MAPS FOR ELECTRON CLOUDS: APPLICATION TO LHC CONDITIONING

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Abstract

In this communication we present a generalization of the map formalism, introduced in[1] and [2], to the analysis of electron flux at the chamber wall with particular reference to the exploration of LHC conditioning scenarios.

INTRODUCTION

The electron cloud driven effects can limit the ability of recently build or planned accelerators to reach their design parameters. The secondary emission yield reduction (called "scrubbing") due to the fact that the electrons of the cloud hit the vacuum chamber wall, modifying its surface properties, may minimize any disturbing effects of the cloud to the beam. Surface scrubbing was studied in various experiments, by measuring the electron dose (the number of impinging electrons per unit area on sample surfaces) dependence of SEY yield. All the available experiments found in literature have been performed by bombarding technological metal surfaces with electron beams of fixed energy as $300 - 500eV$ and $2.5keV$. They showed that even a low electron exposure of about $10^{-6}Cmm^{-2}$ the SEY of material start to decrease, reaching its lower value after about $10^{-2}C/mm^{-2}$. Altough these investigations gave informations about conditioning in accelerators, they are not complete and other studies are required to clarify the scrubbing dependence on the bombarding dose of impinging electron beams, since this parameter is missing. The dependence of "scrubbing" efficiency on beam and chamber parameters can be deduced from e-cloud simulation codes (e.g. PEI [3] , POSINST [4], and ECLOUD [5]) modeling the involved physics in full detail. In [1] it was shown that the evolution of the electron cloud density from one bunch passage to the next can be described using a cubic map whose parameters can be extrapolated from simulations, and are functions of the beam parameters and of the beam pipe features. Simulations based on the above map are orders of magnitude faster than those based on particle-tracking codes. In this paper we generalize the map formalism, introduced in[1] and [2], to the analysis of electron flux at the chamber wall.

MAP FORMALISM

The time evolution of the instantaneous current I_W of electrons bombarding the wall of an LHC arc dipole, computed by ECLOUD, is shown in Fig. 1, for a filling pattern consisting of a train of 72 bunches followed by gaps of 8 empty (zero charge) bunches, and the beam/pipe parameters collected in Table I. The "bunch-by-bunch" electron dose Q_n given to the chamber walls is obtained by integrating the current I_W in the intervals between successive bunch passages, and is showed in Fig. 2. The electron dose grows exponentially in time as more and more bunches passes by, until saturation occurs. The subsequent

Table 1: Parameters Used for ECLOUD Simulations

parameter	units	value
beam particle energy	GeV	7000
bunch spacing t_b	ns	25
bunch length	m	0.075
number of bunches N_b	-	72
bunch gap N_g	-	8
no. of particles per bunch	–	$1.2 \cdot 10^{11}$
bending field B	T	8.4
length of bending magnet	m	1
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}	-	1.5
energy for max. SEY E_{max}	eV	237.125

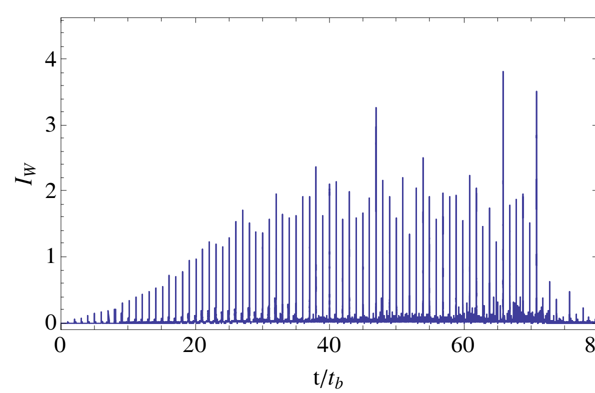

Figure 1: Instantaneous current I_W of electrons bombarding the wall of an LHC arc dipole computed with ECLOUD. The case shown corresponds to a filling pattern featuring 72 charged bunches, with bunch charge of $N = 1.8 \cdot 10^{11}$ protons, followed by 8 empty (zero-charge) bunches. The assumed bunch spacing is 7.48 m, and the SEY is $\delta_{max} = 1.8$.

