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SLAC-PUB-12970

CMAD: A NEW SELF-CONSISTENT PARALLEL CODE TO SIMULATE THE ELECTRON CLOUD BUILD-UP AND INSTABILITIES*

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Abstract

We present the features of CMAD, a newly developed self-consistent code which simulates both the electron cloud build-up and related beam instabilities. By means of parallel (Message Passing Interface - MPI) computation, the code tracks the beam in an existing (MAD-type) lattice and continuously resolves the interaction between the beam and the cloud at each element location, with different cloud distributions at each magnet location. The goal of CMAD is to simulate single- and coupled-bunch instability, allowing tune shift, dynamic aperture and frequency map analysis and the determination of the secondary electron yield instability threshold. The code is in its phase of development and benchmarking with existing codes. Preliminary results on benchmarking are presented in this paper.

INTRODUCTION

In the beam pipe of a positron or proton storage rings, an electron cloud may be first produced by photoelectrons and ionization of residual gases and then increased by the secondary emission process [1,2]. The electron cloud density depends on characteristics of the circulating beam (bunch length, charge and spacing) and the secondary electron yield of the wall from which the electrons are generated. The space charge from the cloud, if sufficiently large, can lead to beam instability and losses ultimately causing a reduction in the collider luminosity. The electron cloud has been observed at many storage rings [2] and it is an issue for future machines aiming at high beam intensity.

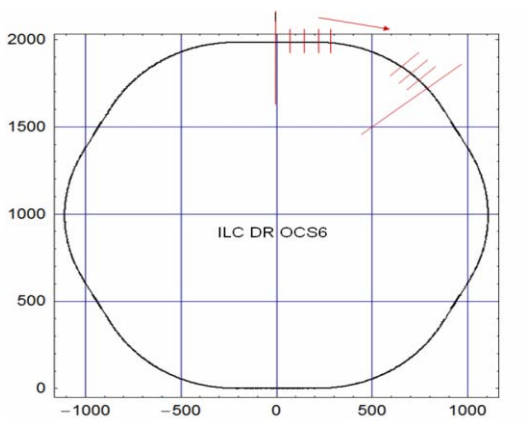

Figure 1. Footprint of the ILC Damping Ring.

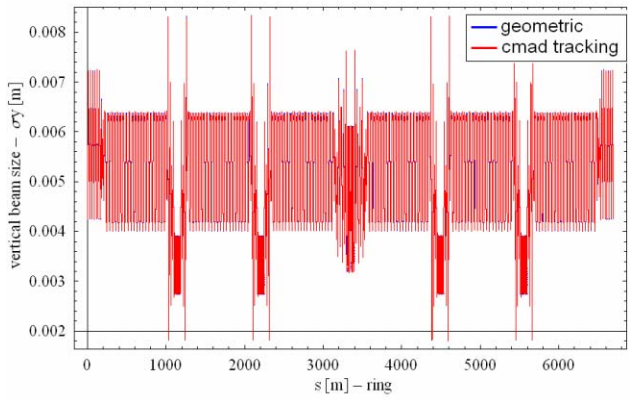

Figure 2. Beam size in the ILC DR. The geometric beam size computed including dispersion is compared to the beam size obtained by CMAD tracking in the positron ring for 100 turns with a cloud density below the instability threshold.

So far, the codes available for the simulation of the electron cloud effect can be divided into two different categories, the build-up and the beam instability simulation codes [3, 4]. The formers simulates the development of an electron cloud in magnetic or field free regions of a storage ring, while the latter simulate the beam instability for a given input electron cloud density.

One of the goals of the development of this code is to simulate the build-up of an electron cloud and the related beam instability in a single code. Another purpose is to simulate the interaction between the beam and the cloud in a large number of interaction points per turn, ideally the number of elements of the ring. This can be rather demanding in term of processor computing time, for example in the case of the ILC damping ring which counts more than 6000 ring elements.

