1L2	1.0	50.3 T/m
QC1L3	1.0	9.8 T/m
QC2L1	1.25	6.7 T/m
QC2L2	1.25	3.2 T/m

The EC build up in each element has been simulated by assuming an initial uniform electron distribution in the vacuum chamber of $10^9 e^-/m$ and by scanning the SEY for different bunch spacings. The secondary emission model used in simulations is described in [4]. According to high order mode power loss computations, bunch spacing of 10ns and 17.5ns are not acceptable for the present cavity geometry and filling schemes with at least 100 RF buckets between the first bunches of consecutive trains are preferred. Therefore, for these studies we assumed 4 trains of 80 bunches interleaved with 25 empty buckets by considering different bunch spacings of 2.5ns, 5ns and 15ns. The nominal bunch intensity of $1.7 \cdot 10^{11}$ e^+/bunch has been used for all simulations. The magnetic parameters of each element are shown in Table 1.

Table 2: Threshold SEY for Multipacting for all the Ring Components

	2.5 ns	5 ns	15 ns
Dipole	1.1	1.1	1.0
Quadrupole	1.2	1.0	<1.0
Drift	1.8	1.3	1.0
QC1L1	1.0	1.1	1.3
QC1L2	1.0	1.0	1.4
QC1L3	1.2	1.3	1.5
QC2L1	1.0	1.0	1.2
QC2L2	1.0	1.0	1.2

Table 2 summarizes the multipacting threshold, defined as the highest SEY without EC build up, for each element and beam, considering the baseline beam parameters presented in [5]. These results show that the highest thresholds for the build up are given by the 2.5ns beam in the arcs and by the 15ns beam in the IR. However, considering that FCC-ee is a warm machine without any cryogenic system, the heat

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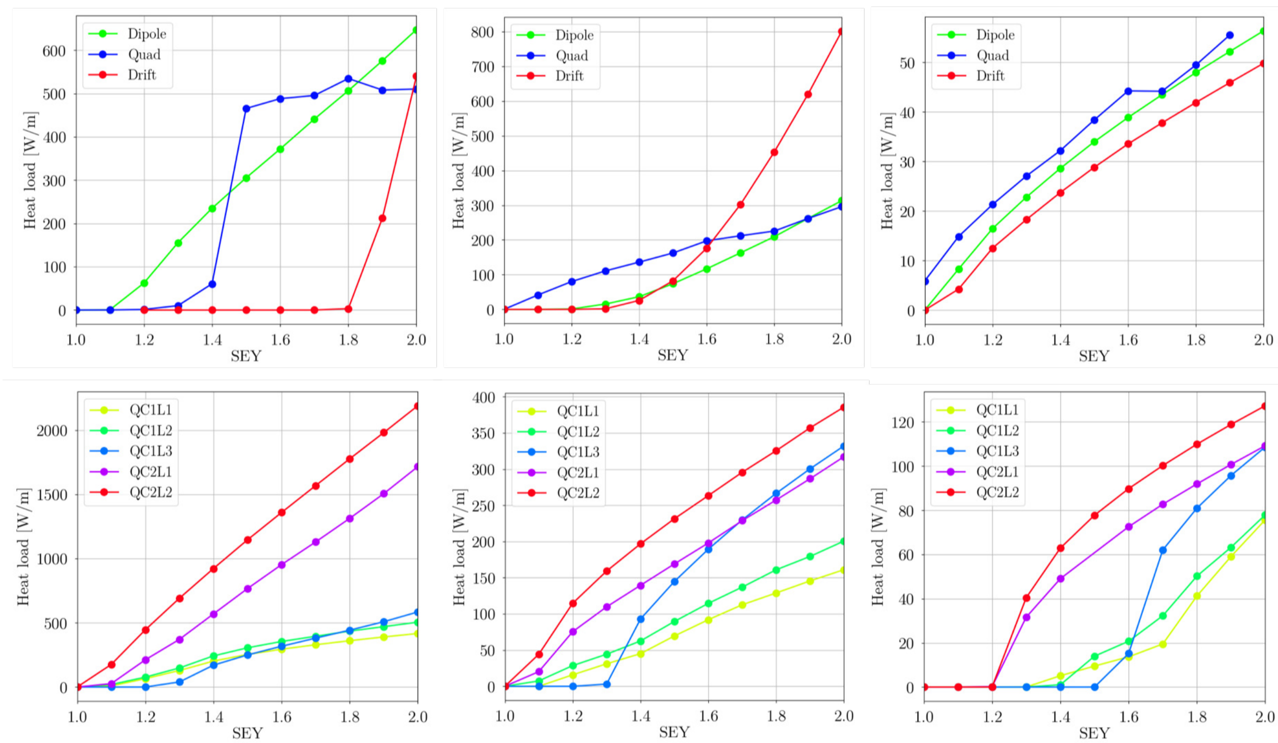

