MAPS FOR ELECTRON CLOUDS: APPLICATION TO LHC

T. Demma, S. Petracca, University of Sannio, Benevento, Italy
F. Ruggiero, G. Rumolo, F. Zimmermann, CERN, Geneva, Switzerland

Abstract

In this communication we show that the cubic map formalism introduced in [1] to model electron cloud in RHIC is also reliable in the range of typical LHC parameters.

INTRODUCTION

The generation of a quasi-stationary electron cloud inside the beam pipe through beam-induced multipacting has become an area of intensive study. The analysis performed so far was based on very heavy computer simulations taking into account photoelectron production, secondary electron emission, electron dynamics, and space charge effects providing a very detailed description of the electron cloud evolution. In [1] it has been shown that, for the typical parameters of RHIC, the evolution of the electron cloud density can be followed from bunch to bunch introducing a cubic map of the form:

$$\rho_{m+1} = a\,\rho_m + b\,{\rho_m}^2 + c\,{\rho_m}^3, \qquad (1)$$

where ρ_l is the average line electron density between two successive bunches, and the coefficients a, b and c are extrapolated from simulations and are function of the beam parameters and of the beam pipe characteristics. Simulations based on this map formalism are orders of magnitude faster than those based on usual codes. In this communication we show that this formalism is also reliable for the typical parameters of the LHC dipole bending magnet region, and apply the map formalism to the analysis of electron cloud evolution for different bunch filling patterns.

Table 1: Input Parameters for ECLOUDSimulations

parameter	unit	value
beam particle energy	GeV	7000
bunch spacing	ns	25
bunch length	m	0.075
number of bunches N_b	–	72
number of particles per bunch N	10^{11}	0.8 to 1.6
bending field B	T	8.4
length of bending magnet	m	14.2
vacuum screen half height	m	0.018
vacuum screen half width	m	0.022
circumference	m	27000
primary photo-emission yield	-	$7.98 \cdot 10^{-4}$
maximum SEY δ_{max}	-	1.3 to 1.7
energy for max. SEY E_{max}	eV	237.125
energy width for secondary e^-	eV	1.8

BUILDING THE CUBIC MAP FOR LHC

We have followed the bunch to bunch evolution of the electron cloud density by averaging the output of the simulation code ECLOUD [2] between the end of a bunch and the start of the next bunch, using the typical parameters of an LHC dipole, shown in Table 1, for the secondary emission yield (SEY) curve model described in [3] scaled to an elastic reflection probability at zero electron energy of 0.5 instead of 1 [4]. The typical time evolution of the electron density is shown in Figure 1 for a train of 72 successive bunches followed by 28 empty bunches (bunches with a null bunch intensity, $N = 0$). The longitudinal electron density, as a function of time grows exponentially until the space charge due to the electrons themselves produces a saturation level. Once the saturation level is reached the average electron density does not change significantly. The final decay corresponds to the succession of the empty bunches. In Figure 1 one can see that the bunch-to-bunch evolution contains enough information about the build-up or the decay time, although the details of the line electron density oscillation between two bunches are lost. Figure

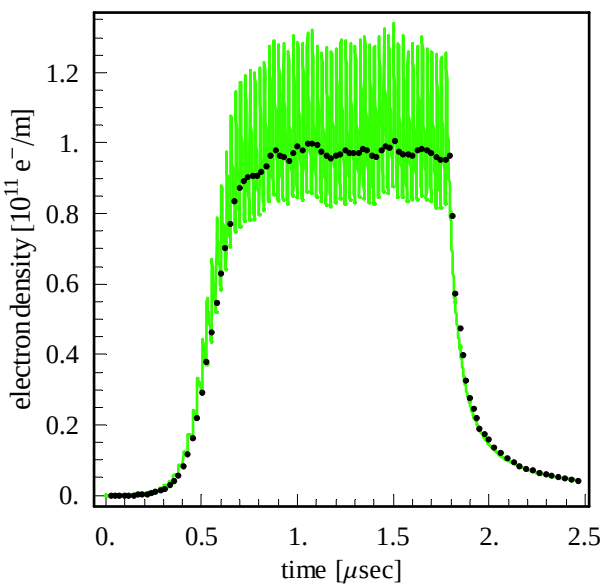

Figure 1: Time evolution of the electron density (green line) computed with ECLOUD. The case corresponds to the injection of 72 successive bunches with a bunch spacing of 25 ns, a bunch intensity of $N = 1.2 \cdot 10^{11}$ protons, and $\delta_{max} = 1.7$, followed by 28 empty bunches. The black dots mark the average electron density between two consecutive bunches.

