RF superconductivity application to synchrotron radiation light sources

Third Harmonic Superconducting passive cavities in ELETTRA and SLS

2 cryomodules (one per machine) with 2 Nb/Cu cavities at 1.5 GHz
Collaboration
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Increase of the Touschek dominated beam lifetime

A 3\textsuperscript{rd} harmonic (1.5 GHz) RF system allows:
- bunch lengthening $\rightarrow$ decrease of charge density
- $\rightarrow$ increase of beam lifetime
Passive superconducting cavities

SOLEIL RF structure type

No power coupler (beam powered)

HOM free RF structure

2 cavities linked by a large tube on which are placed superconducting loop couplers for damping HOMs.

Superconducting Nb loop couplers on inner tube: geometry optimized for HOMs damping (number of couplers, axial and angular position, loop geometry, etc.)
Spécifications

**Bunch lengthening mode:**
- Temperature: 4.4 to 4.5 K
- Fundamental mode frequency: $F_0 = 1498.95$ MHz
- Total max accelerating voltage: $V = 1.0$ MV
- Tuning range: $DF = \pm 500$ kHz
- Tuning resolution: $R \approx 10$ Hz
- $Q_0$ vertical tests at CERN: $> 2 \times 10^8$ at 5MV/m and 4.5 K
- $Q_0$ cryomodule tests at Saclay: $> 2 \times 10^8$ at 4MV/m and 4.4 K
- $Q_l$ loaded: $> 1 \times 10^8$ at 4MV/m and 4.4 K

**Damping:**
- Longitudinal HOMs: $f_R R_\parallel / < 7.0 \, k\Omega \cdot GHz$
- Transverse HOMs: $R_\perp < 130k\Omega/mm$

**Parking mode at 300 K or 4.5 K:** cavities tuned between 2 revolution harmonics

**Max. cryomodule length:** 1.1 m

Optimisation of HOMs damping

Geometric parameters for HOM coupler design optimisation

Model cavity for HOMs damping optimisation
HOMs Damping requirements

10 transverse modes + 10 longitudinal modes:

- **Transverse modes**: \( f_{\text{cutoff}} = 3762 \) MHz
- **Longitudinal modes**: \( f_{\text{cutoff}} = 2880 \) MHz

<table>
<thead>
<tr>
<th>F (MHz) Monopolar</th>
<th>R/Q ((\Omega))</th>
<th>(Q_{\text{max}})</th>
<th>F (MHz) Dipolar</th>
<th>R/Q ((\Omega/\text{m}))</th>
<th>(Q_{\text{max}})</th>
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<tbody>
<tr>
<td>2466</td>
<td>0.17</td>
<td>16000</td>
<td>1721</td>
<td>20.0</td>
<td>6500</td>
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<tr>
<td>2532</td>
<td>2.60</td>
<td>1100</td>
<td>1723</td>
<td>21.8</td>
<td>600</td>
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<tr>
<td>2606</td>
<td>11.0</td>
<td>240</td>
<td>1935</td>
<td>0.01</td>
<td>1.10 (^7)</td>
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<tr>
<td>2695</td>
<td>0.12</td>
<td>22000</td>
<td>2056</td>
<td>255</td>
<td>510</td>
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<tr>
<td>2826</td>
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<td>2103</td>
<td>27.6</td>
<td>4710</td>
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<td>270</td>
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<td>300</td>
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<tr>
<td>3084</td>
<td>1.93</td>
<td>1200</td>
<td>2303</td>
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<tr>
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<td>7500</td>
<td>2503</td>
<td>11.1</td>
<td>11700</td>
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<tr>
<td>3358</td>
<td>0.86</td>
<td>2400</td>
<td>2712</td>
<td>63.8</td>
<td>2040</td>
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<tr>
<td>3594</td>
<td>0.43</td>
<td>4500</td>
<td>2865</td>
<td>10.3</td>
<td>12600</td>
</tr>
</tbody>
</table>
The RF structure

1 Pick-up port per cavity

2 couplers for longitudinal modes damping

4 couplers for transverse modes damping

1 incident coupler port per cavity for RF measurements

couplers for transverse modes

- N connector for RF power output with a semi rigid Kaman cable
- Flexible Nb wave for notch filter tuning
- Ceramic windows brazed on copper with stainless steel flanges
- Cooling copper fan connected to liquid helium via braids

Superconducting niobium with stainless steel flanges

Niobium loop extremities

couplers for longitudinal modes

- 5/8 connector for RF power output with a coaxial line
- \( P_{\text{max}} = 1.2\text{kW} \)

Flexible Nb wave for notch filter tuning
Optimisation of the cell wall thickness

For a constant wall thickness of 3mm, the copper elastic limit (60MPa) is reached for a detuning of ±400kHz (<±500kHz specifications).