Figure 1: Heat load as a function of the SEY for the arc components (top) and IR magnets (bottom) and in the case of 2.5 ns (left), 5 ns (center) and 15 ns (right) bunch spacings.

load in the arcs corresponding to the 15ns beam is about 20-30 W/m for a SEY = 1.3, i.e. within the acceptable limit, as shown in Fig. 1. Numerical simulations have also been performed by including photoemission seeding, showing that photoelectrons do not affect the previous results.

ELECTRON DENSITY THRESHOLD

EC single bunch head tail instability has been analyzed and observed in several machines [6, 7]. This instability is produced by the interaction of the bunch with the electron cloud: if the head of the bunch is slightly displaced from the beam axis when entering the electron cloud, electrons will be attracted towards the head centroid position and there will be an electron cloud formation in this region that will attract the following particles of the bunch. After few passages through the electron cloud, this will result in a strong deflection of the bunch tail.

Electron cloud acts as a short range wake field with frequency

$$\omega_e = \sqrt{\frac{2\lambda_p r_e c^2}{\sigma_y(\sigma_x + \sigma_y)}} \qquad (1)$$

where $\lambda_p = \frac{N}{4\sigma_z}$ is the line density with N bunch population and σ_z bunch length, r_e is the classical electron radius and $\sigma_{x,y}$ are the transverse beam dimensions.

The threshold density for the instability is given by [7]

$$\rho_{th} = \frac{2\gamma Q_s}{\sqrt{3} Q r_e \beta_y C} \qquad (2)$$

where Q_s is the synchrotron tune, C the machine circumference and $Q = min(7, \frac{\omega_e \sigma_z}{c})$. Table 3 shows the baseline beam parameters of FCC-ee at Z running and the corresponding density threshold. Such low threshold can create potential problems for the collider operation and this issue needs to be further investigated by means of numerical simulations.

Table 3: FCC-ee Parameter List for Electron Density Threshold Evaluation

Energy [GeV]	**45.6**
Bunch population [10^{11}]	1.7
Horizontal emittance [nm]	0.27
Vertical emittance [pm]	1.0
Bunch length [mm]	3.5
Synchrotron tune	0.025
Elec. frequency $\frac{\omega_e}{2\pi}$ [GHz]	177.8
Elec. oscillation $\frac{\omega_e \sigma_z}{c}$	25
Density threshold [$10^{10}/m^3$]	**2.29**

EC MITIGATION

As mentioned before, in the case of FCC-ee the electron cloud formation depends mainly on secondary emission. Mitigation techniques involving absorbers for SR photons or surfaces with very low photoelectron yields could be not sufficient to avoid the accumulation of primary electrons

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inside the vacuum chamber. A possible solution to mitigate the electron cloud build up and limit its effects on the single bunch dynamics is to coat the beam pipe surface with materials with low SEY. Based on the positive experience of the warm sections of the LHC [8], Ti-Zr-V Non Evaporable Getter (NEG) films are the preferable option, since they have the advantage of having a low SEY and Photon Stimulated Desorption (PSD) while pumping. Previous studies on collective effects for the lepton collider [9] pointed out that the typical NEG film thickness of $1\mu m$ makes the resistive wall impedance responsible of quite low single bunch instability thresholds, in both transverse and longitudinal planes. More recent studies have indicated that the contribution of the resistive wall to the impedance budget can be reduced by decreasing the thickness of the coating. These results led to the need of investigating NEG thin films with thicknesses below 250nm to find the minimum effective thickness satisfying at the same time impedance, vacuum and electron cloud requirements. Numerical simulations about single bunch instabilities and experimental results on activation performance have been presented in [5].

