PYECLOUD SIMULATIONS OF THE ELECTRON CLOUD FOR THE J-PARC MR

B.Yee-Rendon*, R. Muto, K. Ohmi, M. Okada, K. Satou, M. Tomizawa and T. Toyama
KEK/J-PARC, Tsukuba, Ibaraki, Japan

Abstract

Recently Electron Cloud (EC) simulations were done using an updated version of the computational model developed at KEK. The results obtained were consistent with the measurements during the slow extraction operation mode for the J-PARC Main Ring (MR). Additionally, new EC simulations were performed using PyECLOUD program. This code was created at CERN and it is the update version of ECLOUD program. The main advantage of the PyECLOUD code with respect to the one at KEK is the adjustable numbers of the macro-particles which allowed to manage the large amount of electrons created when the multipactor condition is reached. In addition, this work used a more accurate model for low energy electrons than the previous simulations, consequently, the EC density simulated has a good agreement with the one measured in the surveys. Additionally, due to the continued upgrade in beam power at fast extraction mode for the MR, the EC could reappear again in this scheme, therefore, PyECLOUD simulations were done to estimate the EC density at these beam conditions

INTRODUCTION

The MR of J-PARC accelerates protons to the energy of 30 GeV in two modes: Fast Extraction (FX) for the Neutrino Experimental Facility and Slow Extraction (SX) for the Hadron Experimental Hall [1]. The presence of the EC at SX mode is a main concern for the successful operation and the power upgrade of the machine. Several EC surveys were done to understand the conditions to enhanced the EC build-up and provided countermeasures [2, 3], in addition, EC simulations were developed to corroborate our assumptions about the source of this phenomenon and estimate its impacts for the upgrade conditions [4–7].

The simulations of the EC started with a code developed at KEK from Ohmi for the KEK Photon Factory [8], the program was used to estimate the EC build-up for the J-PARC accelerators [4–7]. The latest results agreed with the EC observations and support the idea of the microbunch structure as one of the main conditions for EC build-up [7]. Furthermore, a new study of the EC was done using the code PyECLOUD developed at CERN [9], one of the advantages of this program is that allows to handle the exponential increase of the electron during the EC build-up and the possibility to use with the PyHeadtail code to estimate the effects of the EC in the transverse beam instability [10].

* byee@post.j-parc.jp

SIMULATIONS

PyECLOUD is the update version of the code ECLOUD [11], it have been extensively used to reproduce the EC measurements in the CERN accelerators. The general description of the PyECLOUD can be found in previous works [9]. Table 1 shows the main parameters used in this simulations, these values were similar that the one used in the last study [7]. The major improvements were adopted similar model for the Secondary Electron Yield (SEY) and the energy spectrum of the true secondaries electrons.

Table 1: Simulations Parameters for the JPARC MR

Parameters	Units	Value
Energy	GeV	30
Beam Power	kW	37 (SX) and 500 (FX)
Circumference	m	1567.5
Beam pipe radius	cm	6.5
rms bunch size	cm	0.5
Ionization cross section	$Mbarn$	2
R_0		0.7
E_0	eV	150
δ_{max}		1.7
s		1.35
E_{max}	eV	287
σ_{true}		1.082
μ_{true}		1.663
Vacuum pressure at 5 ms[1]	μPa	0.2
Vacuum pressure at 75 ms[1]	μPa	0.9
Time step	ns	1

The SEY employed is defined as

$$\begin{aligned}\delta_{total} &= \delta_{elastic} + \delta_{true} \\ &= R_0\left(\frac{\sqrt{E}-\sqrt{E+E_0}}{\sqrt{E}+\sqrt{E+E_0}}\right)^2 + \frac{\delta_{max} s \frac{E}{E_{max}}}{s-1+\left(\frac{E}{E_{max}}\right)^s} \quad (1)\end{aligned}$$

where R_0, E_0, δ_{max}, s, E_{max} are the parameters obtained from the fit for the elastic and the true secondaries contributions [12]. The first part correspond to the electrons that interact in elastic way with the chamber wall ($\delta_{elastic}$) and the second one the electron has a complex interaction with the atoms of the materials the so called true secondaries (δ_{true}). These values are strong dependence of the material and the geometry of the beam pipes. Figure 1 shows the curves of the SEY used for MR J-PARC simulations, additionally, a

[1] The time after debunching starts (P3).

subplot for small range of electron energy is included to observe more clear the contribution of the elastic part.

