EFFECT OF THE LHC BEAM SCREEN BAFFLE ON THE ELECTRON CLOUD BUILDUP

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Abstract

Electron Cloud (EC) has been identified as one of the major intensity-limiting factors in the CERN Large Hadron Collider (LHC). Due to the EC, an additional heat load is deposited on the perforated LHC beam screen, for which only a limited cooling capacity is available. In order to preserve the superconducting state of the magnets, pumping slots shields were added on the outer side of the beam screens. In the framework of the design of the beam screens of the new HL-LHC triplets, the impact of these shields on the multipacting process was studied with macroparticle simulations. For this purpose multiple new features had to be introduced in the PyECLOUD code. This contribution will describe the implemented simulation model and summarize the outcome of this study.

INTRODUCTION

The experience with 25 ns beams has shown that Electron Cloud (EC) effects could pose important challenges to the operation of the Large Hadron Collider (LHC). During the 2015 proton run a strong dynamic heat load due to the EC was observed in the cold sections of the LHC, with a significant impact on the cryogenic system budget [1]. Inside the 1.9 K cold bore of the superconducting magnets, the thermal loads caused by the circulating beam are intercepted by a beam screen, held at an intermediate temperature of 5-20 K. However only a limited fraction of the total cooling capacity for this warmer screen is available for the heat load induced by the EC. The remaining rate is allocated to the heat loads due to the synchrotron radiation and the image current [2].

The LHC beam screen cross section is shown in Fig.1 (left); it is made by a 1 mm thick non-magnetic stainless steel tube with a 75 μm thin layer of copper coating on its inner surface which minimizes the wall resistivity. In order to limit the dynamic pressure rise, the beam screen contains pumping slots over few percent of its surface to allow pumping by the 1.9 K cold mass. The width of these slots in the LHC arcs is 1.5 mm [3]. The drawback of this configuration is that multipacting electrons could penetrate through the slots inducing a significant heat load onto the cold bore. For this reason baffle plates, i.e shields installed 2 mm behind the pumping slots, were added on the outer side of the beam screens, such that the electrons are intercepted before reaching the cold bore of the dipole magnets, at the expense of a pumping speed reduced by a factor of two [4].

Presently new superconducting magnets for the LHC insertion regions are being designed for the High Luminosity Upgrade of the LHC (HL-LHC project). The beam screens for this new magnets are also being designed [5] and the question has been raised whether the electric shielding provided by the beam screen could be sufficient to prevent multipacting, even in absence of baffle plates. This question has been addressed with detailed simulation studies using the PyECLOUD code [6].

THE PYECLOUD SIMULATION SETUP

To study the effect of the baffle plates on the EC buildup we have considered the case of an LHC arc dipole. The effect of a single pumping hole has been studied modeling the hole and corresponding baffle by adding a T-shaped boundary as shown in Fig. 1 (center). The situation with no baffle installed has been modeled as shown in Fig. 1 (right). The width of the added part has been chosen such as not to perturb the field and the dynamics of the electrons. This kind of chamber geometry could not be simulated with the existing PyECLOUD routines since some of the employed algorithms were assuming a convex boundary. Therefore the following modifications had to be introduced in order to allow the EC build up simulation with the required geometry.

In PyECLOUD the electrons are modeled with MacroParticles (MPs), which are tracked under the effect of the externally applied magnetic field and the electric fields of the proton beams and the electrons themselves. The code detects electron impacts on the beam screen by identifying particles that drift outside the chamber domain. The algorithm previously used for this task was assuming a convex boundary as described in [6]. We replaced the existing routine with a new one based on a ray-casting algorithm. For a given electron position, the algorithm counts how many times an arbitrary ray, starting from such point and going in any fixed direction, intersects the edges of the chamber. If this number is even the point lies outside the chamber, otherwise the point is inside [8].