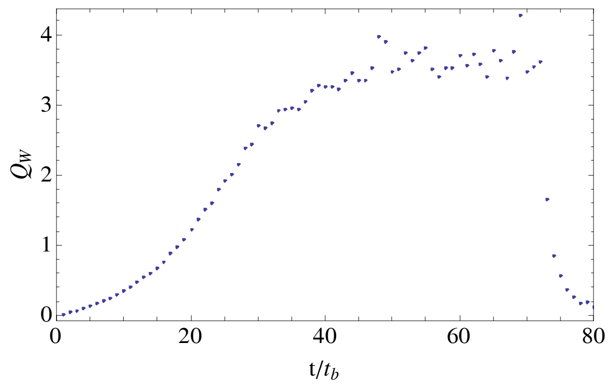

Figure 2: "bunch-by-bunch" electron dose Q_m. The case shown corresponds to a filling pattern featuring 72 charged bunches, with bunch charge of $N = 1.8 \cdot 10^{11}$ protons, followed by 8 empty (zero-charge) bunches. The assumed bunch spacing is 7.48 m, and the SEY is $\delta_{max} = 1.8$.

decay corresponds to the successive passage of the empty bunch train. Figure 3 shows the behavior of the electron

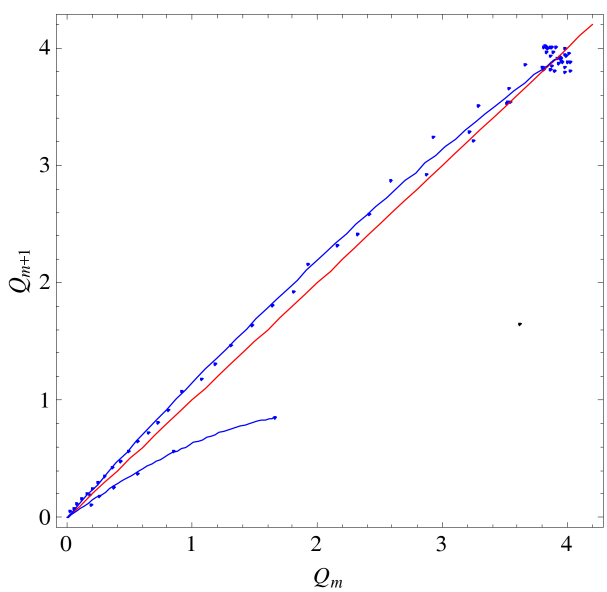

Figure 3: "bunch-by-bunch" electron dose map Q_{m+1} vs Q_m. Circle markers: ECLOUD simulations ($\delta_{max} = 1.8$, all other parameters as in Table I). The red line represents saturation ($\rho_{m+1} = \rho_m$). Markers above the saturation line describe the buildup. Markers below the saturation line describe the e-cloud decay. The blue lines are the corresponding cubic fits. Transitions between filled and empty bunch trains are shown as black circles.

dose (computed as explained above) after the passage of bunch m, denoted as Q_{m+1}, as a function of Q_m. The red line in Fig. 3 corresponds to saturation (fixed points of the $Q_m \rightarrow Q_{m+1}$ map). As more and more bunches pass by, the initially small electron-cloud density builds up (points above the red line, $Q_m > Q_{m+1}$), eventually approaching saturation. In the saturation regime, the Q_m tend to cluster along the red line. Points below the red line ($Q_m < Q_{m+1}$) describe the decay regime. The continuous curves in Fig. 3 correspond to homogeneous cubic fits,

