ERL Wake Fields and One Possible Recovery Technique

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Electromagnetic Self-Interaction of Beam: Wake Function

- **Self-Wake Field**
  - Direct interaction of the bunch with vacuum chamber
    - E-M fields of bunch couple to stationary E-M modes in the vacuum chamber structure. These are associated with discontinuities in the chamber’s cross-section
    - In a smooth chamber, E-M fields travel unperturbed with the bunch, but when the chamber shape changes some field-lines get “disconnected” from the charges in the bunch
    - Strongest fields occur within the bunch since all of the different modes of the structure are excited “in phase”
Wake Voltage

• Beam-Chamber Interaction Can Written as an Induced Wake Voltage
  – Voltage for particle following charge, q depends on its longitudinal position, s, within the bunch - due to the effect of all vacuum chamber components in ERL
    \[ V_{\parallel}(s)_{\text{entire ERL}} = q \ W_{\parallel}(s)_{\text{entire ERL}} \]
  – Increases the energy spread, \( \Delta E \), of the bunch

• Limitation:
  – ERL accelerates beam to 5 GeV & the energy spread is usually not serious,
  – BUT as the beam decelerates to 10 MeV, the effect is magnified x 500
  – Maximum acceptable beam energy spread at the dump places a limit on the maximum wake field, i.e.
    \[ \max\left\{ eV_{\parallel}(s)_{\text{entire ERL}} \right\} \leq \kappa \ \max\left\{ \Delta E_{\text{dump}} \right\} \]
    where \( 0 \leq \kappa \leq 1 \) (e.g. \( \kappa \sim 0.5 \))
Peak Wake Function Limit

• Estimating maximum energy spread at the dump
  – Decelerated beam at the Dump:
    • Average Beam Energy at the Dump: \( E = 10 \text{ MeV} \)
    • Acceptable Maximum Energy Spread at the Dump: \( \Delta E = 5 \text{ MeV} \)

• Cast limit in terms of wake field \( W_\parallel \)

• Limit depends on operating charge:
  – ERL operation (77 pC & \( \sigma_z = 0.6 \text{ mm} \)):

\[
\max \left\{ W_\parallel (s) \right\}_\text{entire ERL} = \frac{1}{q} \max \left\{ eV_\parallel (s) \right\}_\text{entire ERL} \\
\leq 0.5 \frac{1}{q} \max \left\{ \Delta E \right\}_\text{dump} \approx (0.5) \frac{5 \text{ MeV}}{77 \text{ pC}} \approx 32 \text{ kV/pC}
\]
One Example of Self-Wake Functions

- **Linac accelerator RF cavities**
  - 7 cells (scaled from the 9 cell Tesla cavities)
  - Min, Max \{W_{||}\} = -8.1, 0.0 V/pC \quad k_{\text{HOM}} = 7.3 \text{ V/pC}
  - Quantity = 400 (x 2 for the two passes thru the RF)

![Diagram showing SRF Cavity Wake Field with HOM Load and Total Wake = 20% of Limit]
Estimated Total Self-Wake

- Peak Wake

\[
\max\left\{W_{\parallel}(t)\right\}_{\text{ERL}} = 33 \text{ kV/pC}
\]

Same as 32 kV/pC Limit

<table>
<thead>
<tr>
<th>Component</th>
<th>Number</th>
<th>Total (-\text{Wake}) (KV/pC)</th>
<th>Total (+\text{Wake}) (KV/pC)</th>
<th>Total k (KV/pC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Cell RF Cavity</td>
<td>800</td>
<td>\textbf{-5.66}</td>
<td>0</td>
<td>5.81</td>
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<tr>
<td>HOM Load (78 mm)</td>
<td>400</td>
<td>-0.89</td>
<td>0</td>
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<tr>
<td>HOM Load (106 mm)</td>
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<td>-0.50</td>
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<td>0.36</td>
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<tr>
<td>Expansion Joint</td>
<td>356</td>
<td>-0.74</td>
<td>0.10</td>
<td>0.53</td>
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<td>BPM (Button)</td>
<td>664</td>
<td>-0.35</td>
<td>0</td>
<td>0.24</td>
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<td>BPM (Stripline)</td>
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<td>Flange Joint</td>
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<td>Clearing Electrode</td>
<td>150</td>
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<td>0.14</td>
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<td>Gate Valve</td>
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<td>-0.71</td>
<td>0.69</td>
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<tr>
<td>Resistive Wall (12.7 mm)</td>
<td>2500</td>
<td>-4.00</td>
<td>0</td>
<td>2.75</td>
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<tr>
<td>Roughness (12.7 mm)</td>
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<td>\textbf{-14.00}</td>
<td>0.50</td>
<td>8.75</td>
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<td>Undulator Taper (3 mm)</td>
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<td>-0.61</td>
<td>0.37</td>
<td>0.36</td>
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<td>Resistive Wall (3 mm)</td>
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<td>-0.98</td>
<td>0</td>
<td>0.69</td>
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<td>Roughness (3 mm)</td>
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<td>-3.60</td>
<td>0.12</td>
<td>2.52</td>
</tr>
</tbody>
</table>

Total k = 23.8kV/pC

Total HOM Power = 183 KW
Possible Wake Field Correction

- Correcting curvature is hardest - use very High Frequency RF system
  - Good idea, but no large power sources are available
  - Use beam as the power source

1. Use a short bunch to resonantly excite the Source RF Cavity (less curvature)
2. Extract RF power to
3. Excite the Drive RF Cavity, which re-accelerates a longer bunch (more curvature)
Tasks for the Summer

• **Recalculate the Wake Fields**
  – The bunch length has increased

\[ \sigma_z = 0.6 \text{ mm} \Rightarrow \sigma_z = 1 \text{ mm} \]

This changes (largely reduces) the Wake Field shape

• **Test Different RF Structure Designs**
  – Model the cavities
  – Look into technical details