Stair-step Tapered Wiggler
A Novel Concept for High-Efficiency FEL

Dinh C. Nguyen
Los Alamos National Laboratory

Henry P. Freund
SAIC

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Los Alamos National Lab is operated for the Department of Energy by the Los Alamos National Security, LLC.
A stair-step tapered wiggler consists of multiple uniform segments with different gaps or periods.

- Can be tapered in gap or period or both.
  - Taper in gap
  - Taper in period

- Each segment's gap can be independently adjusted while in operation.
- A stair-step tapered wiggler is easier to build and optimize than a continuous one.
Single-step Tapered Wiggler

Resonant energy

$$\gamma_R = \sqrt{\frac{\lambda_w}{2\lambda}} \left(1 + a_w^2\right)$$

Uniform wiggler efficiency

$$\eta = 2\eta_C \sqrt{\frac{a_w a_s}{1 + a_w^2}}$$

Step-tapered wiggler efficiency

$$\eta = 2\eta_{C1} \sqrt{\frac{a_{w1} a_s}{1 + a_{w1}^2}} + 2\eta_{C2} \sqrt{\frac{a_{w2} a_s}{1 + a_{w2}^2}}$$
Performance of the stair-step taper is compared to a linear taper using 3-D MEDUSA simulations

**Stair-step Taper**

<table>
<thead>
<tr>
<th>$B_0$ (kG)</th>
<th>$z$ (m)</th>
<th>$z$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.25</td>
<td>$0 \rightarrow 1.83$</td>
<td>$1.83 \rightarrow 2.53$</td>
</tr>
<tr>
<td>8.05</td>
<td>$1.83 \rightarrow 2.53$</td>
<td>$2.53 \rightarrow 3.10$</td>
</tr>
<tr>
<td>7.75</td>
<td>$2.53 \rightarrow 3.10$</td>
<td>$3.10 \rightarrow 3.66$</td>
</tr>
<tr>
<td>7.35</td>
<td>$3.10 \rightarrow 3.66$</td>
<td>$3.66 \rightarrow 4.27$</td>
</tr>
<tr>
<td>7.05</td>
<td>$3.66 \rightarrow 4.27$</td>
<td></td>
</tr>
</tbody>
</table>

**Linear Taper**

$B_0 = 8.25$ kG  
$B_0 = 8.25$ kG - $(0.48$ kG/m $) \times z$

$z = 0 \rightarrow 1.83$ m

$z = 1.83 \rightarrow 2.53$ m
Stair-step and linearly tapered wigglers produce approximately equal power at the same taper rate.

### FEL Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>80.8 MeV</td>
</tr>
<tr>
<td>Peak current</td>
<td>1 kA</td>
</tr>
<tr>
<td>Wiggler period</td>
<td>2.18 cm</td>
</tr>
<tr>
<td>$K_{\text{rms}}$</td>
<td>1.187</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1.052 $\mu$m</td>
</tr>
<tr>
<td>Input power (peak)</td>
<td>1 MW</td>
</tr>
<tr>
<td>Stair-step taper output power</td>
<td>3.6 GW</td>
</tr>
<tr>
<td>Stair-step taper efficiency</td>
<td>4.5%</td>
</tr>
<tr>
<td>Linear taper output power</td>
<td>3.5 GW</td>
</tr>
<tr>
<td>Linear taper efficiency</td>
<td>4.4%</td>
</tr>
</tbody>
</table>

FEL power increases by approximately the same amount in each section up to five sections in the stair-step tapered wiggler.
MEDUSA-Generated Phase-space Distributions at Different Locations in Stair-step Tapered Wiggler

- z=0 m
- z=1.83 m
- z=2.53 m
- z=3.10 m
- z=3.66 m
- z=4.20 m
Energy spread of electron beams exiting a stair-step tapered wiggler is about 3X the extraction efficiency.
Summary

• We present a novel idea of stair-step tapered wiggler using multiple uniform wiggler segments with different gaps or wiggler periods.

• The stair-step tapered wiggler with the taper in gap is easier to fabricate and optimize than the continuously tapered wiggler.

• 3D MEDUSA simulations show the stair-step tapered wiggler to be as efficient as a linearly tapered wiggler and about 5 times more efficient than a uniform wiggler (4.5% instead of 0.9%).

• The non-adiabatic transitions in a stair-step tapered wiggler cause electrons to spill out of the “bucket” and fill in the energy spectrum. The total energy spread is about 3X the extraction efficiency.