DIRECT NUMERICAL MODELING OF E-CLOUD DRIVEN INSTABILITY OF THREE CONSECUTIVE BATCHES IN THE CERN SPS*

J.-L. Vay†, M. A. Furman, M. Venturini, LBNL, USA

Abstract

Electron clouds impose limitations on current accelerators that may be more severe for future machines, unless adequate measures of mitigation are taken. The simulation package WARP-POSINST was recently upgraded for handling multiple bunches and modeling concurrently the electron cloud buildup and its effect on the beam, allowing for direct self-consistent simulation of bunch trains generating, and interacting with, electron clouds. We have used the WARP-POSINST package on massively parallel supercomputers to study the buildup and interaction of electron clouds with a proton bunch train in the CERN SPS accelerator. Results suggest that a positive feedback mechanism exists between the electron buildup and the e-cloud driven transverse instability, leading to a net increase in predicted electron density. Results also show evidence of correlations between bunches.

INTRODUCTION

Electron clouds have been shown to trigger fast growing instabilities on proton beams circulating in the SPS [1] and other accelerators [2]. Usually, simulations of electron cloud buildup and their effects on beam dynamics are performed separately. This is a consequence of the large computational cost of the combined calculation due to large space and time scale disparities between the two processes. In [3], we have presented the latest improvements of the simulation package WARP-POSINST [4] for the simulation of self-consistent ecloud effects, including mesh refinement, and generation of electrons from gas ionization and impact at the pipe walls. In [5], we presented simulations a batch of 72 consecutive bunches interacting with electrons clouds in the SPS, which included the entire buildup of electron clouds and the self-consistent interaction between the bunches and the electrons. In this paper, we present an extension of this work to the modeling of 3 consecutive batches of 72 bunches each.

SELF-CONSISTENT SIMULATION OF 3 CONSECUTIVE BATCHES IN THE SPS

Three consecutive batches of 72 bunches propagating at injection energy in the SPS were simulated for 1000 turns of the machine, using the parameters given in Table 1. A simulated bunch-to-bunch feedback system is used to stabilize the beam in the horizontal direction. No feedback system is used in the vertical direction. The simulation was performed on a NERSC parallel supercomputer using 9600 CPUs.

Table 1: Parameters Used for Warp-POSINST Simulations

beam energy	E_b	26 GeV
bunch population	N_b	1.1×10^{11}
rms bunch length	σ_z	0.23 m
rms transverse emittance	$\epsilon_{x,y}$	2.8, 2.8 mm.mrad
rms momentum spread	δ_{rms}	2×10^{-3}
beta functions	$\beta_{x,y}$	33.85, 71.87 m
betatron tunes	$Q_{x,y}$	26.13, 26.185
chromaticities	$Q'_{x,y}$	0, 0
Cavity voltage	V	2 MV
momentum compact. factor	α	1.92×10^{-3}
circumference	C	6.911 km
bucket length	δ_b	5 ns
bunch spacing	Δ_b	25 ns
peak SEY	δ_{SEY}	1.18
# of bunches/batch	N_{bunch}	72
# of batches	N_{batch}	3
# of stations/turn	N_s	10
# of slices/bucket	N_{slices}	64

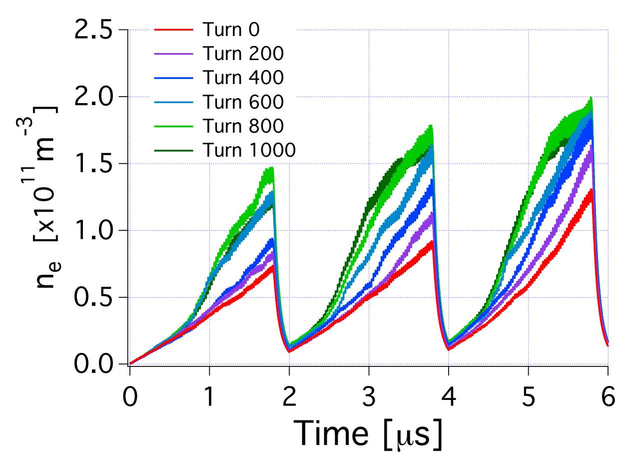

Figure 1: Time history of the charge density of electron cloud averaged over the pipe section at one station around the ring from a WARP-POSINST simulation of 3 batches of 72 bunches.

