

ELECTRON CLOUD BUILD-UP SIMULATIONS IN THE TWO-BEAM COMMON CHAMBER OF THE HL-LHC TDIS WITH NON-UNIFORM SURFACE PROPERTIES*

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Abstract

The segmented injection protection absorber (TDIS) foreseen for the High-Luminosity Large Hadron Collider (HL-LHC) project is designed to protect the machine in case of injection kicker malfunctioning. Since the current LHC injection protection absorber has suffered from vacuum issues possibly induced by electron multipacting, numerical studies were done to estimate the electron flux expected on the internal surfaces of the TDIS. This device will consist of three pairs of movable absorbing blocks above and below one beam and a beam screen surrounding the second circulating beam. The build-up of electron cloud in the TDIS was simulated accounting for the presence of two counter-rotating beams, for the configuration of the jaws and for the different materials used for the different surfaces in the device. The simulation studies have also investigated the possibility of coating the most critical surfaces with amorphous carbon in order to mitigate the multipacting.

INTRODUCTION

Electron cloud (e-cloud) in particle accelerators is known to have a detrimental effect on the vacuum pressure and can cause a large heat deposition on the vacuum chamber surfaces. In a particle collider, in the presence of two beams in the same chamber, the build-up of e-cloud becomes more complicated and the electron density cannot be scaled from the case of a single beam. The complication is due to the fact that the arrival times of the two counter-rotating beams with respect to each other depend on the position along the machine, and hence, there is no simple bunch spacing in the common-chamber device.

PyECLOUD is a 2D numerical code for simulations of e-cloud build-up in the presence of one or multiple circulating beams in one chamber [1, 2]. In order to correctly model the e-cloud profile generated in the presence of two counter-rotating beams, slices along the device at given longitudinal positions have to be simulated, respecting the delay in the arrival of the two beams as well as variations of the transverse beam sizes. Long-Range Encounter (LRE) locations, where the two counter-rotating beams pass simultaneously, occur at evenly spaced locations along the machine. In between LREs the delay of one beam with respect to the other is ranging from -12.5 ns to +12.5 ns (for the HL-LHC bunch spacing of 25 ns).

The injection protection absorber is a critical machine protection element, which is designed to intercept the beam in

case of injection kicker malfunctions and timing issues. Currently, in the LHC, there are two similar devices installed in the common regions, where the two counter-rotating beams, injected and circulating, share the same chamber. During the LHC operation, the LHC injection protection absorbers (TDI) have suffered from vacuum issues, observed when retracting the jaws after the beam injection, as well as from heating and other problems [3–5]. For the future HL-LHC project [6, 7] a new segmented injection protection absorber (TDIS) has been designed. It will have a beam screen surrounding the circulating beam and three pairs of short movable absorbing blocks to allow for a simpler alignment of the device with respect to the injected beam [8]. The device has movable vertical jaws, which are retracted after the injection of the two beams and before their acceleration.

E-cloud build-up was simulated in the TDIS device with the HL-LHC 25 ns beams at 450 GeV (beam parameters listed in [9]). The model of the TDIS absorber is presented in Fig. 1. The jaws in the first two tanks are made of graphite, whereas the jaws in the third tank are metallic with a section in aluminum coated with titanium and a section in copper. Using PyECLOUD simulations we have studied the e-cloud build-up in the TDIS absorber for different positions of the jaws. The possibility of mitigating e-cloud formation by applying surface coatings has also been studied. More details about this study can be found in [10].

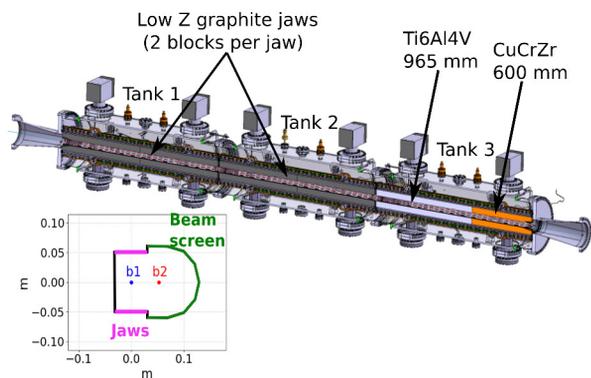


Figure 1: Top: the 3D TDIS model (from [8]). Bottom: the 2D PyECLOUD model with the beam positions indicated in blue and red, the movable jaws in magenta and the beam screen in green.

SIMULATION STUDIES

Due to the non-linearity in the e-cloud build-up process, the electron density cannot be simply scaled from the case of the single beam and the build-up in the devices with common chambers has to be modeled correctly accounting

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for the arrival times of the two beams, as well as for the beam positions and sizes. A first simulation study was made to compare the effects of each beam in the TDIS chamber separately and together.

