Study of Wakefields and Methods for Their Reduction in an Energy Recovery Linac

Jeremy Ong
Advisor: Mike Billing
Cornell University
Laboratory for Elementary-Particle Physics
• The ERL is valued for its efficiency and capability to produce bright x-rays and short x-ray pulses.

• Wakefields can be obstructions that do not allow the ERL to achieve its full potential:
  – Wakefields adversely affect energy spread.

• Energy recovery can be used via “dielectric power extractors” to mitigate wakefield effects.

• Design-oriented project focused on implementation of a “dielectric power extractor” in a two beam acceleration scheme.
If it were possible to superimpose an RF voltage with an erroneous wakefield, one could improve bunch energy spread while accelerating the beam.

Goal - Frequency: 45 GHz, Amplitude: 1.6 MV
• Tested at Argonne National Laboratory.
• Cylindrically symmetric structure that has a thin lining of dielectric.
• Couplers attached to the endpoints of the dielectric layer
1. The first bunch in a series of bunches traversing through the pipe at frequency $\omega$ enters the dielectric power extractor.

2. The bunch excites a wakefield at a specific mode based on the design of the structure.

3. The voltage is a function of the adjusted resonance frequency, the loaded quality factor (assume matched impedance condition), and the loss factor. The RF pulse propagates at a group velocity slower than the bunch velocity (assumed ideally relativistic).

4. The RF pulse is decays as the bunch leaves the dielectric power extractor.

   \[ V_{RF} = 2k(\omega'_{RF})q\cos(\omega'_{RF}t)e^{-\frac{\omega'_{RF}t}{2Q_{loaded}}} \]

5. While the RF pulse is still propagating within the dielectric power extractor, a subsequent bunch enter the structure and excites its own RF pulse that superimposes with the tail of the existing RF pulse.
• The wakefields extracted from neighboring bunches interfere constructively, producing a flat-top amplitude.
In order for the RF pulses to interfere constructively, the power extracting mode must be a harmonic of the bunch frequency.

The desired frequency can be calculated as follows:

\[ n = \left\lfloor \frac{Q_{\text{loaded}} \omega}{\omega_{RF}} \right\rfloor \]

\[ \omega'_{RF} = \frac{2Q_{\text{loaded}} \omega}{n} \]

Simulations suggest that by adjusting the coupler length, one can achieve a tuning range of \(~200\) MHz.
Simulations

• Attempted to optimize dielectric power extractor design by varying:
  – Dielectric layer length
  – Coupler length
  – Dielectric layer thickness
  – Taper length

• All parameters were varied independently and sequentially.

• Desirable features for a given mode were spatial localization, a high R/Q, and a high Q.
Trends Observed

- Frequency inversely related to length.
- When the R/Q for a given mode is maximized, the neighboring modes are more spread apart in frequency.
- R/Q varies sinusoidally as the length of the couplers are varied.
- The Q for a particular mode decreases as length increases.
Trend discontinuities most probably explained by mesh allocation within dielectric
Demonstrates tuning plausibility (able to maintain R/Q while adjusting frequency within a ~200 MHz range)
Results

- Trapped modes found only when couplers were attached.
- Dielectric discontinuity was not enough (so far) to localize modes

<table>
<thead>
<tr>
<th>Dielectric Length</th>
<th>Coupler Length</th>
<th>Frequency (GHz)</th>
<th>R/Q</th>
<th>Q-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.114 m</td>
<td>0.011 m</td>
<td>15.07</td>
<td>21.016</td>
<td>3848</td>
</tr>
</tbody>
</table>
• Calculations for the TBA scheme were done for the “optimal” mode.

<table>
<thead>
<tr>
<th>Tuned Frequency</th>
<th>Peak RF Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.31 GHz</td>
<td>7.164 kV</td>
</tr>
</tbody>
</table>

• Required frequency within tuning range
• At least 2*140 dielectric power extractors are needed (i.e. ~2*21 = 42 meters of structure)
• Additional power extractors will be needed to account for attenuation in lossy walls.
• Bunch length will have to be adjusted
Conclusions

• The use of a dielectric power extractor to accelerate and decelerate the beam has much potential.

• Higher order modes with even more outstanding qualifications may exist but could not be searched for due to software limitations and time constraints.

• Notable discoveries:
  – Tuning the power extractor via minute length adjustments is feasible
  – Couplers play an important role in localizing modes
• Mike Billing
• Heather Williams
• Rich Galik
• Peter Wittich