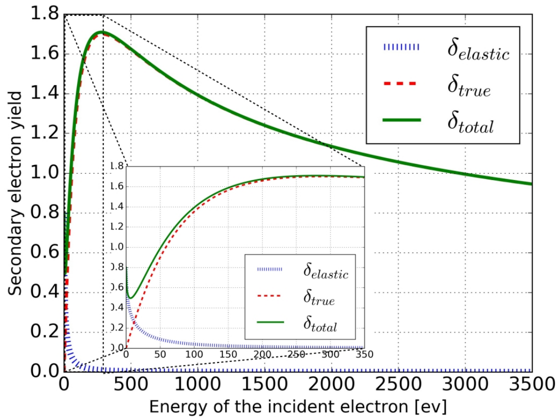

Figure 1: The total SEY (δ_{total}, green solid line) is the sum of the contribution for the elastic part ($\delta_{elastic}$, blue dot line) and the true secondaries (δ_{true}, red dot line).

The energy spectrum of the true secondaries electrons is represented by a log normal distribution [9]

$$\frac{dn_{true}}{dE} = \frac{1}{\sqrt{2\pi}E\sigma_{true}} \exp - \frac{(ln(E) - \mu_{true})^2}{2\sigma_{true}^2} \qquad (2)$$

σ_{true} and μ_{true} were from the fit and they are strong dependence of the material of the beam pipes. In this work, the values used were obtained from measurements of other experiment [13].

In addition, the EC build-up at FX were analyzed to estimate the potential risk during this acceleration mode.

RESULTS

The previous work showed the relevance of the microbunch structure of the beam for the EC build up in the simulations [7]. Smooth bunch shape (low frequencies components) produced less electron that one which have a severe microbunch structure (high frequencies components).

Figure 2 top presents the beam current collected by the Fast Current Monitor (FCT) and used as input for the simulations; on the bottom: the comparison between electron flux measured by the EC detector (green dot line) and the computed using PyECLOUD (blue dot line) at the beginning of the debunching process when the beam has a smooth bunch shape are shown.

In the same way, Figure 3 shows similar data for a time of 75 ms after the debunching started: when the EC reached the highest intensity and the beam distribution has a more spiky longitudinal profile.

In Figure 2 the signal recorded for the EC detector was only detector noise and the calculated by the simulations was around 12 nA/cm^2. In constrant, Figure 3, the simulations reproduced the peaks observed in the measurements.

In addition, comparisons between electron flux of the measurements and the simulations were done for the period of