The impact point on the chamber is found by intersecting the electron trajectory with the boundary. However in the case of non-convex shape, multiple crossing points can be found. In order to correctly identified the physical point ("first impact"), a loop for searching the first intersection has been implemented.

The electric fields acting on the electrons are evaluated by using a Particle In Cell (PIC) code. The Shortely-Weller algorithm [9] is implemented to improve the accuracy in the evaluation of the electric field close to the boundary. Also in this case the Mesh-to-Particles routines of the code had to be modified to correctly deal with non-convex shapes.

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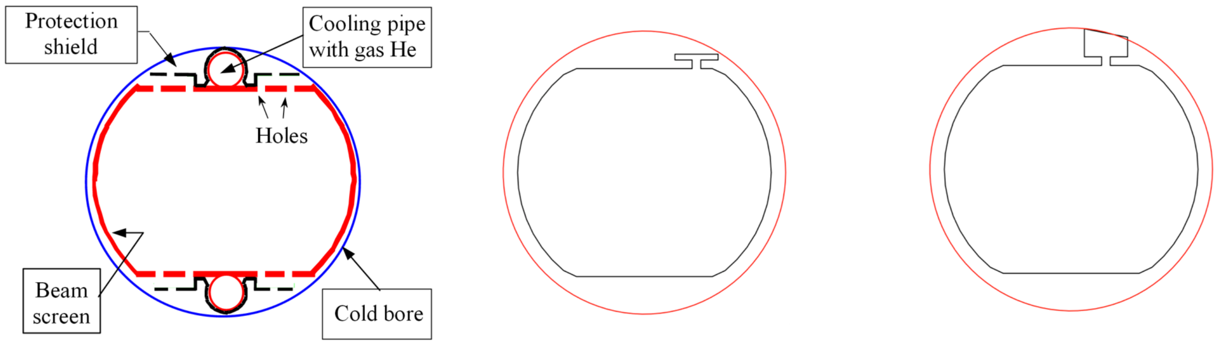

Figure 1: Left: Cross section of the LHC beam pipe with beam screen and shield protections [7]. Center: Chamber shape used to model the beam screen with the shielding baffle plate. Right: Chamber shape used to model the beam screen without the shielding baffle plate.

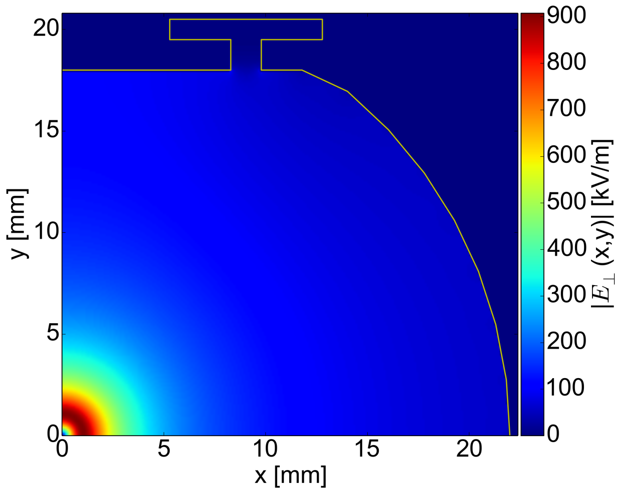

Figure 2: Magnitude of the electric field of the proton beam within the simulation domain.