Time histories of the electron density averaged over the pipe cross section and on axis, taken at one location around the ring, are shown in Figures 1 and 2, from turns 0 to 1000

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† jlvay@lbl.gov

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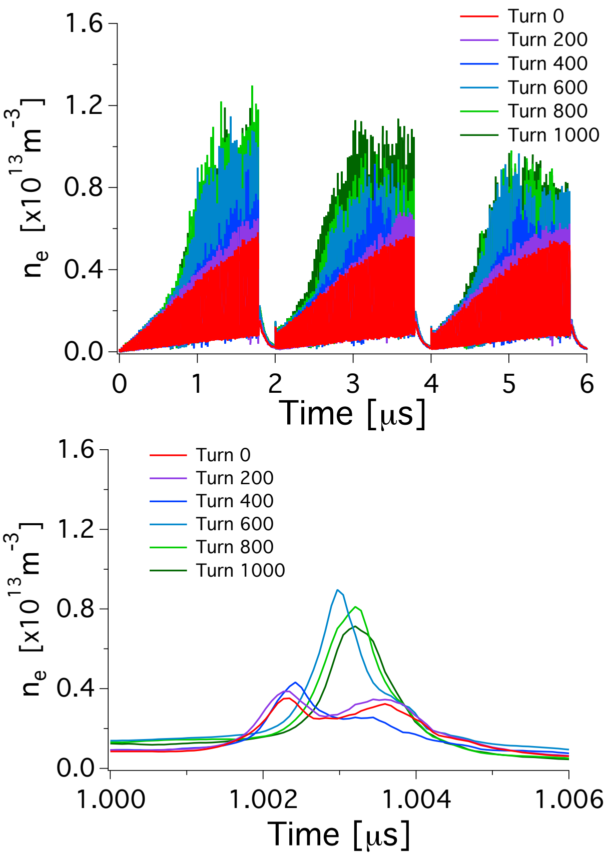

Figure 2: Time history of the charge density of electron cloud on axis at one station around the ring from a WARP-POSINST simulation: (top) between $0\mu s \leq t \leq 6\mu s$; (bottom) between $1\mu s \leq t \leq 1.006\mu s$.

by intervals of 200. There is an increase in average and on axis electron density until turn 800 for approximately the last two thirds of the first batch and the last three quarters of the second and third batch. The maximum enhancement of the average electron density and the electron density is as high as 50% to 100% (i.e. doubling) of the density at turn 0.

The turn-by-turn history of the bunches vertical emittance, RMS size and offset are given in Figure 3. It shows substantial growth of vertical emittance, RMS sizes and amplitude of centroid oscillations in phase-space, with evolutions that coincide with the electron density enhancements with regard to time of passage at a fixed station and to turn number. This suggests that there is a positive feedback between the bunches dynamical response to the electron cloud and the build-up of the cloud (i.e. the beam emittance and offset growths result in higher electron density and vice-versa). Vertical centroid oscillations reach their maxima between turns 400 and 700, followed by an overall decrease. This means that the increase that is observed in vertical emittance and RMS size is initially caused by coherent motion followed by incoherent motion due to phase mixing of the particle trajectories.