Sensitivity to deformation for tuning:
\[ \frac{\Delta F}{\Delta l} = 3.2 \text{ MHz/mm calculated and measured} \]

Sensitivity to helium pressure variations:
- Calculated: \[ \frac{\Delta F}{\Delta P} \sim 150 \text{ Hz/mbar cavities ends free} \]
- Calculated: \[ \frac{\Delta F}{\Delta P} \sim 30 \text{ Hz/mbar cavities ends fixed} \]
- Measured: \[ \frac{\Delta F}{\Delta P} \sim 65 \text{ Hz/mbar} \]
1.5 GHz Nb/Cu cavities fabricated and tested at 4K in vertical cryostat at CERN

1.5 µm Nb coating was deposited by magnetron sputtering inside the copper cavities

A small magnetron cathode was especially developed to sputter the niobium inside the outer tubes Φ61mm in diameter
The tuning system is used to control the voltage (passive cavity) acting on the cavity frequency.

- The tuner works in vacuum at 4K.
- Fixed on He tank.
- Stepping motor with gear box.

Theoretical resolution: 0.5 nm, or 1.7 Hz.

- Stiffness > 1000 kN/mm.
- Stiffness with He tank: 220 kN/mm (10x cavity).
- Maximal amplitude: ± 0.5 mm, or ± 1.5 MHz.

Linearity of the frequency versus motor steps number.

\[ y = 1.72E-06x + 1.499E+03 \]
Cryomodule assembling at Saclay

In class 100 clean room

Cold mass assembling in the workshop
Preparation of the cryomodule test at Saclay
Estimated cryogenic load at 4MV/m, 400mA and Q=2.10^8 (for SLS cryomodule)

<table>
<thead>
<tr>
<th>Component</th>
<th>Load</th>
<th>Comments</th>
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<tbody>
<tr>
<td>2 RF cells</td>
<td>22 W</td>
<td>Directly in LHe bath</td>
</tr>
<tr>
<td>2 L – couplers</td>
<td>3 W</td>
<td>Cooled by conduction</td>
</tr>
<tr>
<td>4 T – couplers</td>
<td>8.5 W</td>
<td>Cooled by conduction</td>
</tr>
<tr>
<td>2 Extremity tubes</td>
<td>0.2 W</td>
<td>With 2 x 0.05 g/s cold GHe</td>
</tr>
<tr>
<td>Cryomodule static losses</td>
<td>5.1 W</td>
<td>With 0.071 g/s cold GHe in thermal shield (60 K)</td>
</tr>
<tr>
<td>Transfer-lines</td>
<td>6.5 W</td>
<td>Assuming 0.5 W/m load</td>
</tr>
<tr>
<td>Total refrigeration power at 4.5 K: 45.3 W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total GHe flow: 0.171 g/s → 5.2 l/h of liquefaction duty</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SLS cryomodule

ELETTRA cryomodule
SLS cryomodule

- Cryomodule installed in June 2002
- “Warm operation” (200mA) starting June 2002
- Cavity cool down September 23-27 2002
  (400 mA stable operation with cold cavity)
- “Cold operation” with beam 30 September 2002

Warm operation: current limited at 200 mA due to overheating of the cavities (with vacuum insulation)

Cold operation: stable operation at 400 mA - maximum elongation demonstrated
  bunch lengthening: x3  - beam life time: x 2.2
  Landau damping: suppression of coupled bunch instabilities
  Stable users operation at 300 mA with reduced Super-3HC voltage

ELETTRA cryomodule

- cryomodule installed in August 2002
- “warm operation” starting September 2002 (140mA at 2.4 GeV)
- cavity cool down January 9th, 2003
- 300 mA at 2.0 GeV stable operation with cold cavity

Warm operation: operational mode at 2.0 GeV forbidden due to interaction between the parked fundamental mode and the beam spectrum lines at 2.4 GeV, 140 mA the cavities can be parked transparent to the beam

Cold operation: the parked cavities don’t influence the beam injection at 0.9 GeV and energy ramping to 2.0 or 2.4 GeV suppression of longitudinal coupled bunch instabilities at 2.0 GeV and 320mA bunch lengthening: x 3  - beam life time: x 3.5 period March to June: cavities were parked because of problems on the tuner of cavity1 that were sorted out during the shutdown in June.
Conclusions:

First demonstration of synchrotron radiation operation with superconducting Landau cavity

Both machines gained a factor 3 on bunch lengthening, and a factor higher than 2 on beam life time (3.5 at ELETTRA).

Landau damping allows suppression of coupled bunch instabilities.

In cold operation, both cryomodules are very stable: no abnormal temperature increase, stable voltage, stable vacuum pressure. No interlock due to the cryomodule during the first year of operation on the SLS cryomodule.

For more information on the commissioning of the cryomodules:

Poster MoP25:
SLS Operational Performance with Third Harmonic Superconducting System

Poster MoP27:
Performance of the 3rd Harmonic Superconducting Cavity at ELETTRA