HOM AND IMPEDANCE STUDY OF RF SEPARATORS FOR LCLS-II
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ABSTRACT

The LCLS-II upgrade requires an rf spreader system to guide bunches into a switchyard delivering beam to two undulators and the primary beam dump. The beam pattern therefore needs a 3-way beam spreader. An rf deflecting cavity concept was proposed that includes both superconducting and normal conducting options. We characterize the higher order modes (HOM) of these rf separator cavities and evaluate beam dynamics effects due to potential HOM excitation. This study includes both short term wake and multi-bunch effects.

LCLS-II RF – SEPARATOR CAVITY OPTIONS

- LCLS-II requires an rf spreader system to transport beam to the undulators or the beam dump
- Considered fast switching devices:
  - Fast bipolar kickers
  - RF deflectors

RF Separator Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final electron energy (Ee)</td>
<td>4.0</td>
<td>GeV</td>
</tr>
<tr>
<td>RF frequency (fII)</td>
<td>325</td>
<td>MHz</td>
</tr>
<tr>
<td>Angle of deflection</td>
<td>1.0</td>
<td>Mrad</td>
</tr>
<tr>
<td>Transverse voltage (Vc)</td>
<td>4.0</td>
<td>MV</td>
</tr>
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</table>

HOM PROPERTIES

- No LOMs in superconducting or normal conducting rf-dipole cavity
- (R/Q) drops with the increasing frequency
- Qext of HOMs
  - For superconducting cavities: 10^8-10^9
  - For normal conducting cavities: 10^6-10^7
- HOM excitation in normal conducting cavities are negligible compared to superconducting cavities

LCLS-II Beam Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal Value</th>
<th>Range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final electron energy (Ee)</td>
<td>4.0</td>
<td>2.0-4.0 GeV</td>
<td></td>
</tr>
<tr>
<td>Electron bunch charge (Qb)</td>
<td>0.1</td>
<td>0.01-0.5 nC</td>
<td></td>
</tr>
<tr>
<td>Bunch repetition rate (CW) (fII)</td>
<td>0.2</td>
<td>0.1 MHz</td>
<td></td>
</tr>
<tr>
<td>Average current (Iavg)</td>
<td>0.02</td>
<td>0.001-0.3 mA</td>
<td></td>
</tr>
<tr>
<td>Peak current (Ipk)</td>
<td>1000</td>
<td>500-1500 A</td>
<td></td>
</tr>
<tr>
<td>rms bunch length (a)</td>
<td>8.3</td>
<td>0.6-52 μm</td>
<td></td>
</tr>
</tbody>
</table>

Beam Loading

- Beam induced voltage for the fundamental mode with Q = 5.5×10^10 for a beam with Iavg=0.02 mA at an offset of 2x=5 mm:
  \[ V_{l\text{ind}} = \frac{R}{Q} Q_k \alpha I_{l\text{avg}} = 8 \text{ kV} \]
- Induced beam power: 0.16 W

Effects due to HOM Excitation for LCLS-II Beam

- In the superconducting rf-dipole cavity the decay times are higher than bunch separation (1 μs) leading to multi-bunch effects
- \( f_{	ext{rel}} \text{ is } 500 \text{ GHz for short bunches of } 0.6 \text{ μm} \)
- In SC-RFD with \( f_{	ext{rel}} = 20 \text{ mm}, \text{ HOMs above cut off frequency propagate through the beam pipe} \)

Multi-Bunch Effects

- \( Q_{\text{ext}} \) with coupling through fundamental power coupler (FPC)
- Deflecting modes in horizontal direction do not couple to FPC
- HOM excitation due to on axis beam

- Total induced beam power ~32 mW
- Induced voltage ~0.11 kV is negligible to generate energy spread in the beam

SUMMARY: HOM excitation in SC-RFD does not lead to beam instabilities. Induced HOM power dissipates through the cavity surface and adds to cryogenic losses.