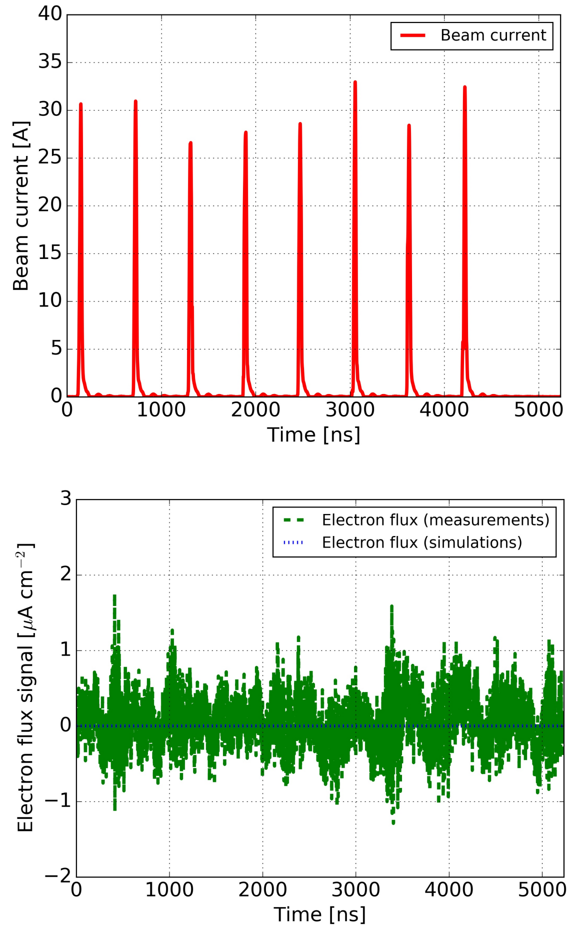

Figure 2: Top: the beam current; bottom: the comparison of the electron flux signals measured (green dot line) and the simulated (blue dot line). These values corresponded to the beginning of debunching process at SX mode of MR.

time in which the EC signal was more intense (See Figure 4). In the case of the measurements the signal was averaged over 100 turns, the error bars included the beam fluctuations and detector noise. For the simulations the signal was averaged over the last 3 turns, the statistics errors were included. Similar as Figure 3 bottom, there was in agreement between the location of the peaks between the measurements and simulations, nevertheless, the code underestimated the high of peak about 20% in average.

Finally, the EC buildup for the beam configuration of FX has been under study. In this case the beam profile signal recorded during neutrino experiments and the same vacuum pressure from the SX studies were used.

Figure 5 shows beam current (top) and the electron flux signal (bottom), the electron flux was lower than the produced any case at SX. Most of the electron produced for this case were for trailing edge multipactor mechanism, however, it can be observed some smaller peaks than can not correspond to this mechanism, the reason is that some small bumps were presented between the bunches of the longitudinal distribution. Those came for some noises in the mea-

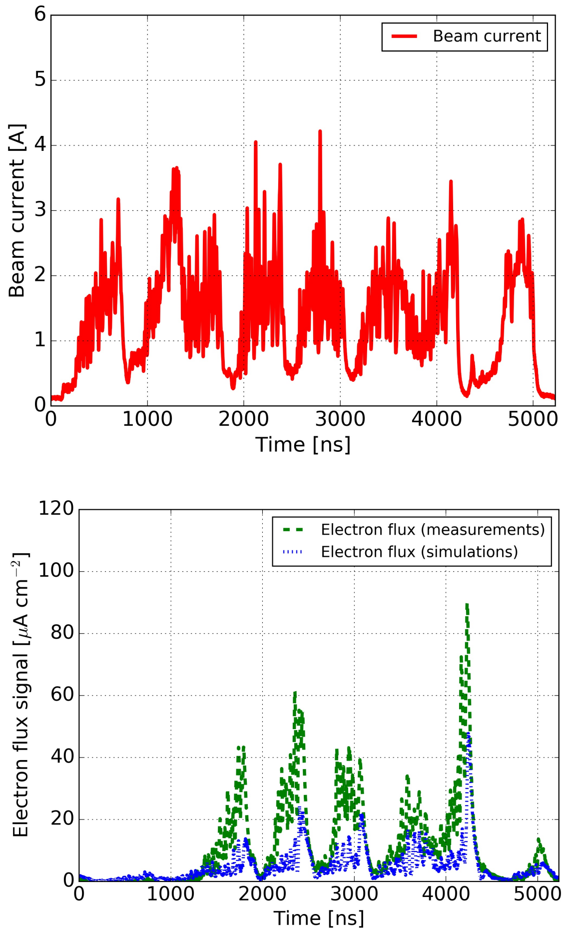

Figure 3: Top: the beam current; bottom: the comparison of the electron flux signals measured (green dot line) and the simulated (blue dot line). The values corresponded at 75 ms after the beginning of debunching.

