UPDATE ON ELECTRON-CLOUD SIMULATIONS USING THE PACKAGE WARP-POSINST

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INTRODUCTION

At PAC05[1] and PAC07[2], we presented the package WARP-POSINST for the modeling of the effect of electron clouds on high-energy beams. We present here the latest developments in the package. Three new modes of operations were implemented: 1) a build-up mode where, similarly to POSINST (LBNL) or ECLIGHT (CERN), the build-up of electron clouds driven by a legislated bunch train is modeled in one region of an accelerator; 2) a quasi-static mode where, similarly to HEADTAIL (CERN) or QuickPIC (USC/UCLA), the frozen beam approximation is used to split the modeling of the beam and the electrons into two components evolving on their respective time scales; and 3) a Lorentz boosted mode where the simulation is performed in a moving frame where the space and time scales related to the beam and electron dynamics fall in the same range. The implementation of modes (1) and (2) was primarily motivated by the need for benchmarking with other codes, while the implementation of mode (3) fulfills the drive toward fully self-consistent simulations of e-cloud effects on the beam including the build-up phase.

BUILD-UP MODE

Figure 1: Sketch of the build-up mode. The dynamics of electrons is followed for a thin (2-D) or thick (3-D) slice located at a given location in the lattice, under the influence of a legislated particle beam passing through the slice.

In order to facilitate direct comparison with build-up codes like POSINST [4, 5, 6, 7], ECLIGHT (CERN) or Cloudland (SLAC), a build-up mode class was implemented in Warp. In this mode, the dynamics of electrons is followed for a thin (2-D) or thick (3-D) slice located at a given location in the lattice, under the influence of a legislated particle beam passing through the slice.

![Figure 1: Sketch of the build-up mode.](image)

QUASISTATIC MODE

We have implemented a quasistatic [8] mode in Warp. In this mode, a 2-D slab of electron macroparticles is stepped backward (with small time steps) through the beam field (see Fig. 4). The 2-D electron fields (solved at each step) are stacked in a 3-D array, that is used to give a kick to the beam. Finally, the beam particles are pushed forward (with larger time steps) to the next station of electrons, using either maps or a Leap-Frog pusher. The first implementation was for accelerator lattices treated in the smooth approximation. A more detailed lattice description was implemented later (see below). This mode allows for direct comparison with the quasistatic codes HEADTAIL [9], QuickPIC [10], PEHTS [11] or CMAD [12]. The parallelization is mono-dimensional (along s) using pipelining, similarly to QuickPIC (see Fig. 5). We have simulated an e-cloud driven instability in an LHC-like ring with Warp.

![Figure 2: Average electron density versus time from POSINST and Warp in build-up mode simulations.](image)
in a quasi-static mode, and HEADTAIL. We used the parameters from table 1 in a drift (Fig. 6) and in a dipole (Fig. 7). Some of the parameters were purposely chosen to be unphysically large, so as to magnify their effects. The two codes predict similar emittance growth under the various conditions, with excellent qualitative agreement and good to very good quantitative agreement. We tentatively attribute the quantitative discrepancies to differences in implementations including: adaptive versus fixed grid sizes, different field solvers and particle pushers, different field interpolation procedures near internal conductors, slightly different values of physical constants, etc.

Table 1: Parameters Used for Simulations of e-Cloud Driven Instability Studies in the LHC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>circumference</td>
<td>26.659 km</td>
</tr>
<tr>
<td>beam energy</td>
<td>450 GeV</td>
</tr>
<tr>
<td>bunch population</td>
<td>$1.1 \times 10^{11}$</td>
</tr>
<tr>
<td>rms bunch length</td>
<td>0.13 m</td>
</tr>
<tr>
<td>rms beam sizes</td>
<td>0.884, 0.884 mm</td>
</tr>
<tr>
<td>beta functions</td>
<td>66.0, 71.54 m</td>
</tr>
<tr>
<td>betatron tunes</td>
<td>64.28, 59.31</td>
</tr>
<tr>
<td>chromaticities</td>
<td>1000.0, 1000.0</td>
</tr>
<tr>
<td>synchrotron tune</td>
<td>0.59</td>
</tr>
<tr>
<td>momentum compaction factor</td>
<td>$0.347 \times 10^{-3}$</td>
</tr>
<tr>
<td>rms momentum spread</td>
<td>$4.68 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

**BOOSTED FRAME APPROACH**

It was shown in [13] that it was possible to perform simulations of electron-driven instabilities from first principles (e.g. using standard Particle-In-Cell methods), at much reduced computing cost by performing the calculation in a suitable Lorentz boosted frame. Numerical developments that were needed have been implemented, including a new particle pusher and field solver, and are described in [14]. Special handling of inputs and outputs between the boosted frame and the laboratory frame are described in [15]. Two
Figure 6: Fractional emittance growth from Warp (red) and HEADTAIL (black) simulations of an e-cloud driven instability in drifts of an LHC-like ring for an electron background density of $10^{14} \text{m}^{-3}$ for (top) $\nu = \alpha = \delta_{\text{rms}} = Q_x = Q_y = 0$, (middle) $Q_x = Q_y = 0$, (bottom) parameters from table 1.

Warp calculations of an electron cloud driven instability showed very good agreement [14] between a full PIC calculation in a boosted frame and a calculation using the quasistatic mode, for similar computational cost.

FURTHER DEVELOPMENTS

We have recently added the capability to use linear maps to push particles in accelerator lattices, within the quasistatic mode and the full PIC mode in a Lorentz boosted frame. Good quantitative agreement was obtained between Warp using the quasistatic mode and CMAD [12]. Similar calculations with the full PIC method in a boosted frame are in progress.

ACKNOWLEDGMENTS

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REFERENCES

[1] JL Vay et al, Particle Accelerator Conference, Knoxville, TN (2005), papers ROPB006 and FPAP016
[12] M. Pivi, These proceedings WE1PB01.