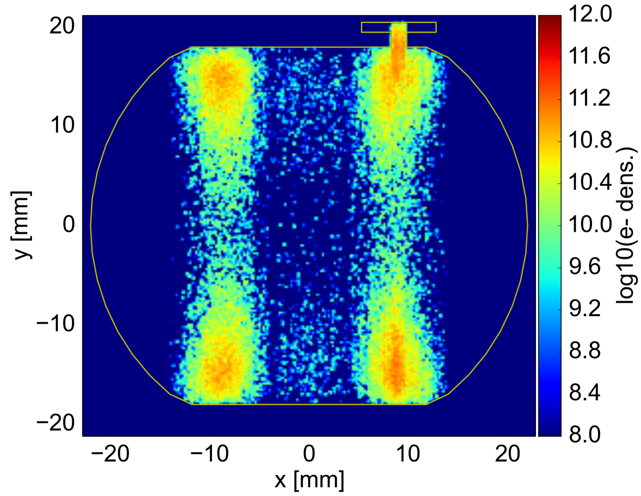

Figure 3: Electron distribution in an LHC arc dipole for SEY=1.4, right before a bunch passage at the end of the bunch train. The effect of multipacting onto the baffe plate can be noticed.

SIMULATION RESULTS

The simulations have been performed for the LHC injection energy (450 GeV), corresponding to a field in the main dipoles of 0.53 T. The 2015 LHC operational beam parameters have been assumed, i.e.1.25×10^{11}p/bunch with transverse r.m.s. emittances of 2.5 µm. The secondary emission process is modeled according to [10], as described in detail in [6]. The maximum of the Secondary Electron Yield curve (SEY) has been scanned between 1.0 and 2.0.

Figure 2 shows the distribution in the transverse plane of the electric field generated by the proton beam, which is found to be very low in the region between the screen and the baffle. Therefore electrons in this region can hardly be accelerated by the beam.

Figure 3 shows a snapshot of the electron distribution obtained from the buildup simulation, right before a bunch passage at the end of a bunch train. The electric field generated in the region of the holes by this distribution is shown in Fig. 4

A non negligible electron density can be observed in the region of the hole, showing that multipacting on the baffle plate is nevertheless taking place. The reason is that a large fraction of the electrons from the baffle drift inside the beam screen even before the following bunch passage.

In fact due to the strong dipolar magnetic field, the electrons are constrained to follow helicoidal trajectories around the field lines. In Fig. 5, we show the dependence of the electron cyclotron radius on the kinetic energy associated to the motion in the plane orthogonal to the magnetic field. The energy of the secondary electrons does not exceed a few tens of electronvolts which means that their cyclotron radius does not exceed a few hundreds of micrometers and is significantly smaller than the size of the pumping slot. In practice the magnetic field is guiding the electrons emitted from the baffle plate towards the inside of the chamber.

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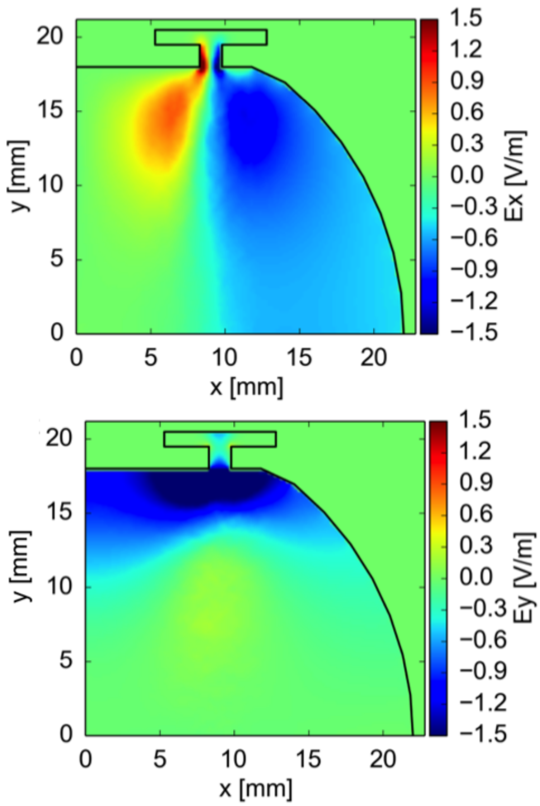

Figure 4: Horizontal and vertical component of the electric field generated by the EC around the baffle region.

