Heat Loads of the XFEL accelerator

Measured static values at 2K, 5-8K, 40-80K and dynamic values at 2K

R. Ramalingam for the MKS group
Hamburg, 19 January 2021
Outlook

01 Methods of Heat load Calculation

02 Single cryomodule Static and Dynamic heat loads – AMTF
   • at 5-8K, 40-80K and at 2K

03 Static and Dynamic heat loads at the XFEL linac
   • at 5-8K, 40-80K and at 2K

04 Results comparison and Conclusions
Heat load calculation: methodology

For the single cryomodules and the XFEL linac

- Heat Load estimated for three different temperature levels:
  
<table>
<thead>
<tr>
<th>Shield Type</th>
<th>Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Shield</td>
<td>40-80 K</td>
</tr>
<tr>
<td>Internal Shield</td>
<td>5-8 K</td>
</tr>
<tr>
<td>Cavity Environment</td>
<td>2 K</td>
</tr>
</tbody>
</table>

- **Static Heat Load calculation at 5-8 K and 40-80K**
  
  - Stable flow
  
  - Calculate heat loads from flow and delta enthalpy

- **Static Heat Load calculation at 2K**
  
  - Stable flow, turn off magnets and RF, subtract heaters
  
  - For XFEL linac, heat loads from flow and delta enthalpy
  
  - For single cryomodules in the AMTF hall, cold flowmeters at 2K not very precise, use warm flowmeter after compressor, close the JT valve and measure amount of evaporated LHe at constant pressure. (no losses from 2KR lines).

- **Dynamic Heat Load calculation at 2K**
  
  - Same method as static measurement, with RF
  
  - Subtract static component from total value

\[
\dot{Q}_{s,5/80K} = \dot{m}\Delta h = \dot{m}(h_{out}(p_{out}, T_{out}) - h_{in}(p_{in}, T_{in}))
\]

\[
\dot{Q}_{s,2K(XFEL)} = \dot{m}\Delta h = \dot{m}(h_{out}(p_{out}, T_{out}) - h_{in}(p_{in}, T_{in}))
\]

\[
\dot{Q}_{s,2K(AMTF)} = L\dot{m} \quad L = 23.06 \, J/g @ 2 \, K, 30 \, mbar
\]

\[
\dot{Q}_{d,2K} = \dot{Q}_{\text{total,2K}} - \dot{Q}_{s,2K}
\]
Static and dynamic heat loads measured in AMTF

40/80 K, 5/8 K and 2 K circuits

- Three test stands available for cold test of single XFEL cryomodules
- Average value of all 103 tested cryomodules at the three test stands (2014 – 2015)
- 2K dynamic loads value at average cavity gradient of 23 MV/m

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Average Heat Load per cryomodule (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40/80 K Static</td>
<td>92.7 W</td>
</tr>
<tr>
<td>5/8 K Static</td>
<td>10.6 W</td>
</tr>
<tr>
<td>2 K Static</td>
<td>5.6 W</td>
</tr>
<tr>
<td>2 K Dynamic</td>
<td>4.2 W</td>
</tr>
</tbody>
</table>
**XFEL overview**

From the point of view of the heat load calculations

- **XTL**, 3 strings
  - L1 - 4 cryomodules 1.3 GHz
  - L2 - 12 cryomodules 1.3 GHz
  - L3 - 80 cryomodules 1.3 GHz

- **Injector**, 1 string
  - 1 cryomodule 1.3 GHz
  - 1 cryomodule 3.9 GHz

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**Heat Loads of the XFEL accelerator**
R. Ramalingam for the MKS group, January 2021
**XFEL static heat loads at 40-80K, 5-8K and 2K**