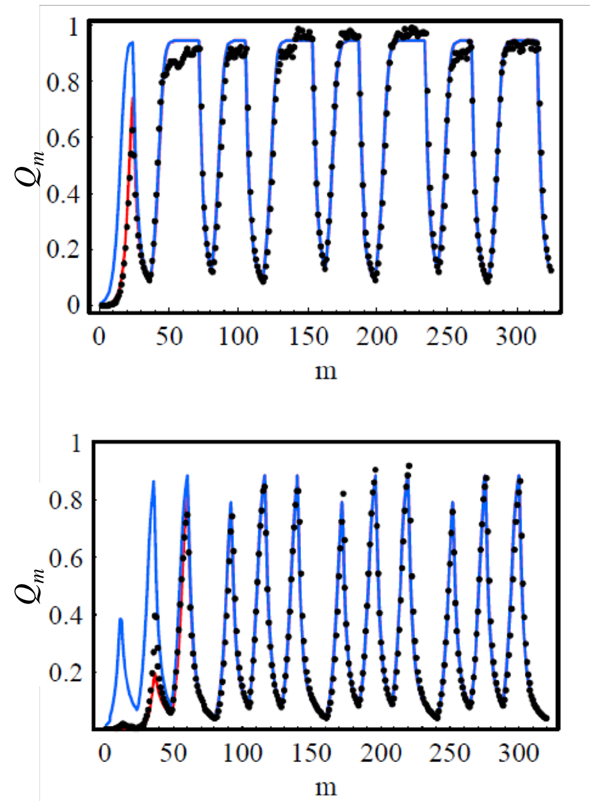

Figure 4: Electron dose "bunch-by-bunch" evolution for two different bunch-train filling patterns, for $N = 1.8 \cdot 10^{11}$ and $\delta_{max} = 1.8$. Top: (24f,12e,36f); bottom: $3 \times (12f12e)$. In both cases, successive bunch trains are separated by gaps whose length corresponds to 28 (empty) bunches. Black markers: ECLOUD results. Blue and red lines: map results corresponding to different initial electron doses.

$$Q_{m+1} = aQ_m + bQ_m + cQ_m \quad (1)$$

which are seen to reproduce the data quite well. The map idea introduced in [1] and [2] for the e-cloud density thus works also for the "bunch-by-bunch" electron dose. The only exceptions are represented by the transitions between filled and empty bunch subtrains, represented by the square markers in Fig. 2. This is not unexpected, and was already noted in [1]. The three terms in the map (1) describe, respectively, the exponential growth/decay mechanism (linear term, larger/ smaller than 1, respectively), the space charge effects leading to saturation (quadratic term, whose sign reflects the concavity of the curves), and an additional correction (cubic term) embodying small corrections. At present, there is only partial clear physical insight into the dependence of the above map parameters on the problems (beam and pipe) configuration, and their values must be deduced empirically from numerical simulations. Once the coefficients have been determined, however, the model is accurate for all filling patterns, as further illustrated in Fig. 4 where are compared results obtained by ECLOUD and the cubic map formalism using the map coefficients corresponding to the reference filling pattern of LHC (72 charged bunches) to predict the electron dose "bunch-by-bunch" evolution for different 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.

CONCLUSIONS AND OUTLOOK

The "bunch-by-bunch" electron dose delivered to LHC dipoles chambers can be described by a cubic map. The coefficients of this map depend on the pipe and beam parameters, and can be simply deduced from e-cloud simulation codes modeling the involved physics in full detail. Remarkably, if all other parameters (namely, the bunch charge N, the SEY, and the pipe parameters) are held fixed, the map coefficients basically do not depend on the filling pattern. The map can be thus used as a quick and (not so) dirty tool for finding filling patterns yielding the highest "scrubbing" efficiency compatible with a given set of beam parameters. Unfortunately, at present, no physical model for relating all map coefficients to the problems parameter is still available. We are working toward adapting approach presented in [6] and [7], for the computation of the linear coefficient in the map describing the evolution of the electron cloud density, to the case presented here.

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