

## Electromagnetic Systems Simulation – “From Simulation to Fabrication”

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*Supercomputing has dramatically advanced the role of computer modeling in the design of accelerating structures for high-energy particle accelerators. SciDAC is supporting the development of new numerical tools some of which, using high-performance computers at DOE’s NERSC, have already shown capable of modeling realistic accelerator components to a level of complexity, speed, and accuracy orders of magnitude beyond what was previously possible. These codes, using unstructured grids and parallel processing, comprise a powerful design capability that is helping to improve present machines and to optimize next-generation accelerators. This breakthrough in accelerator science can be attributed to the multidisciplinary effort assembled through SciDAC that has addressed many challenging issues in computer science and applied mathematics arising in the application.*

The Electromagnetic Systems Simulation (ESS) component of the SciDAC project, “Advanced Computing for 21<sup>st</sup> Century Accelerator Science and Technology”, concentrates on parallel tools for the design, analysis, and optimization of complex electromagnetic components and systems in accelerators. Parallel electromagnetic codes under development include: 1) Omega3P – quadratic finite element eigensolver for calculating normal modes in RF cavities, 2) Tau3P – time domain solver to simulate field evolution on the generalized Yee grid, 3) Track3P – module for tracking particles in Omega3P or Tau3P fields and simulating their interaction with the cavity surface.

**Significant results achieved from applying these codes are:**

1) Prototyping the accelerating cells for the Next Linear Collider (NLC): The Round, Damped, Detuned Structure (RDDS) for the NLC main linac is a fully 3D design that is optimized for higher gradient (14% increase over existing design) and suppression of harmful wakefields that disrupt long bunch train operation. The computational challenge

was to model the complex geometry (Fig. 1) to accuracies close to machining tolerance. It would require an eigensolver that can calculate resonant frequencies accurate to 0.01%, orders of magnitude beyond what existing codes could deliver.

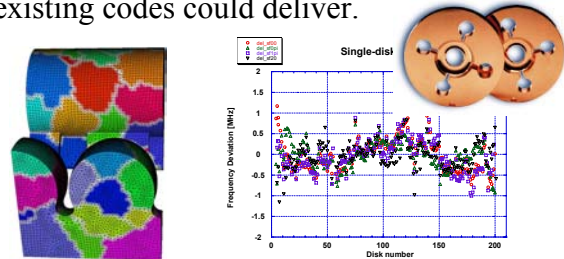


Figure 1. (Left) A distributed model of a quadrant of the RDDS, (right) Microwave QC of the fabricated cells with measured data within 0.01% of target frequency.

Using Omega3P on the NERSC’s Cray T3E, a table of dimensions for all 206 cells along the RDDS was generated for computerized machining based on calculations that met the 0.01% frequency accuracy criteria. Tests on fabricated cells showed that their measured frequencies are indeed within 0.01% of the target value. This significant result indicates that **high resolution modeling** is possible with the new design capability that utilizes unstructured grids and advanced computing.

2) Analysis of Beam Heating in the PEP-II Interaction Region (IR): In the last beam run, the PEP-II B Factory was limited from operating at higher current due to excessive heating of the IR chamber. The IR beamline complex is a long (> 5m) structure with complicated cross sections of several cm in dimensions that makes it challenging to simulate because of the large aspect ratio and detailed features. Furthermore, hundreds of localized modes were needed to calculate the beam heating distribution. Omega3P was used to perform this system scale analysis and results obtained from using the IBM/SP at NERSC agreed with observed data. The simulation provided insight that helped in the redesign of the IR for the upgrade.



Figure 2. A localized mode identified in the PEP-II IR showing high loss (red) near the observed heating area.

3) Simulation of Dark Current: Dark current limits a linac from operating at its designed field gradient. At high fields, the structure walls emit electrons which further generate secondary electrons upon impact with the wall surface. Electrons that are captured by the accelerating field form the dark current which can perturb the main beam and affect the diagnostics downstream. Under SciDAC, a concerted effort aimed at building an accurate, quantitative model of the dark current generation and capture is under way. It involves coupling Track3P to Tau3P so that fields from the latter can be used to drive the particles in the former. Such a simulation is extremely challenging because millions of particles have to be followed on a large, 3D unstructured mesh representing a realistic structure that consists of up to a hundred cells. This effort when completed will provide a powerful tool for reliably predicting the dark current effect in a given structure and represent a major advance in accelerator science enabled by simulation.

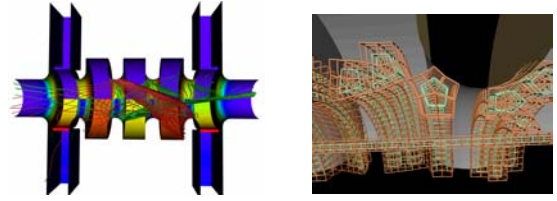


Figure 3. (Left) Particle trajectories in a short structure, (right) Unstructured dual mesh of the structure geometry.

**Collaborations with other SciDAC teams:**

The ESS team is working with collaborators in the applied mathematics and computer science community through SAPP and the ISICs on:

- (1) *Eigensolver algorithms for Omega3P*: G. Golub, P. Husbands, X. Li, O. Livne, E. Ng, Y. Sun, C. Yang (SAPP/TOPS).
- (2) *Discretization studies for Tau3P*: W. Henshaw, P. Knupp (TSTT).
- (3) *Visualization of dark current*: K. Ma, G. Schussman (SAPP).
- (4) *CAD model and meshing*: D. Brown, K. Chand, L. Freitag, T. Tautges (TSTT).
- (5) *Adaptive mesh refinement for Omega3P*: Y. Luo, M. Shephard (TSTT).
- (6) *Partitioning in Tau3P*: A. Pinar (TOPS).

Many of the collaborations already produced useful results, in meshing, discretization, eigensolvers, and visualization. All the activities are an integral part of the ESS effort to strengthen the parallel tools for accomplishing the simulation goals of the next two years. The goals include the dark current simulation and an end-to-end modeling of the wakefields in the NLC structure. Both target applications support ongoing experiments that have high impact on DOE's high energy accelerator programs. The computer resources needed to carry out these large computations are anticipated to be 2M hrs. in FY04, and 3.5M hrs. in FY05.

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