ACE3P Application in High Gradient Structure Research

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US High Gradient Research Collaboration Workshop
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Outline

- Parallel Finite Element Code Suite ACE3P
- ACE3P Application to High Gradient R&D
  1. PBG Structure
  2. X-Band Gun
  3. X-Band klystron
  4. CLIC Cell MP
  5. CLIC PETS & structure
- Summary
Parallel Finite Element Code Suite **ACE3P**
Parallel Higher-order Finite-Element Method

Strength of Approach – Accuracy and Scalability

- **Conformal** (tetrahedral) mesh with quadratic surface
- **Higher-order** elements ($p = 1-6$)
- **Parallel** processing (memory & speedup)

\[ E(x, t) = \sum_i e_i(t) \cdot N_i(x) \]

**End cell with input coupler only**

67k quad elements (<1 min on 16 CPU, 6 GB)

**Error ~ 20 kHz (1.3 GHz)**
Accelerator Modeling with EM Code Suite **ACE3P**

**Meshing - CUBIT** for building CAD models and generating finite-element meshes
http://cubit.sandia.gov

**Modeling and Simulation** – SLAC’s suite of conformal, higher-order, C++/MPI based parallel finite-element electromagnetic codes

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**ACE3P (Advanced Computational Electromagnetics 3P)**

**Frequency Domain:**
- Omega3P – Eigensolver (damping)
- S3P – S-Parameter

**Time Domain:**
- T3P – Wakefields and Transients

**Particle Tracking:**
- Track3P – Multipacting and Dark Current

**EM Particle-in-cell:**
- Pic3P – RF guns & klystrons

**Multi-physics:**
- TEM3P – EM, Thermal & Structural effects

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**Postprocessing - ParaView** to visualize unstructured meshes & particle/field data
http://www.paraview.org/

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Accelerator Design and Analysis with **ACE3P**

- **Model** CAD
- **Meshing** Cubit
- **Partitioning** ParMetis
- **Solvers**
- **Visualization** ParaView

**Constraint**

\[ f = f_0 ; \]

Maximize \((R/Q, Q)\)

Minimize \((\text{wakefields})\)

Minimize \((\text{surface fields etc.})\)

**ACE3P EM Field Computations**

Determine Cavity Dimensions

**Fabrication**

**Cell QC**

Single-disk RF-QC

**Wakefield Measurement**

Quasi coupled Dipole Wakefield \((Q=2000)\)

0.01% in freq
ACE3P Capabilities

- **Omega3P** can be used to
  - optimize RF parameters
  - reduce peak surface fields.
  - determine HOM damping, trapped modes & their heating effects
  - design dielectric & ferrite dampers, and others

- **S3P** calculates the transmission (S parameters) in open structures

- **T3P** uses a driving bunch to
  - evaluate the broadband impedance, trapped modes and signal sensitivity
  - compute the wakefields of short bunches with a moving window
  - simulate the beam transit in large 3D complex structures

- **Track3P** studies
  - multipacting in cavities & couplers by identifying MP barriers & MP sites
  - dark current in high gradient structures including transient effects

- **Pic3P** calculates the beam emittance in RF gun designs

- **TEM3P** computes integrated EM, thermal and structural effects for normal cavities & for SRF cavities with nonlinear temperature dependence
ACE3P Application to High Gradient R&D

(1) PBG Structure
(2) X-Band Gun
(3) X-band klystron
(3) CLIC Cell – Multipacting
(4) CLIC PETS & Structure
T3P – Photonic Bandgap Structure

MIT PBG structure
- Operated at 17 GHz for high gradient acceleration
- Study effects of transients of drive pulse on dark current
- Evaluate power radiation from multi-beam transit

Power coupling
Multi-beam transit
Pic3P - SLAC/LLNL X-Band Gun

3D Emittance Calculations for Bunch with Offset

- f = 11.424 GHz, 200 MV/m peak Ez on cathode
- Solenoid Bz_max = 0.5658 T at Z = 6.3 cm
- Beer can (r = 0.5 mm, 2 ps flat top, 0.4 ps rise time), 250 pC
- Bunch injected 30 degrees after zero-crossing