NEG Thin Films: SEY Measurements

As already described in [5], copper samples have been coated with NEG thin films at target thicknesses of 1000nm, 200nm, 100nm and 50nm via DC magnetron sputtering [10], obtaining actual thicknesses of 1100nm, 203nm, 87nm and 30nm, respectively. SEY measurements were performed by using an electron gun to produce primary electrons with energies up to 1800 eV, a collector for emitted electrons and a holder with the samples under study. The total SEY was then computed as

$$\delta = \frac{I_{coll}}{I_{coll} + I_{sample}} \qquad (3)$$

where I_{coll} is the collector current and I_{sample} is the sample current. Figure 2 shows the SEY curves of NEG thin films for all the thicknesses under study after the fourth activation cycle of 4 hours up to a temperature of 250°C. For these studies, samples were exposed to air between two consecutive activation cycles. The highest SEY of about 1.5 is obtained for the thinnest coating of 50nm, due to incomplete activation [5], while the SEY value for a 100nm coating is about 1.25 and it decreases for thicker films. Further SEY measurements have been performed for a 100nm coating after longer activation cycles of 24 hours which are typical activation cycles for accelerator use. Observations after longer activation times show a lower SEY compared to the one obtained after shorter activation times, as shown in Fig. 3, where the maximum SEY was reduced from 1.25 to 1.16. Activation is a diffusion limited process, therefore longer activation times allow oxygen at the film surface to migrate away and reduce its contribution to electron yield. Additional mitigation strategies as laser treatment to further reduce the effective SEY of the surface, solenoid fields and/or electric clearing field have to be taken into account and investigated.

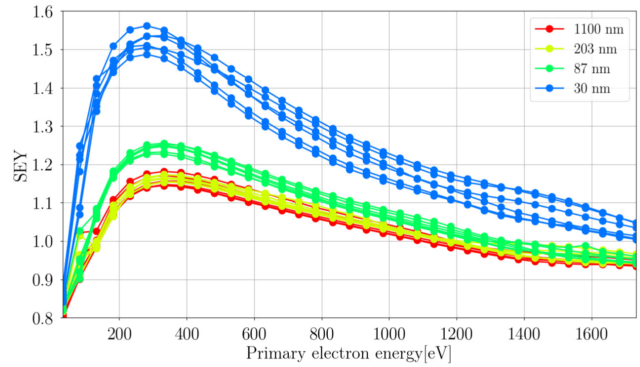

Figure 2: SEY as a function of the photoelectrons energy for all the thicknesses under study after the fourth activation cycle of 4 hours up to a temperature of 250°C.

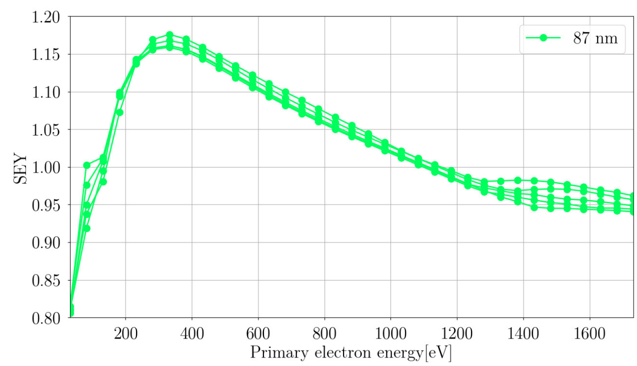

Figure 3: SEY as a function of the photoelectrons energy for the 100nm coating after the fourth activation cycle of 24 hours up to a temperature of 250°C.

CONCLUSIONS

Electron cloud build up simulations have been performed for the main elements of the lepton collider FCC-ee, in both the arcs and interaction region. Multipacting thresholds and heat load have been evaluated for each component in the case of different bunch spacings, indicating that the 15ns beam is the preferable option to suppress the EC build up in the interaction region and to have a lower heat load in the arcs. Several measurements were carried out to evaluate the SEY for all film thicknesses under study after 4 activation cycles and these values can be reduced by performing longer activation cycles. For the 15ns beam, the SEY values obtained experimentally are too high to suppress the EC build up in the arcs but the heat load is below the acceptable limit. However, further mitigation techniques have to be investigated.

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