Dark Current Simulation for Linear Collider Structure R&D

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Outline

• Numerical Methods and Models
  – Transient time domain (Tau3P)
  – Particle tracking (Track3P)

• Peak Field Calculations
  – Rise time effects

• Dark Current Simulations
  – Bend waveguide
  – Single Cell
  – 55-cell H60VG3 NLCSstructure
Parallel EM Codes on Unstructured Grids

Generalized Yee Grid

Finite-Element Discretization

Tau3P/T3P

Omega3P

S3P

Time Domain Simulation With Excitations

Frequency Domain Mode Calculation

Scattering Matrix Evaluation

Track3P – Particle Tracking with Surface Physics

V3D – Visualization/Animation of Meshes, Particles & Fields
Simulation Codes Track3P & Tau3P

**Track3P** (Particle tracking module)

\[
\frac{d\vec{p}}{dt} = e(\vec{E} + \frac{1}{c} [\vec{v} \times \vec{B}]), \quad \vec{p} = m\gamma\vec{v}, \quad \gamma = \frac{1}{\sqrt{1 - v^2 / c^2}}
\]

using \(E\) & \(B\) fields from the parallel time-domain solver **Tau3P** on unstructured grid

\[
\frac{\partial \vec{B}}{\partial t} = -\nabla \times \vec{E},
\]

\[
\frac{\partial \vec{E}}{\partial t} = \nabla \times \vec{H} - \vec{J}.
\]

with particle injection given by

\[
I(t) = \frac{I_{\text{max}}}{1 + \left(\frac{v_0}{a} \left( t - \frac{\varphi_0}{\omega} - iD_t \right) \right)^2}
\]
Surface Physics in Track3P

• Thermal Emission (Child – Langmuir)

\[ J(r, t) = \frac{4}{9} \varepsilon_0 \sqrt{\frac{2QE^2}{Md}} \]

• Field Emission (Fowler - Nordheim)

\[ J(r, t) = 1.54 \times 10^{-6} \frac{4.52}{\sqrt{\varphi}} \left( \frac{\beta E}{\beta E} \right)^2 \left( \frac{6.53 \times 10^9 \varphi^{1.5}}{\varphi} \right) \]

• Secondary emission

\[ \sigma = \frac{l_{sec}}{l_{pri}} = \delta + \eta + r; \]

\( \delta \) - true secondary emission =

(0-50 eV). \( \varepsilon_m \sim 2-4.5 \text{eV}; \Delta \varepsilon \sim 12-15 \text{eV}; \)

\( \eta \) - non elastic reflection (50 eV-\( \varepsilon_{pri} \))

\( r \) - elastic reflection = 0.05-0.5 for metals.
Benchmarking Particle Trajectories

Comparing 2D and 3D models

G = 50 MV/m
G = 100 MV/m
Field Evolution in 30-cell Structure – Tau3P

- NLC X-band structure showing damage after high power test
- Pulse rise time results in dispersive effects that increase peak fields
- Field simulation sheds light on surface emission and dark current

Rise time = 10, 15, 20 ns

Drive pulse
Peak Field Increase During Rising Pulse

The transient peak field is higher than its steady state value. The overshoot is larger for shorter rise time, ~ 17% at 10 ns.

Electric field as a function of time at different cell disks

“Click on pic for movie”
Benchmarking Surface Physics Model

High power test on a 90 degree square bend provided measured X-ray data to allow the secondary emission model in Track3P to be Benchmark on a simple geometry

Square Bend Waveguide Used at NLCTA to Transport SLED II Output Power to Structures

Time-varying fields from Tau3P

- Electric field
- Magnetic field
Dark Current in Square Bend – Track3P

X-Ray Energy Spectrum – Good agreement between Track3P simulation and measurement indicates high energy X-Rays seen in experiments are due to elastically scattered secondary electrons.
Modeling Single Cell Experiment – Track3P

X-ray Spectrum, P=25 MW

X-ray Spectrum, P=50MW
Simulating H60VG3 Structure – Track3P

Efforts are under way to model the 55-cell H60VG3 structure, considered to be the NLC baseline design, for which measured data is available on dark currents for different operating conditions in pulse lengths and field gradients.

H60vg3N-6C Measured Data (C. Adolphsen)

Fowler-Nordheim Plots

Downstream Dark-currents

Dark-currents vs Surface field