Technology Challenges for SRF Guns as ERL Sources in View of Rossendorf work

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Basic Design

Normal-conducting cathode inside SC cavity


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity</td>
<td>Niobium 3+½ cell (TESLA Geometry)</td>
</tr>
<tr>
<td></td>
<td>Choke filter</td>
</tr>
<tr>
<td>Operation</td>
<td>T = 1.8 K</td>
</tr>
<tr>
<td>Frequency</td>
<td>1.3 GHz</td>
</tr>
<tr>
<td>HF power</td>
<td>10 kW</td>
</tr>
<tr>
<td>Electron energy</td>
<td>10 MeV</td>
</tr>
<tr>
<td>Average current</td>
<td>1 mA</td>
</tr>
<tr>
<td>Cathode</td>
<td>Cs₂Te</td>
</tr>
<tr>
<td></td>
<td>thermally insulated, LN₂ cooled</td>
</tr>
<tr>
<td>Laser</td>
<td>262 nm, 1W</td>
</tr>
<tr>
<td>Pulse frequency</td>
<td>13 MHz &amp; &lt; 1 MHz</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>77 pC &amp; 1 nC</td>
</tr>
</tbody>
</table>
Main Components of the SRF Photogun in Rossendorf

- Tuning system
- RF input coupler
- 3½-cell cavity
- Test benches for:
  - Critical component
- SRF-Gun
- Cryostat:
  - Cathode insert & cooling
  - He-vessel & port
  - LN₂ cooling & port
  - Magnetic shield, vacuum diagnostics
- LHe transfer line & distribution box
- Control systems:
  - Synchronisation
  - He-pressure & level
  - Tuning, rf system, laser
  - Beam line devices
  - PSS, MPS, Vacuum
- Power rf system
- Low level rf system
- Diagnostic beam line:
  - View ports, current, beam shape
  - Energy and energy width
  - Bunch length, emittance
- Driver Laser
- Laser beam line
- Photocathode transfer & storage
- Photocathode preparation equipment
- ELBE connection beam line

Radiation Source ELBE
Dietmar Janssen
16.03.2005
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Design consideration of the gun cell

L1 is mainly determined by technological conditions (pressure, multipacting, etching)

The optimal L2 value follows from the beam properties

One dimensional model calculation:

\[ E(\Phi) \rightarrow \text{max}, \quad E_{\text{cath}} \sin(\Phi) \rightarrow \text{max} \]

\[ L_1 = \frac{\lambda}{4} \cdot \alpha_0 \cdot A_0 \]

L = L1 + L2 width of the gun cell

L1 = \alpha_0 \cdot A_0 \cdot \lambda / 2\pi
Result of numerical optimization

Numerical minimization of the beam emittance by variation of the gun cell shape with the condition, that $B_{\text{max}} < 115 \text{mT}$ and $E_{\text{max}} < 52 \text{MV/m}$ when $E_{\text{acc}} = 25 \text{MV/m}$

1st cell

Shortened TESLA cup

TESLA cups

Choke

Cathode holder housing

Input coupler and pick up ports

Obtained result: [mm]
$L_1 + L_2 = \lambda/4 - 20 = 37.7$
$a_1 = 9$, $b_1 = 16$,
$R_1 = 102.5$, $r_1 = 11.4$,
RRR40 and RRR300 cavity of the SRF gun
Cavity Design Parameter

RF focusing in SC gun cavities


<table>
<thead>
<tr>
<th>1. 3 GHz, 10 kW</th>
<th>optimized half cell &amp; 3 TESLA cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{z,\text{max}} = 50 \text{ MV/m (T cells)}$</td>
<td>$= 33 \text{ MV/m (1/2 cell)}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>77 pC</th>
<th>1 nC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{av} = 1 \text{ mA}$</td>
<td>$E = 9.5 \text{ MeV}$</td>
</tr>
</tbody>
</table>

| 0.5 mm mrad | 2.5 mm mrad |

Fields are normalized to the accelerating gradient in the TESLA cells of 25 MV/m.
Magnetic RF field inside the cavity

\begin{align*}
E_{TM} \text{ field pattern (1300 MHz)} & \quad B_{TE} \text{ field pattern (3802 MHz)} \\
\end{align*}
**Design parameter including the magnetic mode**

