POSINST SIMULATION ON FERMILAB MAIN INJECTOR AND RECYCLER RING

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Abstract

The Fermilab accelerator complex is currently undergoing an upgrade from 400kW to 700kW. This intensity could push operations into the region where electron cloud (e-cloud) generation could be observed and even cause instabilities. [1] The POSINST simulation code was used to study how increasing beam intensities will affect electron cloud generation. Threshold simulations show how the e-cloud density depends on the beam intensity and secondary electron yield (SEY) in the Main Injector (MI) and Recycler Ring (RR).

POSINST AND INPUT PARAMETERS

POSINST is a code that simulates the build-up and dissipation of electron cloud with realistic beam parameters and values for the externally applied magnetic field [2–5]. The electric fields due to the electron cloud are calculated in POSINST using a Particle In Cell (PIC) technique. These electric fields could be used as an input for codes that simulate beam dynamics, or for analytical calculations (for example beam instability growth rate due to field from electron cloud). POSINST simulates electron motion in 3D space, but calculates the electric field only for a 2D cross-section of the accelerator. POSINST treats externally applied magnetic fields as a predetermined uniform constant either parallel or perpendicular to the ideal beam trajectory, and thus can only simulate dipole or solenoidal fields. The secondary electron generation is based on the Furman-Pivi probabilistic model [4]. The beam parameters used in the simulations are given in Table 1. The beam fill pattern is show by Figure 1.

Figure 1: The 588 RF buckets are grouped into 7 batches of 84 buckets. Six batches have beam in them, while the seventh batch is empty. Each batch with beam has 82 filled buckets and 2 empty buckets.

The SEY curves are generated based on a set of parameters in POSINST governing the generation of backscattered electrons, rediffused electrons, and true secondary electrons. These parameters determine the shape of the SEY curve, which is scaled by an input for the peak SEY value. The POSINST electron generation parameters were obtained by fitting the Furman-Pivi probabilistic model to a real SEY measurement of steel. [4] The SEY curves used in simulations are shown in Figure 2.

Table 1: Simulation Inputs Parameters

general parameters	
Beam energy [GeV]	8
Bunch Intensity [protons/bunch]	5.5e10 - 11.5e10
Total Intensity [protons]	2.71e13 - 5.41e13
ring circumference[m]	3319.419
revolution frequency [kHz]	90
Harmonic number	588
RF frequency [Mhz]	53
Total RF bucket filled	492
SEY	1.2-1.9
MI specific parameters	
σ_x [mm]	3
σ_y [mm]	3
σ_z [m]	0.3
σ_t [ns]	1
Bunch length [σ][m][ns]	10; 3; 10
Ellipse chamber major/minor semi-axis [cm]	5.88; 2.39
Dipole Field[T]	0.234
RR specific parameters	
σ_x [mm]	3.6
σ_y [mm]	1.6
σ_z [m]	0.75
σ_t [ns]	2.5
Bunch length [σ][m][ns]	4; 3; 10
Ellipse chamber major/minor semi-axis [cm]	4.7 2.2
Dipole Field[T]	0.137

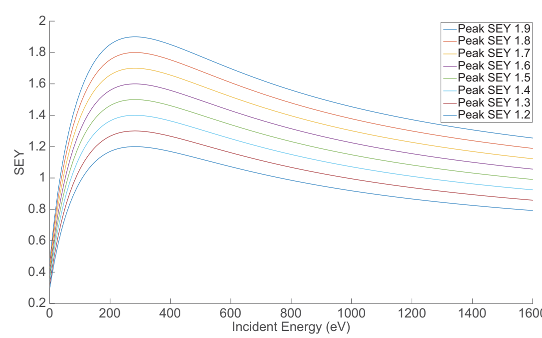

Figure 2: The SEY curves used in simulation.

THRESHOLD SIMULATION RESULT

Figure 3 shows a typical simulation of electron cloud build up at one location in the accelerator for a time duration of one revolution period of the machine. The density of the E-cloud build up matches the filling pattern. The E-cloud builds up rapidly and then saturates. After saturation is reached, the E-cloud density oscillates as bunches pass and dips as the two empty buckets between batches pass. Eventually, after the 6 filled batches pass, the E-cloud vanishes in the one batch (84 bucket) gap with no beam.

A series of simulations were done for both the MI and RR to determine the predicted electron cloud density for specific combinations of beam intensity and Secondary Electron Yield (SEY) of the beampipe material. Results were obtained for the cases of (1) a dipole field region, and (2) a field-free region. The build up of an electron cloud is different in these regions due to trapping of the electrons by the dipole field. The simulated beam intensity ranged from 27.06×10^{12} to 54.12×10^{12} protons with an increment of 2.46×10^{12} protons, or a bunch intensity of 5.5×10^{10} to 11×10^{10} protons per bunch with an increment of 0.5×10^{10} protons per bunch. This range of beam intensities corresponds to beam powers from 391kW (27.06×10^{12} protons) to 782kW (54.12×10^{12} protons), where 700kW corresponds to 48.7×10^{12} protons. The simulated range of peak SEY values corresponds to the in-situ measured values of the SEY of SS316L in the MI [6]. The SEY starts near 1.9 but drops to around 1.3 as the material is conditioned. The E-cloud densities were averaged over the full turn (revolution period) for each intensity/SEY pair.