Figure 2 shows the electron current on the surface as a function of the Secondary Electron Yield (δ_{max}) generated by beam 1 alone, beam 2 alone, and both beams passing simultaneously (LRE location) or with a 12.5 ns delay. It is evident that the electron currents from beam 1 and beam 2 alone do not add up to the total current obtained when both beams are present in the chamber. The multipacting threshold can also be different. It is also evident that the dependence on the delay between the two beams is strong. The simulation results for the HL-LHC beams have shown that the electron current is increasing for larger delays between the two beams, however the opposite behavior can be observed for other beam intensities [10].

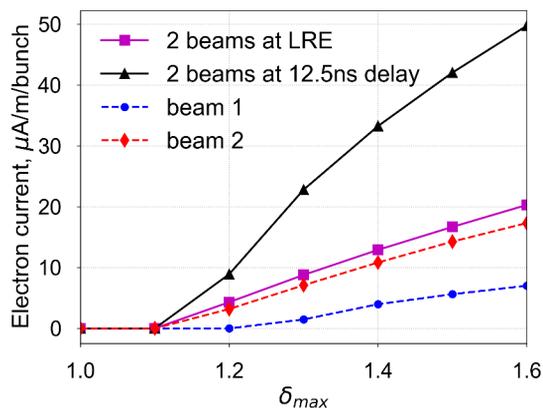


Figure 2: Electron current versus δ_{max} at a section of the TDIS with 2 beams delayed by 0 ns (magenta, squares) and 12.5 ns (black, triangles), for beam 1 alone (blue dashed, dots) or beam 2 alone (red dashed, diamonds).

A pressure increase was observed in the LHC injection protection absorber when retracting the jaws after the beam injection. To investigate this behavior we studied the dependence of the e-cloud formation on the position of the jaws. Simulations were performed for different half-gaps in the range from 1 mm to 50 mm. The δ_{max} was considered uniform within the device. Figure 3 shows the total electron current in the TDIS versus half-gap for different δ_{max} . The strongest multipacting is observed when the half-gap is 40 mm. The electron current is much smaller when the jaws are closed for injection (half-gap smaller than 10 mm).

By design the TDIS will have three separate tanks with different absorbing blocks inside their jaws. The blocks in the first two tanks are made of graphite, which has a low δ_{max} , close to 1.0. The jaws in the third tank, instead, have blocks of metal alloys (Ti6Al4V, 965 mm long and CuCrZr, 600 mm long), which have larger δ_{max} . To account for the presence of materials with different properties a set of simulations with non-uniform δ_{max} along the device was made. For the metallic parts (sides of jaws, beam screen,

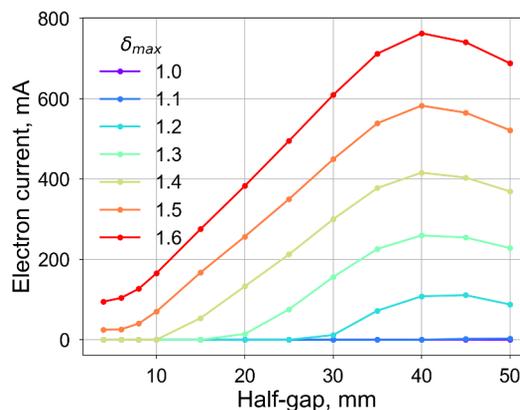


Figure 3: Total electron current in the TDIS as a function of the half-gap for different δ_{max} values.

metallic jaws) we assume a $\delta_{max} = 1.6$, corresponding to a partially conditioned surface. $\delta_{max} = 1.0$ is instead assumed for the graphite jaws. The total electron current as a function of the half-gap for this δ_{max} configuration is shown by the green curve in Fig. 4.

a-C Coating of the Metallic Jaws

Simulations were performed to study the effect of coating the jaws in the third tank with amorphous Carbon (*a-C*), aiming at a reduction of the electron current. For these coated surfaces we assume $\delta_{max} = 1.0$ as for the graphite jaws. Figure 5, top shows the δ_{max} distribution along the three tanks for the initial “uncoated model” and “coated J3 model”. The rest of the chamber, *i.e.* the back plate (opposite the beam screen), the sides of jaws and the beam screen, are simulated with $\delta_{max} = 1.6$.

The longitudinal electron current profiles for the two scenarios are shown in Fig. 5 (bottom) for the chamber configuration with a 40 mm half-gap (worst case identified in Fig. 3). Different colors mark contributions from different surfaces of the chamber. The effect of the *a-C* coating on the jaws in tank three is clearly visible. However, we can identify the surface of the beam screen as a major contributor to the electron current. More than half of the electrons are impacting on the surface of the beam screen, including the round and flat parts, in both of the studied scenarios.

a-C Coating of the Beam Screen

Based on the results of the simulations discussed above we have explored the possibility of reducing the production of electrons from the beam screen surface. For this purpose, the e-cloud build-up in the TDIS was simulated assuming *a-C* coating on the beam screen with δ_{max} of 1.0 (as shown in Fig. 1). We consider two scenarios: *a-C* coating of the beam screen only (“coated BS model”) and *a-C* coating of the beam screen and of the jaws in tank three (“coated J3+BS model”).