2 shows the average electron density, ρ_{m+1}, after the passage of bunch m as a function of the electron density, ρ_m, for different bunch intensities, N. The points in Fig. 2 show the average electron cloud density between two bunches using results from ECLOUD, the lines are cubic fits to these points. Figure 2 is explained as follows: starting with a small initial linear electron density, after some bunches the density takes off and reaches the corresponding saturation line ($\rho_{m+1} = \rho_m$, red line) where the space charge effects due to the electrons in the cloud itself take place. In this situation, all the points (corresponding to the passage of full bunches) are in the same spot. The justification of the three terms in equation (1) is explained as a consequence of the linear growth (this term has to be larger than unity in case of electron cloud formation), a parabolic decay due to space charge effects (this term has to be negative to give concavity to the curve ρ_{m+1} vs ρ_m), and a cubic term corresponding to perturbations. Neglecting the point corresponding to the electron cloud density after the first empty bunch, the longitudinal electron density follows a similar decay independently of the initial value of the saturated line electron density. The points corresponding to the first empty bunches coming from different saturation values lie on a general curve (black curve in Figure 2). Thus the electron density build up for a given bunch intensity is determined by a cubic form , while decay is described by two different cubic forms, one corresponding to the first empty bunch, and a second to the rest. The behavior of the map coefficients is not well understood and the determination of their values is purely empirical.

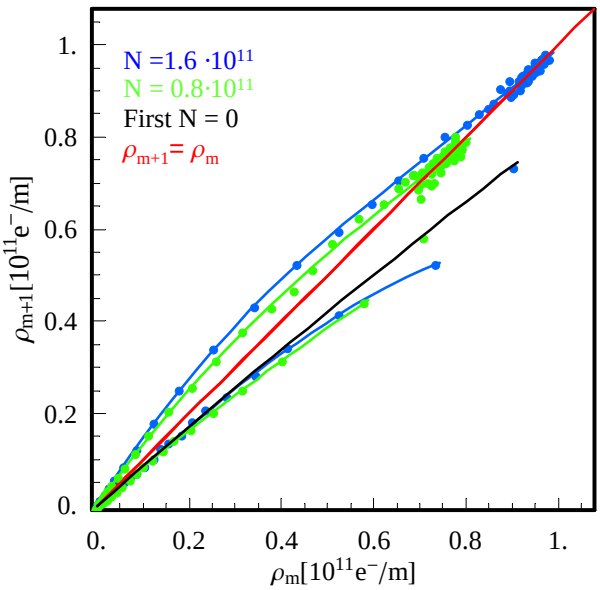

Figure 2: Average longitudinal electron density ρ_{m+1} after the passage of bunch m as a function of longitudinal electron density ρ_m before the passage of bunch m, for different bunch intensities ($N = 0.8 \cdot 10^{11}$ green, $N = 1.6 \cdot 10^{11}$ blue), and $\delta_{max} = 1.7$. The lines correspond to cubic fits applied to the average bunch to bunch points. The red line corresponds to the identity map $\rho_{m+1} = \rho_m$. Points above this line describe the initial growth and saturation of the bunch-to-bunch evolution of the line electron density, those below describe the decay. The black line represents the cubic fit to the points corresponding to the first empty bunches.

BUNCH PATTERNS

A possible application of the map formalism is in the search of the optimal distribution of bunches along the LHC circumference. A promising scheme to suppress the build up of the electron cloud is to increase the bunch spacing, or to introduce additional gaps in the bunch train [5]. The goal is to find out a bunch pattern using uneven bunch spacing around the LHC circumference that minimizes the electron cloud density. The nominal LHC beam consists of trains of 72 bunches, spaced by $25ns$, separated by a gap of 8 missing bunches. Several additional gaps can be easily introduced in the 72 bunch train, such as gaps of one or more trains of 12 missing bunches (e.g. cases like 24 bunches, 12 missing bunches, 36 bunches, or 12 bunches, 24 missing bunches, 36 bunches, etc.), obtaining a large number of different bunch filling patterns. Hence in order to determine the best filling pattern for a fixed set of beam pipe parameters, several simulation runs have to be launched for all the possible bunch filling patterns. The cubic map formalism can be used to reproduce the results.

As it can be seen in Figure 3 where the bunch filling pattern (24 bunches, 12 missing bunches, 36 bunches) is reproduced, not only it takes two bunches to jump from the curve $N \neq 0$ to $N = 0$, but it also takes two bunches to jump from $N = 0$ to $N \neq 0$. Hence four different cubic form are needed to describe a particular bunch filling pattern. However the coefficients of these forms do not depend on the particular bunch pattern, and can be extrapolated from a single simulation for a fixed set of physical parameters. As an example in Figure 4 results are compared obtained by ECLOUD and the cubic map formalism using the coefficients extrapolated for the case (24 bunches, 12 missing bunches, 36 bunches), for different bunch filling patterns. In particular, regardless of the initial longitudinal electron density, the map results agree within an error range of 10% for all bunch filling patterns. The speed up in simulation time is several orders of magnitude (for the parameters listed in Table 1, ECLOUD takes about 12 h for each simulation run, the map only few milliseconds).

