Vector Sum accelerating field parameters regulation of single EX-FEL module working in CW mode in high QI (6e7) conditions

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Agenda

1. Introduction,

2. Motivation,

3. Challenges in this solution

4. Control mechanisms used

5. Performance results

Motivation

- High gradient operation of superconducting resonators in CW,
- Evaluation of cryomodule setup (CMTB env.) feasibility for CW/LPO, VS and single cav. operation
- Different mechanical and RF effects determination (effects not visible in the short pulse work regime)
- Various operation conditions scenarios evaluation.

<table>
<thead>
<tr>
<th></th>
<th>FLASH</th>
<th>XFEL</th>
<th>CW I</th>
<th>CW II</th>
<th>CW III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 value</td>
<td>3,00E+06</td>
<td>4,60E+06</td>
<td>2,00E+07</td>
<td>4,00E+07</td>
<td>6,00E+07</td>
</tr>
<tr>
<td>Half BW [Hz]</td>
<td>216,67</td>
<td>141,30</td>
<td>32,50</td>
<td>16,25</td>
<td>10,83</td>
</tr>
<tr>
<td>Input Power [W] @ 16 MV/m</td>
<td>2,08E+04</td>
<td>1,36E+04</td>
<td>3,13E+03</td>
<td>1,56E+03</td>
<td>1,04E+03</td>
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<tr>
<td>Input Power [W] @ 25 MV/m</td>
<td>5,09E+04</td>
<td>3,32E+04</td>
<td>7,63E+03</td>
<td>3,81E+03</td>
<td>2,54E+03</td>
</tr>
</tbody>
</table>

Vector Sum accelerating field parameters regulation of single EX-FEL module working in CW mode in high Q1 (6e7) conditions

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Challenges

- **Microphonics**
- **HPC (IOT) nonlinearity**

- **Static drop**
- **QI vs temperature**

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Some other system limitations

- Coupling between cavities - full reflection from one structure changes conditions for neighboring resonators,
- Limited cryo system capacity -> heat load up to 120 W,
- Couplers overheating -> temperature have been kept below 160 K limit,
- Vacuum pumps oscillations.
CW - LLRF system setup

- **RF field regulation loop:**
  - P and MIMO controller,
  - similar to short pulse with 4,5MHz feedback sampling,

- **Cavity frequency regulation:**
  - DC voltage offset,
  - PI controller (mainly I component used) for low freq (<10Hz) regulation,
  - ANC based solution for persistent microphonics effects reduction
Vector Sum accelerating field parameters regulation of single EX-FEL module working in CW mode in high Ql (6e7) conditions

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RF feedback loop and piezo PI loop + ANC filters (30 or 50 Hz ) used.

Amplitude regulation (red line – XFEL spec.)

Phase regulation
**CW study with Q_l~6e7 @ 20 MV/m**

Table:

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOR power [kW]</td>
<td>1.61</td>
<td>1.851</td>
<td>1.826</td>
<td>1.894</td>
<td>1.665</td>
<td>1.76</td>
<td>2.126</td>
<td>1.9</td>
</tr>
<tr>
<td>Gradient [MV/m]</td>
<td>20.00</td>
<td>20.52</td>
<td>20.28</td>
<td>20.60</td>
<td>20.12</td>
<td>18.99</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Q_l</td>
<td>61.55M</td>
<td>62.1M</td>
<td>63.09M</td>
<td>60.7M</td>
<td>60.94M</td>
<td>62.37M</td>
<td>28.1M</td>
<td>26.29M</td>
</tr>
<tr>
<td>FPC temp (70K)</td>
<td>1.03E2</td>
<td>1.13E2</td>
<td>1.11E2</td>
<td>1.07E2</td>
<td>1.16E2</td>
<td>1.11E2</td>
<td>99.52</td>
<td>93.78</td>
</tr>
</tbody>
</table>

VS composed from 6 cavities (last two detuned)
Achieved performance $dA/A \sim 0.007\%$, $d\phi \sim 0.01$ deg

**LLRF Workshop Series**

Second Topical Workshop on Cryomodule Microphonics and Resonance Control

Hosted by Brookhaven National Laboratory and Jefferson Lab
October 25-26, 2018

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Summary

• VS operation of the X-FEL cryomodule in CW mode that can satisfy performance criteria have been achieved,

• Narrow bandwidth cavity operated in high gradient may require more tuning range from fast tuners (piezos),

• VS focused RF loop and cavity oriented frequency tuning loop not always play together – amplitude control decoupling from phase control have to be used,

• There is still a place for improvement (higher gradients, improvement in phase regulation, Ql vs. temp. compensation ),

• LPO challenges to be investigated……..
Thank You