Collimator Wakefields

ALCPG Meeting
January 2004

GLC/NLC – X-Band Linear Collider
Overview of the Problem

Beam which passes off-axis thru collimator jaws gets a transverse kick

Leads to “jitter amplification” (kick in one phase ~ offset in the other -> RMS jitter amplitude grows)

Machine protection issues -- kick goes nonlinear far from center of collimator (saturation value?)

Emittance growth -- head of bunch gets no kick so RMS kick > 0
Wakefield Theory

• Two main contributions to wakefield
  – Resistive wall wakefield
    • due to finite conductivity of collimators
    • Present even for perfectly regular vacuum pipe
    • Well developed, simple theory (but maybe not correct!)
  – Geometric wakefield
    • due to change in vacuum chamber x-section at collimator
    • Fairly complicated, esp. for flat (x gap >> y gap or vice versa) collimator (like spoiler)
    • Level of “benchmarking” relatively low
**Geometric Wakefield: Mean Kick for Near-Center Bunches**

- **Rectangular collimator**
- **“Shallow Taper”:**
  \[ y' = \frac{\sqrt{\pi}}{2} \frac{N_r}{\gamma} \frac{\theta_T h}{\sigma_z r^2} y \]
  - \( \sqrt{\frac{\theta_T r}{\sigma_z}} \ll \frac{r}{h} \)
- **“Steep Taper:”**
  \[ y' = \frac{N_r}{\gamma} \frac{1}{r^2} y \]
  - \( \sqrt{\frac{\theta_T r}{\sigma_z}} > 1 \)
- \( y' = 2.7 \frac{N_r}{\gamma} \sqrt{\frac{\theta_T}{\sigma_z r^3}} y \)
Circular collimator

\[ y' = \frac{1}{\sqrt{\pi}} \frac{N_{re}}{\gamma} \frac{\theta_T}{\sigma_z r} y \]

\[ \sqrt{\frac{\theta_T r}{\sigma_z}} < 1 \]

\[ y' = \frac{N_{re}}{\gamma} \frac{2}{r^2} y \]

\[ \sqrt{\frac{\theta_T r}{\sigma_z}} > 1 \]
Resistive Wakefield: Mean Kick for Near-Center Bunches

\[ y' = F_G \frac{N r_e}{\gamma} \frac{\Gamma(0.25)}{\sqrt{2\pi^3}} \frac{L}{r^3} \sqrt{\frac{c}{\sigma_z \sigma}} \]

\[ F_G = 1, \text{ round collimator} \]
\[ \pi^2/8, \text{ flat collimator} \]
Main concern is growth of beam jitter at IP – driven by collimators in phase with final doublet

After some manipulation, collimator kick equations and BDS lattice functions can be rearranged to yield amplification factor $A$ for a given collimator design

If beam jitter is $n$ sigmas at entrance to BDS, collimator with factor $A$ in FD phase $\rightarrow n(1+A^2)^{1/2}$ sigmas at IP
For collimators in given betatron phase, values of $A$ combine by adding \textit{linearly}.

Also define a factor $A_\delta$ which defines coupling of energy jitter to betatron jitter by energy collimators (sigmas of beta jitter / % energy jitter).

Use of this formalism allows straightforward “jitter accounting” to be carried out – did just that for TRC report (TESLA, NLC, CLIC 2002 baseline designs, no tail-folding octupoles).
### Jitter Amplification Accounting – TRC Report

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TESLA</th>
<th>NLC</th>
<th>CLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$A_x$</td>
<td>$A_y$</td>
<td>$A_\delta$</td>
</tr>
<tr>
<td>δ Spoilers</td>
<td>0.0349</td>
<td>0.0540</td>
<td>0.2679</td>
</tr>
<tr>
<td>δ Absorbers</td>
<td>0.0063</td>
<td>0.0335</td>
<td>0.0582</td>
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<tr>
<td>β Spoilers</td>
<td>0.0655</td>
<td>0.5514</td>
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<tr>
<td>β Absorbers</td>
<td>0.0324</td>
<td>0.5145</td>
<td>0</td>
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<tr>
<td>FF Spoilers</td>
<td>0.0801</td>
<td>0.7260</td>
<td>0.0186</td>
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<tr>
<td>FF Absorbers</td>
<td>0.0287</td>
<td>0.4563</td>
<td>0.0396</td>
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<tr>
<td><strong>Total</strong></td>
<td>0.2478</td>
<td>2.3357</td>
<td>0.3472</td>
</tr>
</tbody>
</table>

All values of $A_x, A_\delta$ probably OK for all designs

$A_y$ too large for all designs – $A > 1$ means IP jitter dominated by collimator contribution!

January 2004  Peter Tenenbaum
GLC/NLC – X-Band Linear Collider

Progress since TRC

For USColdLC Reference Design – combine TESLA-like linac with NLC-like BDS, adjust lattice functions to get desired beam parameters at IP

For both: re-estimate collimator wakefield amplification factors for with/without tail-folding octupoles (values courtesy A. Seryi)

<table>
<thead>
<tr>
<th>$A_y$</th>
<th>Cold</th>
<th>Warm</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Octupoles</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Without Octupoles</td>
<td>0.9</td>
<td>1.2</td>
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</tbody>
</table>
Emittance Growth

For USColdLC/TESLA, intra-train feedback can (probably!) eliminate effect of IP beam jitter

Emittance growth from collimators then limits permitted jitter incoming to BDS:

\[ \frac{\Delta \gamma \varepsilon}{\gamma \varepsilon} \approx n^2 \left(0.4A\right)^2 \]

Warm: \( n=0.3 \) required for IP, emittance growth limited to 3% worst case

Cold: \( n \leq 1 \) probably required for emittance preservation
Assume that the collimator gaps are set such that they shadow the detector; therefore the gap sizes in mm must stay constant.

From 500 GeV to 1 TeV CM, US BDS designs don’t change vertical beta functions but beam energy increases – wakefields have less impact on beam.

For CM energy below 500 GeV, beam is limited by IP divergence, so vertical beta functions reduced in collimators, but energy also reduced; effects cancel (ie, no worse at lower energy IF betas are scaled!)
Experimental Tests

- CollWake Test Facility
- @ 1.19 GeV point in SLAC linac
- Procedure
  - Insert coll in beam path (x mover)
  - Move collimator vertically (y mover)
  - Measure centroid kick to beam via BPMs
  - Analyze kick angle vs collimator position
Summary of Results

- **Geometric Wakes:** OK agreement with theory
  - measured kicks sometimes weaker than theory
    - up to a factor of 2
  - MAFIA sims agree with theory
    - not always possible – short bunches and long collimators are tough

- **Resistive Wakes:** OK agreement with theory
  - C, Ti collimators: agree with theory
  - Long Cu collimator: kick about 2x theory
Tentative Conclusions

• Collimator Wakefields likely to play important role in dynamics of beam delivery system
  – With tail-folding octupoles, theory says present design is OK
  – Without tail-folding octupoles, present design is marginal to unacceptable
  – Wakes will limit acceptable incoming beam jitter even in case of USCold/TESLA

• Theoretical/Numerical estimates of wake kicks not yet at acceptable level
  – Factor of 2 discrepancies – want to reach 10% level
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