RECENT ADVANCES IN THE SYNERGIA ACCELERATOR SIMULATION FRAMEWORK

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Abstract

The Synergia framework has been enhanced to include new Poisson solvers and new collective physics effects. Synergia now includes Sphyraena, a solver suite that provides the ability to handle elliptical beam pipes. Resistive wall effects, including intra- and inter-bunch effects in the presence of multiple bunches are also available. We present an overview of the updates in Synergia, focusing on these developments.

INTRODUCTION

Synergia [1] is an accelerator physics modeling framework emphasizing simulations of collective effects. Synergia has taken advantage of existing state-of-the-art modules for such topics as non-linear optics, CHEF [2], and space charge, IMPACT [3]. We have recently enhanced Synergia to include a new three-dimensional Poisson solver suite, Sphyraena, and a new resistive wall impedance module. We have also updated the core of Synergia to allow porting to the BlueGene platform. Finally, we have incorporated a module to allow the advanced three-dimensional visualization tool VisIt to directly import Synergia particle (and, soon, field) data.

THE SPHYRAENA SOLVER SUITE

The Sphyraena Poisson solver suite is the most substantial recent addition to Synergia. To date, the suite contains solvers for the following three-dimensional boundary conditions: open in all directions, open transverse and periodic longitudinal, closed (i.e., perfectly conducting) circular transverse and periodic longitudinal, closed elliptical transverse and open longitudinal, and closed elliptical transverse and periodic longitudinal. Figure 1 shows a sample field produced by the elliptical solver. The Sphyraena solver suite also includes a two-dimensional, analytical approximation for Gaussian beams to allow very fast solutions for simple problems. The ability to simply switch between different solvers within the same simulation framework is one of the main strengths of Synergia. Initial parameter scans can be performed quickly with the two-dimensional solver. Once basic parameters have been determined, detailed simulations can be performed with the three-dimensional solvers.

For a newly-developed solver suite, testing the accuracy of the solutions is of utmost importance. The typical approach is to test using the sorts of highly-symmetric field configurations that are exactly solvable. Among the downfalls of this approach is the insensitivity to errors in the symmetric dimensions. In order to avoid this problem, we have developed a testing method by which we postulate a non-trivial analytic expression for a field obeying the solver's boundary conditions, then differentiate that field to generate a corresponding charge density. The resulting charge density is used as input to the solver, whose output is compared with the analytical expression. An example of this approach is the equation

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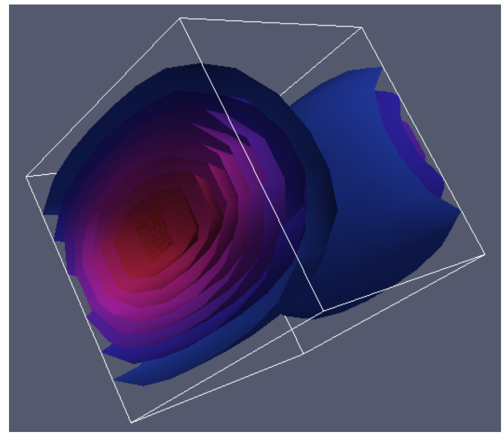

Figure 1: Test field solution using the Sphyraena elliptical solver.

$$\begin{aligned}\rho(r,\theta,z) \quad = \quad & \Big[\left(\left(18\,{r_0}^2-14\,r^2\right)\,\sin^2\left(3\,\theta\right)+\right. \\ & \left.\left(18\,r^2-18\,{r_0}^2\right)\,\cos^2\left(3\,\theta\right)\right)\times \\ & \cos^2\left(\frac{\pi\,z}{z_0}\right)\,{z_0}^2+ \\ & \left(2\,\pi^2\,r^4-2\,\pi^2\,r^2\,{r_0}^2\right)\times \\ & \sin^2\left(3\,\theta\right)\,\sin^2\left(\frac{\pi\,z}{z_0}\right)+ \\ & \left(2\,\pi^2\,r^2\,{r_0}^2-2\,\pi^2\,r^4\right)\times \\ & \sin^2\left(3\,\theta\right)\,\cos^2\left(\frac{\pi\,z}{z_0}\right)\Big] \\ & \Big/\left(r^2\,{r_0}^2\,{z_0}^2\right), \qquad (1)\end{aligned}$$

which comes from the field expression

$$\phi(r,\theta,z)=\left(1-\frac{r^2}{r_0^2}\right)\sin^2\left(3\theta\right)\cos^2\left(\pi\frac{z}{z_0}\right). \qquad (2)$$

Figure 2 displays the test solver output.

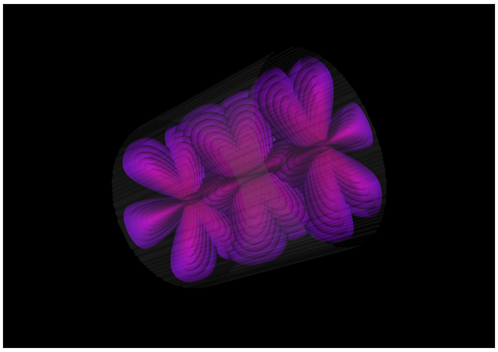

Figure 2: Test field solution using the Sphyraena cylindrical solver with non-trivial structure in all dimensions.