Simulations have shown that the *a-C* coating of the beam screen alone allows for a significant reduction of the electron

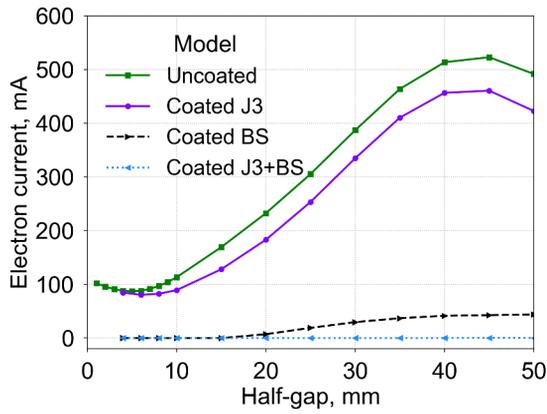


Figure 4: Total electron current in the TDIS as a function of half-gap for the different scenarios.

current. The total electron current versus half-gap for the different scenarios is shown in Fig. 4. By coating also the jaws in tank three together with the beam screen, the e-cloud in the TDIS can be completely suppressed.

CONCLUSIONS

E-cloud build-up simulations with two beams in a common chamber require particular care. The dependence on the location along the device needs to be taken into account due

to the changing arrival times of the two beams at different locations along the device.

E-cloud was simulated in the HL-LHC injection protection absorber TDIS accounting for the presence of two circulating beams, different jaw openings and realistic material distribution. Simulations have shown that the half-gap of 40 mm between the jaws creates the conditions for the strongest electron multipacting. Most of the electrons were found to impact the beam screen surface. Build-up simulations were performed also assuming *a-C* coating on different surfaces, aiming at a reduction of the electron current. Coating the beam screen was found to be the most efficient way to mitigate the e-cloud.

Based on these results the TDIS absorber design includes the *a-C* coating of the beam screen in order to strongly reduce the electron current. Due to technical complications the metallic jaws will not be coated. The estimated e-cloud-induced heat load on these jaws can be handled by the cooling system. Dynamic vacuum simulations have shown that an acceptable pressure, smaller than 5×10^{-9} mbar, can be achieved with the chosen configuration [11].

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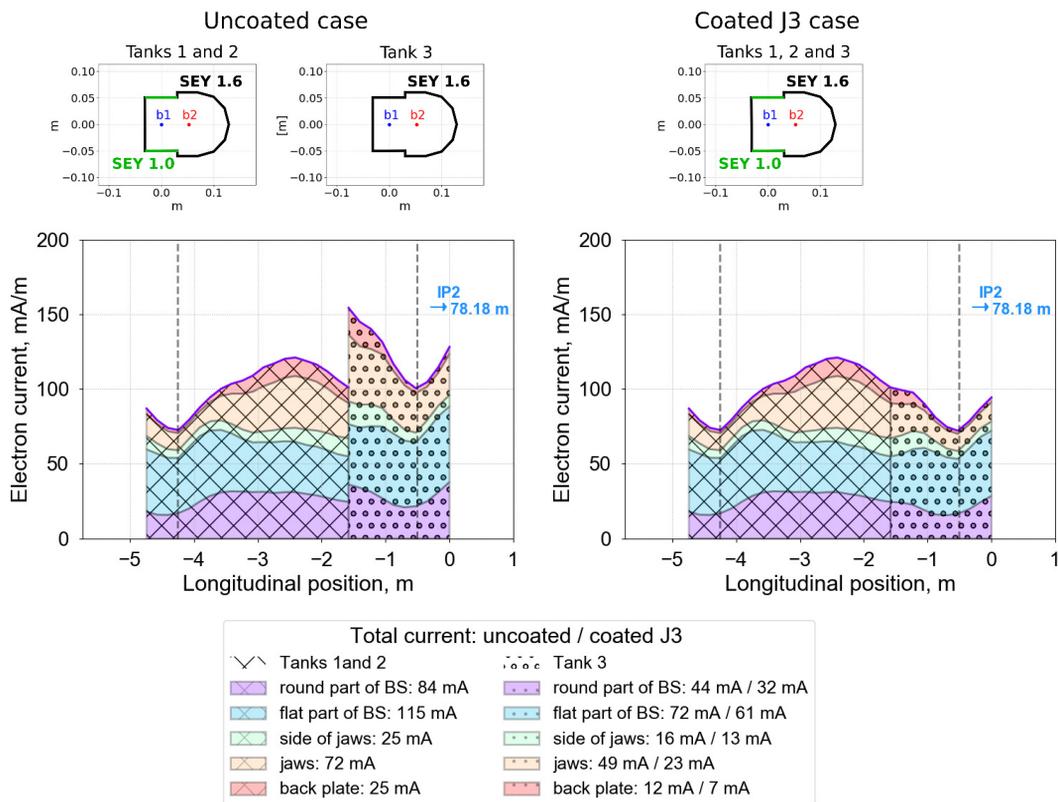


Figure 5: Top: δ_{max} configuration for two simulated scenarios. Bottom: contributions to the total electron current from different surfaces in the TDIS for “the uncoated” (left) and “the coated J3” (right) scenarios. The configuration with 40 mm half-gap is considered.

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