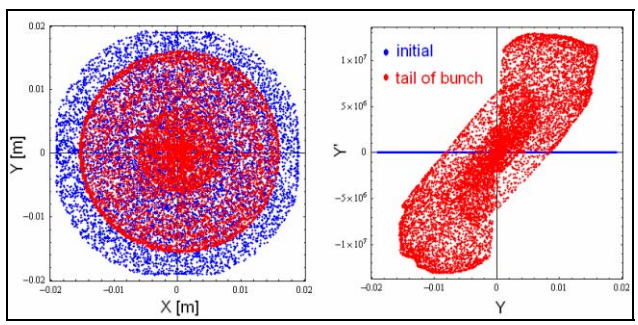

Figure 3. Pinching effect. (Left) x-y and (Right) y-y' phase spaces, cloud distribution at the head (blue dots) and tail (red dots) of bunch pass. The initial cloud distribution is uniform and cold.

* Work supported by the Director, Office of Science, High Energy Physics, U.S. DOE under Contract No. DE-AC02-76SF00515.

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To resolve the interaction between the beam and the cloud at each element location we developed the code with the possibility of running in parallel (Message Passing Interface - MPI) computation. The code also runs in serial single-processor mode.

The intent is to simulate electron cloud instability threshold in the ILC DR, LHC, SPS and other storage rings where the electron cloud has been observed or it has been predicted.

The development of the code is based on the author's previous experience in developing the electron cloud build-up code POSINST [5] and in running the related ECLOUD and HEAD-TAIL codes [6, 7].

ACCELERATOR MODEL AND BEAM CLOUD INTERACTION

The code accepts in input the files "sectormap" and "optics" generated previously by running MAD (mad8 or madx) with the ring lattice. Sectormap and optics files respectively include the information on the first and second order transfer maps and the twiss lattice parameters for each element of the ring. The code can simulate also beam lines. The beam is then tracked along the ring by first order R and second order T transfer maps. Note that second order tracking is not symplectic, but we have checked that the phase space is 98% conserved after 1000 turns (typical number of turns in electron cloud simulations) in the case of the ILC DR OCS6 lattice [8]. Figure 1 shows the footprint of the ILC Damping Ring and Figure 2 shows the beam size obtained by CMAD tracking in the positron ring for 100 turns with a cloud density below the instability threshold compared the geometric beam size computed - including dispersion.

An example of the ILC DR bunch at injection is shown in Figure 4. At each element, the beam and cloud interaction is resolved with an electron cloud distribution that is specific for that given element. The bunch and the cloud are modeled by macroparticles and allowed to move in 3 dimensions (3D). During the beam-cloud interaction, the 2D forces from the beam and the cloud are computed. The bunch is typically sliced longitudinally and a number of kicks are applied to the electron cloud which is pinched by the positive beam potential, see Figure 3. The electron cloud space charge force is computed at each bunch slice. The cloud experiences both the electric fields from the beam and the cloud. The dynamics of the electron is computed including the magnetic fields of the element and their position is updated with a Leap-frog and Boris rotation integrator scheme.

The particles in the beam experience the space charge force from the cloud and the particle momentum is update

$$\Delta x' = \frac{eE_x}{\gamma m_p c^2} L$$

$$\Delta y' = \frac{eE_y}{\gamma m_p c^2} L$$

where C and Δx' and Δy' are the normalized momentum, e is the particle charge, $E_{x,y}$ are the electric fields γ the relativistic factor, m_p the particle mass, c the speed of light and L is the length of the ring element.

At this stage in the code, the single-bunch instability module has been completed, while the electron cloud build-up needs to be added including the informations on the vacuum chamber, the secondary electron yield, etc.

To compute the electron cloud build-up and its transverse distribution we have so far used an external simulation code. The cloud density is estimated and for each element class (drift, bend quadrupole, etc.) and distributed to all respective elements in the ring. An example of the electron cloud distribution in the arc bends and drift field free region of the ILC DR is shown in Figure 5.

When the code will be able to compute also the build-up of the electron cloud, the evolution of the cloud and build-up will be updated for each element class at every turn as the beam evolves.