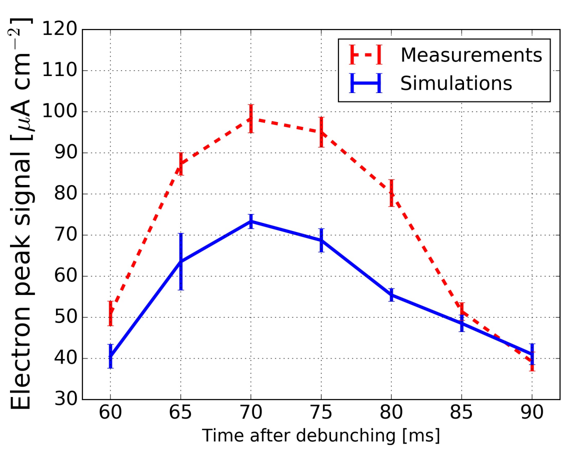

Figure 4: The comparison of the electron peak flux measured (red dot line) and the simulated (blue solid line). The error bars are included

surements, the experiment could only measured one time the longitudinal profile, that were not completed removed during the conversion from the voltage signal (recorded by the oscilloscope) into current.

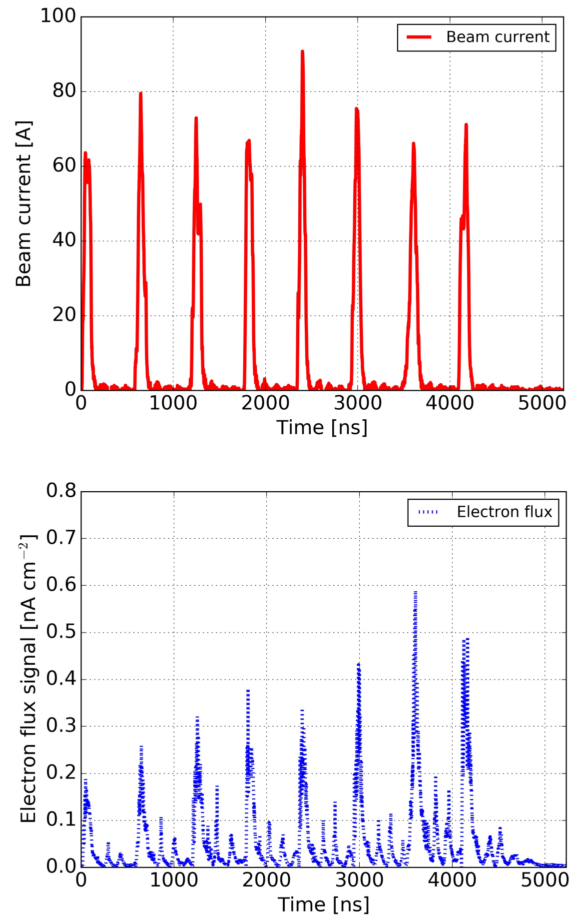

Figure 5: The beam profile for FX measured by the neutrino group at J-PARC (top) and the corresponding electron cloud density simulated by PyECLOUD (bottom), using the same values of the SX simulations for the rest of the parameters.

CONCLUSION AND OUTLOOK

PyECLOUD was able to reproduced similar results as the previous code [7]. The code reconfirmed the importance of the bunch structure for the enhancing of the EC. In addition, PyECLOUD allowed us to made a direct comparison between the signal recorded by the EC detector and simulated one as is seen in the Figure 3. There was a good agreement in the location of the peaks (Figure 3), nevertheless, the simulations underestimated their peak amplitude. Moreover, Figure 4 shows that the peak produced by the code were in average 20% lower than the measurements.

This difference could be due to the models of the SEY and energy spectrum of the secondary for this simulations. For the SEY, the δ_{true} was based in previous measurements several years ago [14], thus, the SEY curves must be changed due to scrubbing effect, moreover, for $\delta_{elastic}$ the values of the copper were employed. In the case of the energy spectrum, the parameters were obtained in other experiments [13]. In addition, when the electron hit the collector plate this produced also secondaries electrons, this effects is not simulated.

For the case of FX (See Figure 5), in the actual operation the bunch shape is smooth and has a high current, this conditions produced that the electrons that impacts the walls had an energy beyond 40 keV. At that energy region the rate of secondary electron production is lower than one, thus, EC build-up was not reached.

During the last year, EC simulations were developed to reproduced the signals measured during the studies and corroborate the main condition that enhanced the EC. To continue improve the EC simulations and shed light on the conditions of the EC several surveys were done or are under process. For instance, the measurements of the energy distribution which impacts the beam walls presented in this conference [3] and the measurements of the SEY of the same materials of MR beam walls.

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