4D Emittance vs <Z>
Pic3P/Gun3P – X-Band Klystron Design

( Collaboration with Aaron Jensen – Klystron Dept)

Goal is to perform 3D end-to-end simulation using High Performance Computing

XL4 Output cavity
- Comparing efficiency with MAGIC

XC8 Output Cavity
- Comparing start oscillation with measurement
CLIC TD18(24) Multipacting Analysis
Brazing Gap - Multipacting Analysis

Cutoff Picture Reveals a Possible Bonding Problem

Juwen Wang, IWLC2010, & this workshop
Metallographic Pictures for Bonding Area in a C10 Structure

- Very good bonding
- Corner radius is much smaller than drawing specified 0.005" (127 microns). The red bar is 254 microns.

Juwen Wang, IWLC2010, & this workshop
CERN Pictures for TD18 Structure after High Power Test

Part C
Down-stream side - Cell Wall S-W!
Tilt 30°

Juwen Wang, IWLC2010, & this workshop
Model With “Gap”

- Gap – local chamfer
- Primary electrons emitted around the gap region
CLIC TD24 Cell

* E&B fields
Multipacting Simulation Around the Gap

* Primary electrons emitted around the gap region
* Identify resonant trajectories
* Use impact energy to estimate potential SEY

(Copper SEY, variations from different docs)

Figure 2: The S.E.Y. of copper for various surface treatments
Gap: opening=0.05mm, d=0.2mm
Gap: opening=0.1mm, d=0.3mm
Gap due to rounded corner

* Rounding radius: 0.125mm
No Brazing Gap

Primaries emitted in the area around the HOM coupler opening corner
No Brazing Gap - Larger Area Scan

* Will scan more surface areas for primary emission
* MP analysis continues
CLIC PETS and Accelerator Structure

- Wakefield Simulation
T3P - CLIC Two-Beam Accelerator

Compact Linear Collider
two-beam accelerator unit

PETS + TD24
Converged SLAC results have served as a reference for CERN

Led to CERN’s improved understanding of GdfidL results and its usage

Now the codes agree well – Important cross-check for CLIC design

Typical runtime:
- 20 hours, 80 CPUs
- 0.6 hours, 1200 CPUs
- 6 hours, 4800 CPUs
T3P – Dipole Wakefield Coupling

For this geometry, the coupled wakes are only about one order of magnitude below the TD24 self-generated wakefields (assuming 100x higher current in PETS).

Wakefield excited by an off-axis PETS drive bunch ($\sigma_z=2$ mm), using dipole boundary conditions.

- **Wakefield coupling: potentially critical for CLIC**
- **More studies planned with more realistic coupling geometry**

Dipole wake in TD24 generated by PETS drive bunch

Computed dipole wake coupled into TD24
Summary

- Parallel finite-element (FE) electromagnetics (EM) method demonstrates its strengths in high-fidelity, high-accuracy modeling for accelerator design, optimization and analysis.

- ACE3P code suite has been benchmarked and used in a wide range of applications in Accelerator Science and Development, including High Gradient Research.

- Track3P for multipacting and dark current simulations provides an effective tool for observing quantities inside structure, helping to understand the HG processing process.

- Progress is being made in simulating MP in CLIC TD18 structure using Track3P.

- Will simulate other high gradient structures by using Track3P to understand MP and dark current issues.
ACE3P User Community - CW10 Code Workshop

CW10 @ SLAC

Accelerator Code Workshop (CW10) at SLAC for the ACE3P (Advanced Computational Electromagnetics 3P) Code Suite organized by the Advanced Computations Group (ACG)

Date — September 20-22, 2010
Time — See agenda
Place — SLAC National Accelerator Laboratory
          Menlo Park, California

Contact — ACD-CW10@slac.stanford.edu
           650-926-2864
           650-926-4603 (FAX)

(www-conf.slac.stanford.edu/CW10/default.asp)
# CW10 Attendees & Agenda

## CW10 @ SLAC

### CW10 ACCELERATOR CODE WORKSHOP

### SLAC NATIONAL ACCELERATOR LABORATORY

### Attendees

<table>
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### CW11 is being planned

All sessions are 1 hr 45 min

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