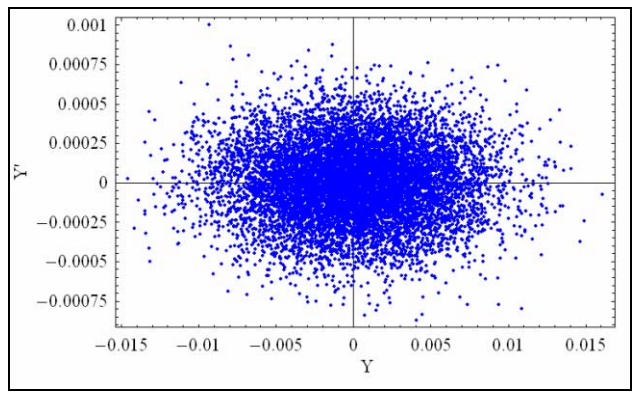

Figure 4. ILC DR bunch at injection as input for simulations, y y' phase space is shown.

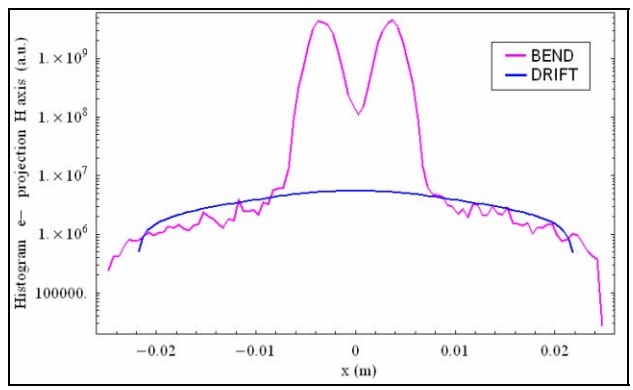

Figure 5. Electron cloud distribution in bend and drift field free regions. The cloud distribution are computed using POSINST [5] code and used as input for the instability simulations.

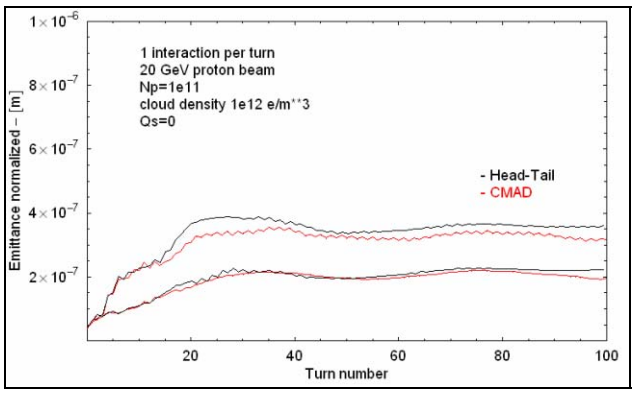

Figure 6. Compare between HEAD-TAIL and CMAD, for 1 beam-cloud interaction point per turn.

PRELIMINARY RESULTS

The single-bunch part of the code has been benchmarked against codes at CERN web page [9]. Good agreement was found with existing codes (HEAD-TAIL "new simulation results 2006") for 1 interaction point/turn. The results of the benchmarking are shown in Figure 6. In this simulation, the bunch population is 1e11 and the cloud density 1e12 e/m^3. The cloud extent is 10 beam sigmas and is the one shown in Figure 3.

At the moment, simulation benchmarking is ongoing also for the SPS and for the ILC DR [10].

SUMMARY

We presented the features of the newly developed self-consistent parallel simulation code which intent is to simulate the electron cloud build-up and instabilities. One of the purposes for the development of such code is to simulate the interaction between the beam and the cloud in a large number of interaction points per turn, ideally corresponding to the number of elements of the ring. The code tracks the beam in an existing (MAD-type) lattice and continuously resolves the interaction between the beam and the cloud at each element location, with different cloud distributions at each magnet location. At this stage, the single-bunch instability module has been completed, and benchmarked against existing simulation codes. Good agreement was found with existing codes for 1 interaction point/turn. The electron cloud build-up module, including vacuum chamber and secondary yield, is to be added.

AKNOWLEDGMENTS

Thanks to T. Raubenheimer, F. Zimmermann, L. Wang, M. Furman, G. Rumolo, K. Ohmi, J. L. Vay, C. Celata and W. Bruns for many useful discussions.

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