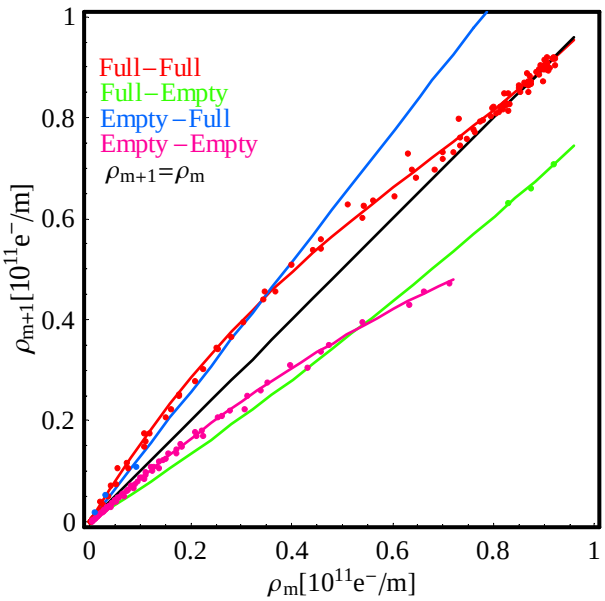

Figure 3: Average electron density ρ_{m+1} as a function of ρ_m, for the case of 24 bunches, 12 empty bunches, 36 bunches.The lines correspond to cubic fits applied to the four different cases: full bunch followed by another full bunch; full bunch followed by an empty bunch; empty bunch followed by a full bunch; empty bunch followed by another empty bunch.

CONCLUSIONS AND OUTLOOK

The electron cloud build-up in an LHC dipole can be described using a cubic map. The coefficients of this map are functions of the pipe and beam parameters. This dependence can be extrapolated from simulation codes. For a given beam pipe and beam parameters the map coefficients are fixed and can be used to simulate the bunch to bunch evolution of electron cloud for different bunch filling patterns, obtaining a reduction of orders of magnitude of the simulation time. Another possible application of this formalism could be the construction of a map including the heat load. Deeper insight of the map formalism would be gained if a model of the dependence of the map coefficients on the physical parameters influencing the electron cloud were available. Work in this direction is in progress.

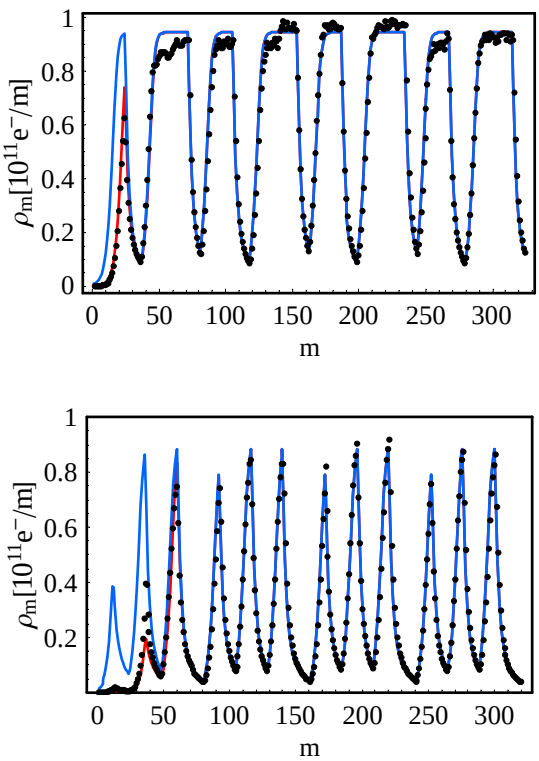

Figure 4: Electron cloud density evolution for two different bunch pattern (24 f.,12 e.,36 f. top, and 12 f.,12 e.,12 f.,12 e.,12 f.,12 e. bottom),for $N = 1.2 \cdot 10^{11}$ and $\delta_{max} = 1.7$, using ECLOUD (black dots) and cubic map with two different initial electron densities $\rho_0 = 10^{-2}\left[10^{11} \cdot e^-/m\right]$ (blue line) and $\rho_0 = 10^{-4}\left[10^{11} \cdot e^-/m\right]$ (red line).

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