![Graph showing beam size and transverse emittance](image)

<table>
<thead>
<tr>
<th>Beam parameter</th>
<th>Field parameter</th>
<th>Laser parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_z [\text{mm mrad}]$</td>
<td>$B_{\text{TMSurf}} [\text{mT}]$</td>
<td>115</td>
</tr>
<tr>
<td>$\sigma_x [\text{mm}]$</td>
<td>$B_{\text{TEsurf}} [\text{mT}]$</td>
<td>136</td>
</tr>
<tr>
<td>$\varepsilon_z [\text{keV mm}]$</td>
<td>$</td>
<td>B_{\text{TM}} + B_{\text{TE}}</td>
</tr>
<tr>
<td>$\Delta z [\text{mm}]$</td>
<td>$E_{\text{TM, axis}} [\text{MV/m}]$</td>
<td>50</td>
</tr>
<tr>
<td>$E_{\text{av}} [\text{MeV}]$</td>
<td>$\varphi_{\text{TM}} [\text{grad}]$</td>
<td>74.6</td>
</tr>
<tr>
<td>$\Delta E_{\text{rms}} [\text{keV}]$</td>
<td>$\varphi_{\text{TE}} [\text{grad}]$</td>
<td>0 - 180</td>
</tr>
</tbody>
</table>

Puls length [ps]: 20
Raise time [ps]: 1
Spot size [mm]: 2.6
Bunch charge [nC]: 1
Dual tuning system

- Gun-cell tuner
- TESLA-cell tuner
- Choke-cell setting

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gun cell</th>
<th>TESLA cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>±0.25mm</td>
<td>±0.3mm</td>
</tr>
<tr>
<td>Resolution</td>
<td>2nm</td>
<td>2nm</td>
</tr>
<tr>
<td>Load</td>
<td>±2250N</td>
<td>±2700N</td>
</tr>
<tr>
<td>Frequency</td>
<td>±137kHz</td>
<td>±286kHz</td>
</tr>
</tbody>
</table>
Liquid $N_2$ Cathode Cooling

Cone in cooler
- centres cathode
- cathode is pressed in by spring
- thermal contact of cone surface?

Test bench
thermal conductance measurements, cathode temperature? & test of the cathode transfer system
Test bench for the cathode cooler

- heater
- cathode
- cathode cooler
- LN$_2$ reservoir
Cavity with cathode tuning system

- Cathode input
- End of the cryostat
- LN$_2$ reservoir
- Pic up flange
- Titanium bridge
- Cavity tube
Beam tube with higher order mode – and main coupler

HOM coupler
(TESLA design)

Main coupler
Max. power 10kW
Design M.Champion
Development of HEPL, Stanford
RF power input around the cathode

- Power input
- Warm RF window
- Cold RF window
- Tube for cathode exchange
- End of the cryostat
- Quater wave choke
- Bellow for adjustment of $Q_{ext}$ and heat isolation
- $\Delta z$
- $L$
- $\text{LN}_2$ cooling

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Dietmar Janssen
External quality factor and head load of a cathode-RF coupler

Field parameters for $W = 29.755J$

$E_{z\max}(r=0) = 50\text{MV/m}$, $U_{r\max} = 6.5\text{kV}$

$E_{s\max} = 43.6\text{MV/m}$, $B_{s\max} = 0.11\text{T}$
Cryomodule design of the SRF gun
LN$_2$ cooling shield of the cryostat
Present Status and next steps

Cavity: Fabrication finished
Fabrication of 2 (RRR 40 & 300) cavities at ACCEL finished
next steps: warm tuning in Rossendorf, BCP, HPR, tests at 2K at DESY

Cavity tuners: Fabrication finished
design of a test bench

Cathode cooling system:
Fabrication finished
tests are running

Cathode transfer system:
Design finished, in the workshop

Cathode preparation chamber:
Design and fabrication finished, assembling and tests

Cryomodule: Design finished, in fabrication