Status of the SwissFEL C-band Linac


(Paul Scherrer Institute)
The SwissFEL Linac:

- **Linac 1-3**
  - 5.5 GeV acceleration
  - C-band, 28 MV/m, new high shunt impedance structures to minimize overall costs
  - No choke mode required (no bunch trains)
  - Preassembled module with waveguides and pulse compressor to minimize work in tunnel
- Fast switch-yard to distribute bunches between Aramis and Athos (see **MOP039**)
- Bunch compressor BC2
- Transverse deflecting C-band structures

**SwissFEL parameters**

- Wavelength from 1 Å - 70 Å
- Photon energy 0.2-12 keV
- Pulse duration 1 fs - 20 fs
- e⁻ Energy 5.8 GeV
- e⁻ Bunch charge 10-200 pC
- Repetition rate 100 Hz
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SwissFEL Main Linac building block

C-band-klystron
5.7 GHz, 50 MW, 3 μs, 100 Hz

BOC pulse compressor

four 2 m long C-band structures, 28 MV/m
0.22 GeV energy gain per module (+10% overhead)

<table>
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<th>Main LINAC</th>
<th>#</th>
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C-Band test stand

Pulse-Genesis Modulator
Tested since Sept. 2012
Limited to single pulses
Reached 300 kV / 370 A pulse operation on resistive test load

ScandiNova K2 Modulator:
In regular use: 24/7 100 Hz operation for tests of waveguide components, pulse compressor and accelerating structures
Modulators are now disassembled to make space for new prototypes.
Prototype modulator ordered from Ampegon

Type-μ modulator prototype for PSI C-band
Prototype modulator ordered from Scandinova

K2-3 for PSI C-band:
50 MW, 370kV / 344A / 3µs / 100 Hz

Design of C-Band K2-3 Modulator
Based on K2-series: new control system, new mechanical layout.
Achieves excellent pulse shape and an rms stability of 13 ppm.

50MW Klystron and K2-3 Modulator
C-band structure

Structures are built without a tuning step

**Specifications:**
- Phase adv.: $2\pi/3$
- Filling Time: 322 ns
- $v_g/c$: 3.10% - 1.19%
- $R/Q$: 7.23 k$\Omega$ – 8.70 k$\Omega$
- $Q$: 10035 - 9950
- Iris radius (20°C): 7.244 mm – 5.436 mm

**Dimensions:**
- Length ($L$): 2050 mm
- Cells: 113

**Diagram Details:**
- J-Coupler input
- J-Coupler output
- Cut drawing
- Double-rounded cups
- Cooling
Stacking of C-band structure
First 2 m C-band structures

- **5 structures have been brazed**
  - First two structures were not vacuum tight after the brazing but they could be repaired with a second brazing step.
  - Brazing procedure changed for third structure. Structure 3 & 4 are vacuum tight after the brazing. Structure 5 had again a vacuum leak (repaired).

- **Structures have been characterized with a bead pull measurements**

- **High power results for first structure:**
  - 52 MV / m (~28 MW from klystron), limit was radiation shielding
  - Break-down rate at 52 MV / m is ~2.1 x 10^{-6}
  - At the nominal gradient, this gives excellent break-down rate
2 m C-band structure: reflection parameter

- Structure 1: Operating frequency $S_{11} = -30.2$ dB
- Structure 2: Operating frequency $S_{11} = -33.1$ dB
2 m C-band structure: longitudinal field distribution

\[ E_z (\text{arb. units}) \]

\[ \text{position along structure (m)} \]

- **structure 1**
- **structure 2**
2 m C-band structure: phase advance errors
Strategy for series production

C-band structures:
- Main partner for production of cups: TEL Mechatronics
- Additional cups produced by VDL
- J-couplers produced by VDL
- Brazing of J-couplers and stacking / brazing of structures at PSI

BOC pulse compressors:
- Production at PSI

Waveguides / loads
- MHI will produce the waveguide network
- CML will produce the water loads
Pulse compressor
Whispering gallery mode: intrinsically high Q

RF design:
Very simple design:
- Single cavity
- Whispering gallery mode with analytical solution
- Intrinsic high Q

