LARGE SCALE BEAM DYNAMICS SIMULATION IN LINEAR ACCELERATORS

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INTRODUCTION

The beam dynamics code TRACK [1] has been developed at ANL over the past few years. TRACK is a ray-tracing code that was originally developed to fulfil the special requirements of the Facility for Rare Isotope Accelerator Beams (FRIB) systems [1]. The code was applied for designing and commissioning various medium energy high-intensity accelerators worldwide [4-8]. The status of the serial TRACK code has been reported in [3]. In this paper, we present the new parallel version of the beam dynamics code PTRACK [2] and its application for large-scale accelerator simulations. The parallel code PTRACK has been used to simulate beam dynamics in the 8-GeV FNAL proton driver Linac, which includes a 325 MHz RFQ, a MEBT, a room temperature linac and a superconducting linac in the energy range from 50 keV to 8 GeV. The 45 mA beam at the entrance of the RFQ was represented by 100 million micro particles in a bunch. The number of particles is close to the actual number of particles per bunch and beam halo formation in both transverse and longitudinal phase spaces can be clearly observed. The choice of the number of particles is dictated not only by the space charge considerations but also by the beam behavior in combined external and space charge fields.

PARALLEL ALGORITHMS & SOLVERS

Parallel Algorithms

The code comprises two major parts: particle tracking and space charge (SC) calculation. Particles are distributed evenly over all processors for tracking while each processor has its own copy of the fields. Each processor has only part of a global mesh for the space charge calculations. The field mesh and space charge mesh are different. This scheme has the advantage of easy implementation and no communication for particle tracking is required. However, this method requires large memory in each processor and intense communication for the parallel Poisson solver.

Parallel Solvers

The Poisson solver routine used in TRACK takes beam particle distributions as input and produces the EM fields of the beam on a predefined 3D SC grid as output. The first step is to transform the particle distribution to the rest frame of the beam and perform the deposition of the electric charges carried by the beam particles (macro particles). This is done using the so called ‘‘cloud in cell’’ method, where depending on distance, a particle deposits a fraction of its charge on the closest 8 nodes of the SC grid defining the SC cell the particle belongs to. At the end of this step the beam is represented by a space charge distribution on the SC grid. The next step consists of solving the corresponding Poisson equation for the electric potential U. We have implemented the Poisson solver in both the Cartesian and the Cylindrical coordinates with Dirichlet boundary condition in the transverse directions and periodic boundary condition in the longitudinal direction. The solution is performed using the fast Fourier transforms (FFT); sine transforms in the transverse directions and real transforms in the longitudinal direction. Once the potential U is determined on the SC grid, it is straightforward to derive the induced electric field in the rest frame of the beam. By boosting back to the laboratory frame, the EM fields could be determined on each node of the SC grid. A second order interpolation method is used to obtain the (*E; B*) fields in the location of a given particle in the next tracking step. A Cartesian Poisson solver has been parallelized through 1D, 2D and 3D domain decompositions, and good scaling has been achieved on 4096 processors.

RESULTS

Recently we have used PTRACK for the end-to-end beam dynamics simulations of the proton driver (PD) being developed at FNAL. Figure 1 compares the particle distribution for 1M, 10M and 100M macro-particles calculated following the procedure described in [8]. As is seen from the figures, larger number of macro particles improves the visualization of the beam halo.

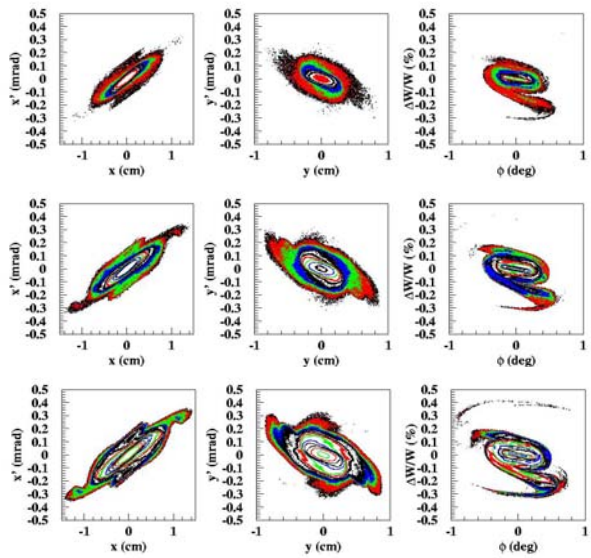

Figure 1: Phase space contours in the ($\phi, \Delta W/W$)-plane for 1M (on the top), 10M (in the middle) and 100M (on the bottom) macroparticles.

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