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High-Order Methods and Wake Field Simulations

Misun Min[*] and Paul Fischer, Argonne National Laboratory

Summary

We have developed a large-scale computational code, NEKCEM, for wake field and wake potential calculations in 3D accelerating cavity structures. NEKCEM employs a high-order numerical scheme that enables accurate and efficient computations with high performance in parallel on body-conforming meshes. This work is critical for accelerator design.

In accelerating cavities, electron beams with short bunches create very high frequency electromagnetic fields. A fraction of the field stays in the structure for a very long time. The remainder can interact with the bunch and reduce its kinetic energy. The energy loss is inversely proportional to the square root of the bunch size. Understanding the effects of the electromagnetic wake fields behind the bunch in various cavity shapes is important for accelerator design.

Computational Method

As the bunch lengths for modern accelerator are getting shorter, accurate and efficient numerical codes for wake field simulations have become critical for computational accelerator problems. Current production codes use second-order finite-difference or finite element time domain methods which, because of their limited convergence rates, result in serious computational bottlenecks and high memory demands for short-bunch simulations.

In order to break these bottlenecks, we have developed a code, NEKCEM, for wake field calculations that is based on a high-order spectral element discontinuous Galerkin method. NEKCEM is open source and is designed for high performance on parallel computers The numerical discretization employs body-fitted unstructured hexahedral meshes and several boundary conditions are implemented, including perfectly electric conducting boundaries, perfectly matched layers, and periodicity.

Wake Field Calculations

To provide the electrostatic field at the device inlet, we have implemented a 2D Poisson solver for arbitrary cross-sections in a 3D structure. Figure 1 shows a case of a cylindrical tube. The 2D electrostatic solution at a cross-section is scaled with a Gaussian beam distribution in the longitudinal direction to represent the initial state of the 3D field. Figure 1 also shows the

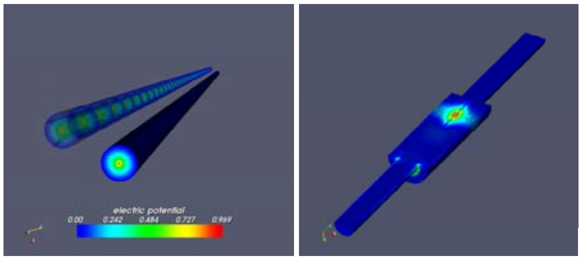

Fig. 1. 2D Poisson solutions for cross-sections of a cylindrical tube in 3D (left); contour lines for electric fields in amplitude on a half side of a pillbox cavity with circle-cross sections for a Gaussian bunch (right).

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[*] 630-252-5380, mmin@mcs.anl.gov

electric field amplitudes for a Gaussian bunch interacting with a pillbox cavity.

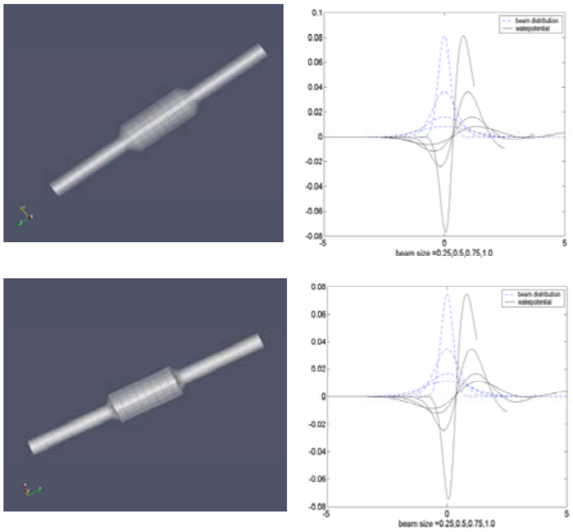

Fig. 2. (top) Mesh with linear transition between circle cross-sections (left), and wake potentials on the mesh for bunch sizes with 0.25, 0.5, 0.75, 1.0 (right); (bottom) Mesh with quadratic transition between circle cross-sections (left) and wake potentials on the mesh for bunch sizes with 0.25, 0.5, 0.75, 1.0 (right).

Wake potentials are calculated by integrating the longitudinal electric fields over time. The use of body-fitted meshes in NEKCEM allows one to easily vary cavity configurations in order to optimize the wake potential. Figure 2 shows meshes for cavities with linear and quadratic transitions between sections. The corresponding wake potentials are shown on the left. Figure 3 shows NEKCEM's mesh capability to handle typical structures for a collimator and TESLA cavity.

Future Work

This research is conducted in collaboration with Argonne physicists in the Advanced Photon Source (APS) division. We anticipate using NEKCEM on advanced parallel platforms to simulate short-bunch (~0.1 mm) wake fields in 1-km-long accelerator structures. Realistic simulations of such long-time integrations are only possible with advanced computing capabilities and minimally dispersive discretizations, such as provided by NEKCEM. Results at these scales will be significant in accelerator science in general and to scientists working on the future APS upgrade project and the International Linear Collider (ILC).

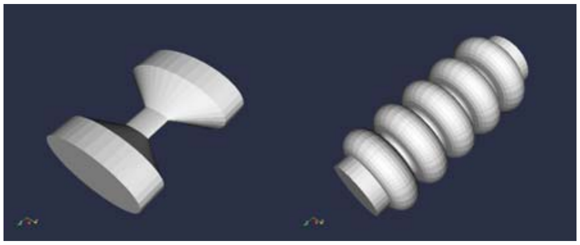

Fig. 3. NEKCEM meshes: (left) linear transitions between elliptic cross-sections for a collimator structure; (right) mesh for TESLA cavity structure.

For further information contact:

Dr. Misun Min
Mathematics and Computer Science
Argonne National Laboratory
mmin@mcs.anl.gov

or

Dr. Anil Deane
Applied Mathematics Research Program
Office of Advanced Scientific Computing
Phone: 301-903-1465
deane@ascr.doe.gov

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[*] 630-252-5380, mmin@mcs.anl.gov