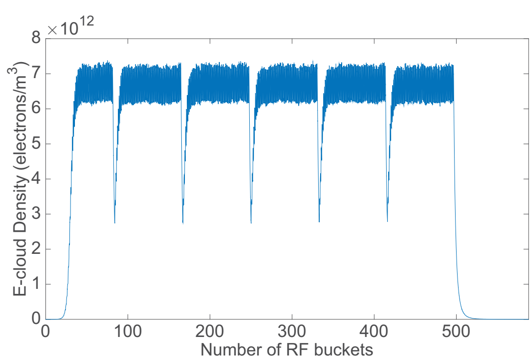

Figure 3: E-cloud density build-up for one turn at 1.9 SEY and 11×10^{12} protons per bunch (field free region).

Main Injector

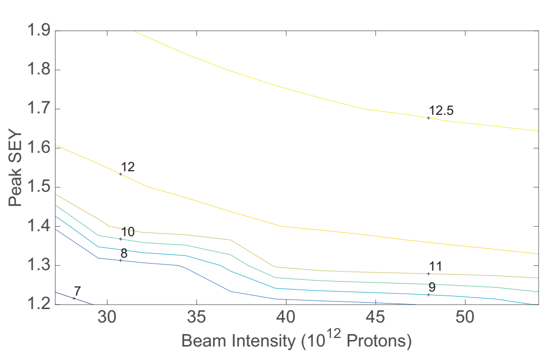

Figure 4: MI field-free region E-cloud density ($electrons/m^3$) contour in log scale.

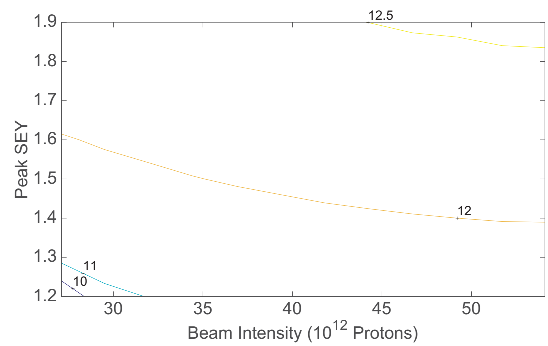

Figure 5: MI dipole region E-cloud density ($electrons/m^3$) contour plot in log scale.

Figure 4 and Figure 5 show the MI threshold simulation results for the field free region and dipole region respectively.The E-cloud dips to a lower density in the field free region compared to the dipole region as the SEY and beam intensity go down. The E-cloud density reaches all the way below $10^7 electron/m^3$ in the field free region while in the dipole region the E-cloud density only reaches $10^{10} electron/m^3$. On the other hand, as the beam intensity and SEY go up, the E-cloud density reaches higher values in the field free region. For example, in the field free region, it takes less than 35×10^{12} protons for the E-cloud density to reach above $10^{12.5} electron/m^3$ at 1.9 SEY while in the dipole region it takes over 45×10^{12} protons to get the same E-cloud density at the same SEY.

Recycler Ring

Figure 6 and Figure 7 show the RR threshold simulation results for the field free region and dipole region respectively. A comparison between the dipole region and the field free region shows the same trend as in MI. The E-cloud density reaches $10^7 electron/m^3$ in the field free region faster than in the MI, while on the other hand, in dipole region, the E-cloud density goes down to $10^8 electron/m^3$ in RR (compare to $10^{10} electron/m^3$ in the MI). The RR dipole regions behave completely differently than the MI dipole region, it seems that because of the difference in the chamber dimensions and beam size, the E-cloud density is relatively independent of the beam intensity in the RR dipole region. The E-cloud formation is only dependent on the SEY in this region.

Overall, the E-cloud density has a slightly higher saturation in a field free region, while on the other hand, the E-cloud persists longer in a dipole region. In the both the field free regions of the RR and the MI, the E-cloud density decreases from 10^{11} to 10^8 when the peak SEY decreases by 0.2 for almost all intensities. While in the MI dipoles region, such a break point was never reached.