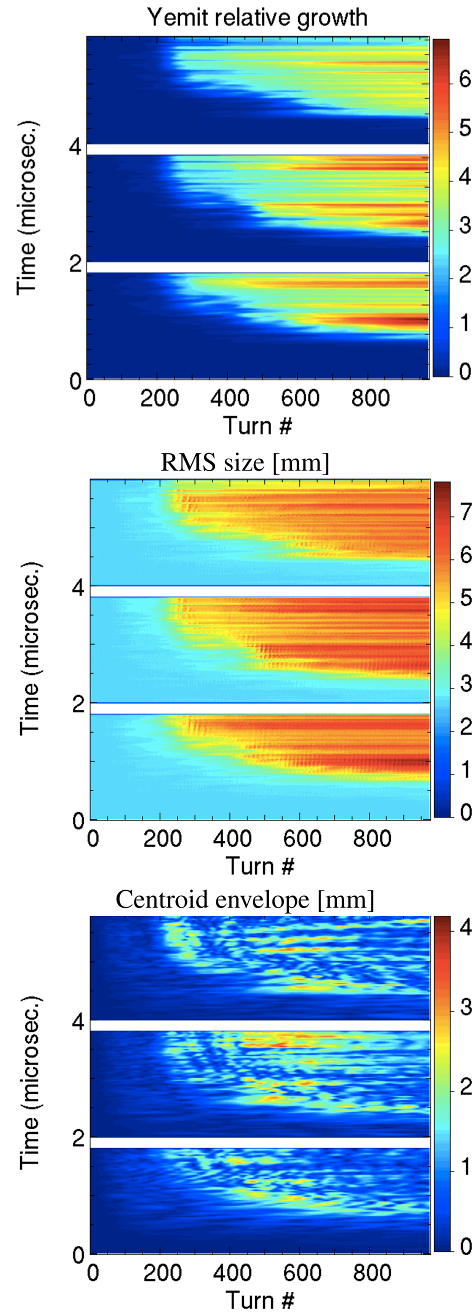

Figure 3: Bunch vertical (Y) quantities versus time of passage and turn numbers: (top) emittance growth $(\epsilon_y(t)/\epsilon_y(0) - 1)$; (top-right) RMS size $\sqrt{\overline{(y-\bar{y})^2}}$; (bottom-left) amplitude of centroid oscillations in phase-space $\sqrt{\bar{y}^2 + \beta_y^2 \overline{y'}^2}$.

The history of vertical bunch offsets versus time of passage and turn number, is given in Fig. 4 for turns 0 to 50. Betatron oscillations result in an alternation of positive and negative offsets with turn number. In the absence of correlation between bunches, the phase of the oscillations should be random from one bunch to the next but there is a pattern of stripes that suggest that the phase of the oscillations is

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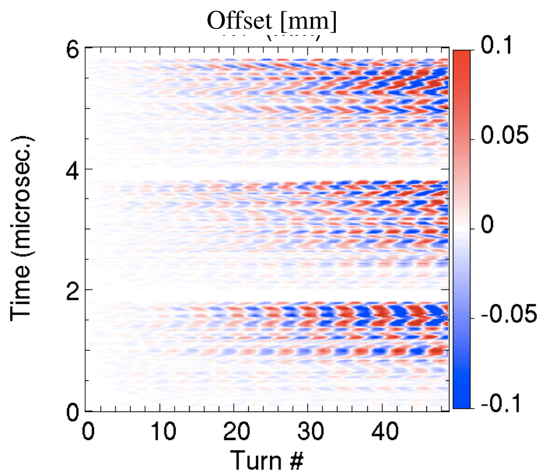

Figure 4: Bunch vertical offset $\overline{y}$ versus time of passage and turn numbers.

not purely random, and is correlated to some degree between bunches.

CONCLUSION

Direct simulation of three successive batches of 72 bunches propagating in the CERN SPS accelerator, including the self-consistent build-up of electrons clouds and their interaction with the bunches, where performed with the WARP-POSINST package on massively parallel supercomputers. Analysis of the turn-by-turn evolution of the electron buildup and of the bunches vertical motion shows that the vertical bunch size, emittance and offset increase that ensue from its interaction with the electron cloud are associated with a net increase of up to 50% to 100% in average electron density and electron density on axis. This suggests that a positive feedback mechanism exists between the electron buildup and the e-cloud driven transverse instability, leading to a net increase in predicted electron density. Analysis of the history of bunch offsets reveals some evidence of correlation induced by the memory of electron clouds between bunches.

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