RESISTIVE WALL MODULE

The most recent feature enhancement to Synergia is the addition of a resistive wall impedance module. Resistive wall effects can now be combined with Synergia's nonlinear optics and space-charge capability. The current implementation contains a simple dipole approximation for resistive-wall wakefields in the thick wall limit [4]

$$\frac{\Delta \vec{p}_\perp}{p} = \frac{2}{\pi b^3}\sqrt{\frac{c}{\sigma}}\frac{N_i{<}\vec{r}_i{>}}{\beta\gamma}\frac{L}{\sqrt{z_i}} = W_0 L <\vec{r}> . \quad (3)$$

This module is a new addition to Synergia. However, its original implementation was as an addition to the beam-beam simulation package BeamBeam3d. As a module for BeamBeam3d, it was validated through a series of tests, including demonstrating the validity of the resistive wall simulation with respect to synchro-betatron coupling behavior, growth rate of dipole motion as a function of intensity, and growth rate as a function of head-tail phase, showing predicted linear growth near 0 and near-universality near -1 [4].

Resistive wall effect occur both within a single bunch and between bunches. In order to support bunch-to-buch effects in the resistive wall module, Synergia was extended to include multiple loosely-coupled bunches. Previously, multiple bunch support in Synergia was limited to strongly-coupled bunches, which in turn were limited to a very small number because they all had to be accommodated on a single space-charge grid. The new multiple bunch support can accommodate very large numbers of bunches.

As a first example, we have presented [6] results from simulations of the Fermilab Main Injector incorporating resistive wall and space charge effects. A typical result is shown in Figure 3.

SYNERGIA ON BLUEGENE

Although Synergia can be run on desktop computers, it was designed to take advantage of massively parallel

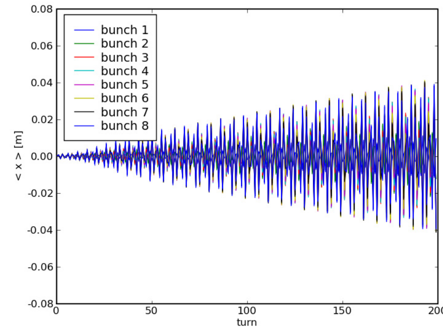

Figure 3: Resistive wall instability modeled with eight coupled bunches in Fermilab's Main Injector.

machines. Currently, the fastest available computer for open science is the BlueGene/P installation at Argonne National Laboratory's Argonne Leadership Computing Facility (ALCF). Synergia has an advanced Python-driven architecture. Porting Python-driven applications to the specialized BlueGene environment has only recently become possible. A port of Synergia to BlueGene was completed in April 2009. Figure 4 shows the result of a scaling study performed at ALCF with a medium-sized problem: 200 million particles with space charge calculated on a $64 \times 64 \times 1024$ grid. Synergia demonstrates excellent parallel scaling up to 2048 cores.

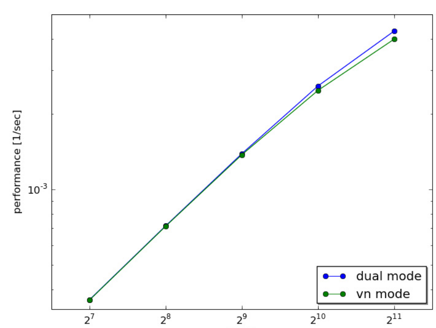

Figure 4: Parallel scaling results on ALCF's Surveyor BlueGene/P machine. The two curves were produced using two computational cores per processor (dual mode) and four computational cores per processor (vn mode), respectively.

VISUALIZATION WITH VISIT

Advanced three-dimensional visualization applications such as VisIt [7] provide many tools relevant for the investigation of simulations such as those performed with Synergia. A major impediment to using these tools for daily work has been the difficulty in getting the relevant multi-dimensional data into the visualization tool. We have recently worked with the VisIt team to produce a VisIt plugin for Synergia data. With the plugin, Synergia particle data can be read directly into VisIt. Visualizations such as Figure 5 can now be generated with just a few clicks. Creating a three-dimensional animation of beam evolution is possible with only a few more clicks. An extension to the plugin to include field data is under development.

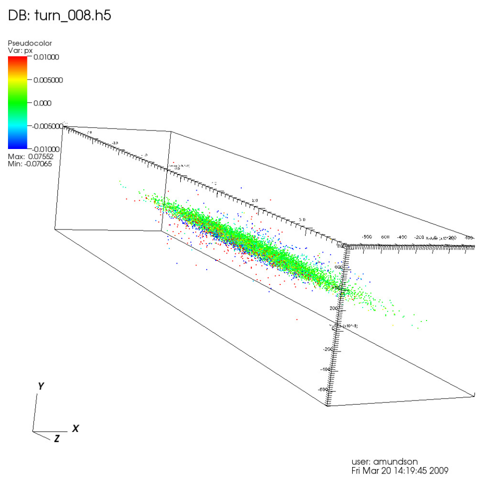

Figure 5: VisIt visualization of the Mu2e beam in the Fermilab Debuncher. The particle colors represent the magnitude of their transverse momentum.

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