FIELD FROM SECONDARY ELECTRONS

To further understand the effect of E-cloud on beam, an effort was made to extract the electric field due to the E-cloud from the simulation. Figure 8 shows the development

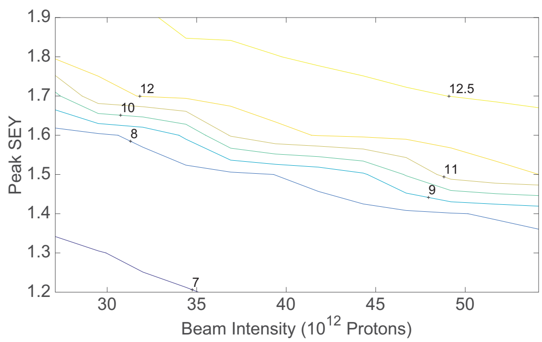

Figure 6: RR field-free region E-cloud density ($electrons/m^3$) contour plot in log scale.

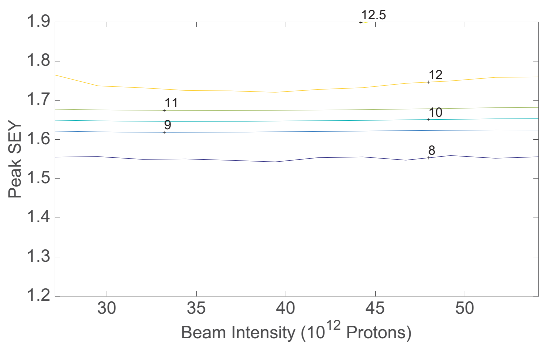

Figure 7: RR dipole region E-cloud density ($electrons/m^3$) contour plot in log scale.

of the field at a specific location as the bunches pass by. This field was calculated using 5×10^{10} protons per bunch and 2.2 SEY in the dipole region. All buckets are filled in this simulation. Figure 9 shows the development of E-cloud density in the same simulation. Figure 10 shows the E-cloud density at the center of the vacuum chamber. The E-cloud starts to build up after about 50 bunches have passed, the field development matches the E-cloud build up. The field reaches a maximum 10-20 buckets into the saturation region of the total electron cloud density, and then drops off. The field reaches maximum after about 120 bunches have passed, after the E-cloud density near the vacuum chamber center has leveled out.

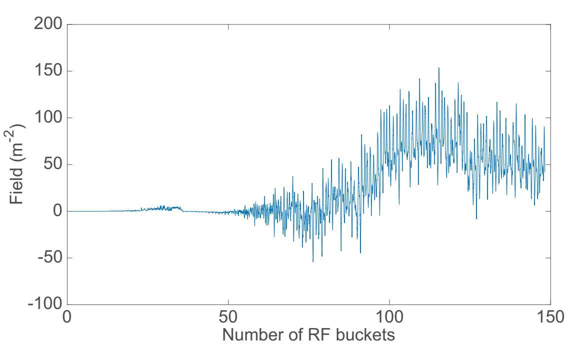

Figure 8: Field extracted from the POSINST.

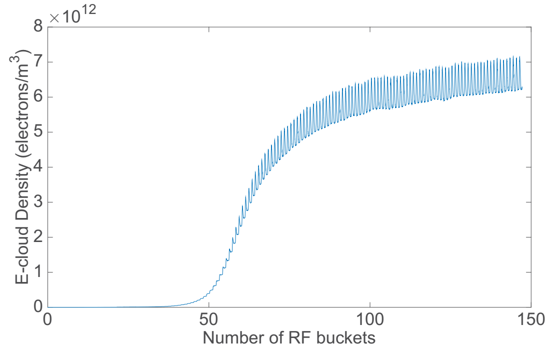

Figure 9: E-cloud density for the Field extraction simulation.

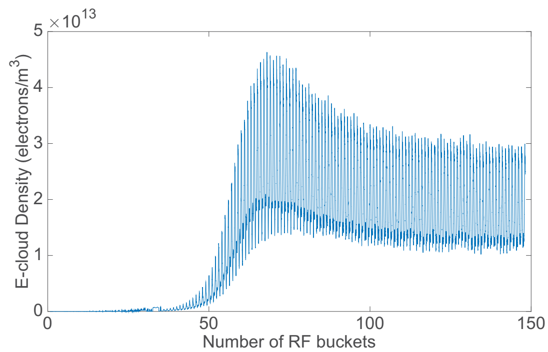

Figure 10: E-cloud density for the Field extraction simulation within a 3mm circle around the vacuum chamber center.

CONCLUSION

Electron cloud density simulations were presented for the Main Injector and Recycler Ring at Fermilab using realistic parameters for the beams and machines. E-cloud simulations were done for both dipole field and field free regions. Based on the simulation results, in most cases the E-cloud generation can be greatly suppressed when the SEY of the beam pipe material is below 1.3. The only exception is in a MI dipole region, where below 1.3 SEY the E-cloud density is only suppressed by one order of magnitude. Further studies of effects of the E-cloud generation on the beam are in progress. The field from the secondary electrons has been successfully extracted from the simulation. It should now be possible to calculate an effective impedance and instability growth rate due to the presence of the electron cloud using a simplified analytic model.

ACKNOWLEDGMENT

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