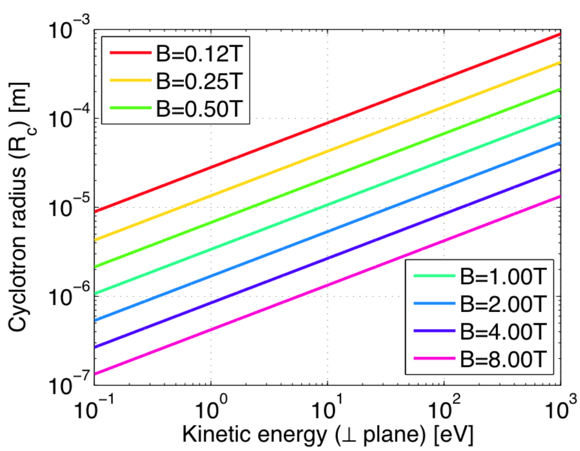

Figure 5: Cyclotron radius as a function of the magnetic field and of the kinetic energy associated to the motion in the plane orthogonal to the field lines.

The heat loads deposited on the baffle and on the cold bore for the cases with and without baffle respectively have been simulated as a function of the SEY of the surface and compared with the heat load on the whole chamber. These results are shown in Fig. 6.

The simulated additional heat load induced by impacting electrons on baffle is shown in Fig. 6. Even for SEY values as low as 1.4, as achieved in the LHC after the 2015 extended

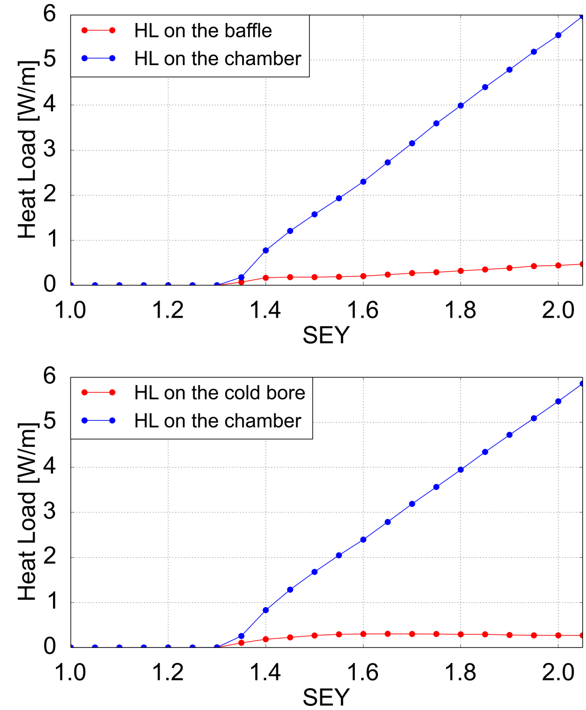

Figure 6: Heat load induced by the EC as function of the SEY. Top: Heat load deposited on the whole chamber and on the baffle plate. Bottom: Heat Load deposited on the whole chamber and on the cold bore, in the case in which the baffle plate is not installed.

scrubbing campaign [1], the heat load deposited on the cold bore due to the effect of a single hole is of the order of 0.15 W/m, definitely non negligible when compared to the cooling capacity available on the beam screens, which is of the order of 1.0 W/m.

CONCLUSIONS

The PyECLOUD simulation code has been extended in order to support the simulation of non-convex chamber shapes. This has allowed to model the effect of the pumping holes on the e-cloud formation and to study in detail the power deposition on the shielding baffle plates. The simulation results show that, in absence of baffle plates, multipacting could indeed occur on the cold bore. This would entail an heat load deposition on the 1.9 K surface of the order of 0.15 W/m for a single hole, which is almost 10% of the cooling capacity available on the beam screen.

Therefore, this study confirms the importance of installing shielding baffles around the pumping slots of the beam screens. This option should be included in the design of the new interaction region magnets foreseen by the HL-LHC upgrade.

ACKNOWLEDGEMENT

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