Mechanical design:
Very simple and robust design:
- Inner body from a single piece
- Two brazing steps

R. Zennaro
## BOC production at PSI

<table>
<thead>
<tr>
<th>#</th>
<th>Maker</th>
<th>Tuning steps</th>
<th>f (MHz)</th>
<th>$Q_0$</th>
<th>Power test</th>
<th>Breakdown rate ¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>VDL</td>
<td>4</td>
<td>5711.952</td>
<td>219000 ± 4000</td>
<td>✔️</td>
<td>$3 \cdot 10^{-8}$ (35 MW; phase jump) (1) $2\times10^{-8}$ (40 MW phase modulation) (1)</td>
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<tr>
<td>1</td>
<td>PSI</td>
<td>4</td>
<td>5712.061</td>
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<td>✔️</td>
<td>$1\times10^{-7}$ (40 MW phase jump) (2)</td>
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<tr>
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<td>-</td>
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<tr>
<td>3</td>
<td>PSI</td>
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<td>218000 ± 4000</td>
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<td>-</td>
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<tr>
<td>4</td>
<td>PSI</td>
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<td>5711.979</td>
<td>217000 ± 4000</td>
<td>Next test</td>
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</tr>
<tr>
<td>5-8</td>
<td>PSI</td>
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<td>Under production</td>
<td></td>
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</tr>
<tr>
<td>9-30</td>
<td>PSI</td>
<td>0</td>
<td>Series production</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹) Very likely the BDR was limited by a waveguide bend placed at the BOC output. Post test inspection shows no clear BD indication on the BOC surface, instead we had a large amount of BD spots on the bend surface. BDR with phase jump at 40 MW was only $5\times10^{-7}$.

2) PSI BOC 1 conditioned much faster. This BDR result has been obtained only after removal of the waveguide bend which was limiting the performance before.

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R. Zennaro
Simultaneous brazing of 3 BOCs

For more information see THP056
High power results from first BOC prototype
(40 / 50 MW, 3 μs pulse from klystron)
Principle of the temperature regulation units

Principle:

- Mixing ratio of ~ 1:10 improves temperature stability in stabilized circuit by factor of 10 compared to supply water
- A linearly regulated heater is used in a regulation loop to improve the stability further
- Temperature sensors are used as monitors when RF is turned off
- LLRF-based temperature measurement is used as an additional monitor during RF operation

Prototype system was commissioned in spring 2013
BOC temperature stabilization

Temperature stability (T-sensor based): ~3 mK rms
BOC frequency stability (LLRF based): ~300 Hz
BOC temperature stability (LLRF based): ~3 mK rms
Lowering response time when BOC temperature is changed:

1. LLRF-based loop with integrator only
2. LLRF-based loop with integrator & proportional control
3. Additional cubic term in feed-forward loop
Storage and assembly area for C-band modules
Storage and assembly area for C-band modules
C-band module assembly area
Thank you!
Simultaneous operation of Aramis and Athos

Time structure:

Aramis

Athos

Microbunches

28 ns

10 ms / 100 Hz

28 ns

Switch-yard:

Will allow simultaneous operation of Aramis and Athos at 100 repetition rate
Switch-yard: Fast resonant kicker development

**Kicker system**
- Number of kickers: 2
- Kickers type: In vacuum
- Bunch separation: 28 ns
- Total deflection angle: 1 mrad (vertical)
- Deflection stability: ±80 ppm pk-pk
- Total magnetic length: 1.5 m
- Line field integral: 10 mT.m
- Deflecting current: 500 A pk-pk

**Septum**
- Number of septums: 1
- Septum type: Lambertson, DC
- Total deflection angle: 2° (horizontal)
- Deflection stability: ±10 ppm pk-pk
- Total magnetic length: 1.0 m
- Line field integral: 350 mT.m

For more information check the poster contribution MOP039: M. Paraliev at al.

"High Stability Resonant Kicker Development for the SwissFEL Switch Yard"

(the poster was presented yesterday)

Achieved kicker (prototype) stability: < ±15 ppm pk-pk