**Measurement at the XLVB box**

<table>
<thead>
<tr>
<th>Circuit (at XLVB)</th>
<th>Total heat load (W) 2017</th>
<th>Total heat load (W) 2020</th>
<th>Average heat load / cryomodule (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40/80 K Static</td>
<td>9720 W</td>
<td>9750 W</td>
<td>~ 102 W</td>
</tr>
<tr>
<td>5/8 K Static</td>
<td>795 W</td>
<td>775 W</td>
<td>~ 8 W</td>
</tr>
<tr>
<td>2 K Static</td>
<td>579 W</td>
<td>630 W</td>
<td>~ 7 W</td>
</tr>
</tbody>
</table>

- Measurement performed for the entire linac
  - It includes transfer lines, cryogenic boxes and caps

- The values are an average on different time periods in 2017 and 2020

- Average heat load per cryomodule is approximate calculation
  - it includes the transfer lines XLTL1, XLTL2, XLTL3, the feed and end caps and string connection boxes
  - results are conservative values

- Choice of thermal sensors verified with different methods

XFEL dynamic heat loads at 2K

- \( \dot{Q}_{d,2K} = \dot{Q}_{\text{total},2K} - \dot{Q}_{s,2K} \) (630 W)

<table>
<thead>
<tr>
<th>Year of measurement</th>
<th>Dynamic Heat Load, W (14 GeV)</th>
<th>Dynamic Heat Load, W (16.5 GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>427 W</td>
<td>627 W</td>
</tr>
<tr>
<td>2020</td>
<td>403 W</td>
<td>612 W</td>
</tr>
</tbody>
</table>
# Summary

## Static and Dynamic heat loads at XFEL linac

### Total values for the XFEL

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Static</th>
<th>Dynamic (14 GeV)</th>
<th>Dynamic (16.5 GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 – 80 K</td>
<td>9750 W</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5 – 8 K</td>
<td>775 W</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2 K</td>
<td>630 W</td>
<td>403 W</td>
<td>612 W</td>
</tr>
</tbody>
</table>

### Average value of single cryomodules

<table>
<thead>
<tr>
<th>Circuit</th>
<th>AMTF</th>
<th>XFEL linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 – 80 K static</td>
<td>92,7 W</td>
<td>102 W *</td>
</tr>
<tr>
<td>5 – 8 K static</td>
<td>10,6 W</td>
<td>8 W *</td>
</tr>
<tr>
<td>2 K static</td>
<td>5,6 W</td>
<td>7 W *</td>
</tr>
<tr>
<td>2K dynamic</td>
<td>4,2 W</td>
<td></td>
</tr>
</tbody>
</table>

* conservative values, include ECs, FCs, TLs
Thank you

A special thank to many colleagues for their material, discussion and advice, in particular:

Y. Bozhko, S. Barbanotti, T. Schnautz
Effective (average) cavity $Q_0$ from measured dynamic load

\[
Q_{0,\text{eff}} \approx \frac{f_{\text{rep}}(t_{\text{fill}} + t_{\text{flat}})}{(r/Q)P_{\text{cryo}}} \sum_{i=1}^{N_{\text{cav}}} \langle V_i^2 \rangle
\]

where

\[
\langle V_i^2 \rangle = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} V_i^2(t) \, dt
\]

calculated from DOOCS history of probe amplitude sample:

\[\text{XFEL.RF/LLRP.CONTROLLER/Cc.Mm.Aa.L1/PROBE.AMPL.SAMPLE}\]

<table>
<thead>
<tr>
<th>RF CONFIG</th>
<th>Time Frame</th>
<th>Average Dynamic Load (W)</th>
<th>Effective average $Q_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>REDUCED-V</td>
<td>01.09—15.10.2020</td>
<td>400</td>
<td>$1.04 \times 10^{10}$</td>
</tr>
<tr>
<td>14 GeV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIGH-V</td>
<td>20.10—15.11.2020</td>
<td>600</td>
<td>$0.98 \times 10^{10}$</td>
</tr>
<tr>
<td>16.5 GeV</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Courtest**

Nicholas Walker  
DESY - MPY group