High Rep Rate Guns:  
FZD  Superconducting RF Photogun


FLS 2010 Workshop, SLAC, March, 1-5, 2010
INTRODUCTION – HISTORY OF SRF GUN R&D

1988-91 proposal & first experiment

Univ. Wuppertal, 1992

2002 first beam from a SCRF gun @ FZD


since 2004: Development of the 3½-Cell SRF Photoinjector for ELBE

first cool-down 1 – 2 August 2007

$\Delta f = 2.02 \text{MHz}$
first beam of the 3½ cell SRF gun on November 12\textsuperscript{th}, 2007

**RF:**
- $E_{\text{acc}} = 5 \text{ MV/m}$
- $f = 1300.38327 \text{ MHz}$, 150 Hz bandwidth
- $P_{\text{diss}} = 6 \text{ W}$

**Laser:**
- 263 nm, 100 kHz repreate
- 0.4 W power (4 µJ)

**Cathode:**
- Cu, Q.E. $\approx 10^{-6}$

**Electron beam:**
- 2.0 MV energy
- 50 nA average current, 0.5 pC bunch charge
**ELBE Superconducting RF Photoinjector**
- New Injector for the ELBE SC Linac
- Test Bench for SRF Gun R&D

**Specifications**

<table>
<thead>
<tr>
<th>Mode</th>
<th>ELBE</th>
<th>High Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>final electron energy</td>
<td>≤ 9.5 MeV</td>
<td></td>
</tr>
<tr>
<td>RF frequency</td>
<td>1.3 GHz</td>
<td></td>
</tr>
<tr>
<td>operation mode</td>
<td>CW</td>
<td></td>
</tr>
<tr>
<td>bunch charge</td>
<td>77 pC</td>
<td>1 nC</td>
</tr>
<tr>
<td>repetition rate</td>
<td>13 MHz</td>
<td>500 kHz</td>
</tr>
<tr>
<td>laser pulse (FWHM)</td>
<td>4 ps</td>
<td>15 ps</td>
</tr>
<tr>
<td>transverse rms emittance</td>
<td>1 mm mrad</td>
<td>2.5 mm mrad</td>
</tr>
<tr>
<td>average current</td>
<td>1 mA</td>
<td>0.5 mA</td>
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</tbody>
</table>
Design for the SRF-Gun @ ELBE

- CW + high rep rate - 500 kHz, 13 MHz and higher
- medium average current 1 – 2 mA (< 10 mA)
- high energy (stand alone) - 3½ cells
- low - high bunch charge 80pC – 1 nC
- low transverse emittance 1 – 3 mm mrad
- normal-conducting, lqN₂-cooled, exchangeable, semi-conductor photo cathode
- highly compatible with ELBE cryomodule (1.3 GHz cavity, 10 kW coupler, He & N₂ support, etc.)

Application @ ELBE

- high peak-current operation for FELs with (13 MHz, 80 pC)
- high current (1 mA) @ low rep rate (<1 MHz) -> high charge pulsed secondary particle beams: neutrons, positrons with ToF measurements
- low emittance @ medium charge (100 pC) for short pulses THz-radiation x-rays by inverse Compton backscattering
### SRF Gun Parameter

<table>
<thead>
<tr>
<th>parameter</th>
<th>present cavity</th>
<th>new “high gradient cavity”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>measured ’08</td>
<td>ELBE</td>
</tr>
<tr>
<td>final electron energy</td>
<td>2.1 MeV</td>
<td>3 MeV</td>
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<tr>
<td>peak field</td>
<td>13.5 MV/m</td>
<td>18 MV/m</td>
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<tr>
<td>laser rep. rate</td>
<td>1 – 125 kHz</td>
<td>13 MHz</td>
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<tr>
<td>laser pulse length (FWHM)</td>
<td>15 ps</td>
<td>4 ps</td>
</tr>
<tr>
<td>laser spot size</td>
<td>2.7 mm</td>
<td>5.2 mm</td>
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<tr>
<td>bunch charge</td>
<td>≤ 200 pC</td>
<td>77 pC</td>
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<tr>
<td>max. aver. Current</td>
<td>1 µA</td>
<td>1 mA</td>
</tr>
<tr>
<td>peak current</td>
<td>13 A</td>
<td>20 A</td>
</tr>
<tr>
<td>transverse. norm. emittance (rms)</td>
<td>3 1 mm mrad</td>
<td>2 mm mrad</td>
</tr>
</tbody>
</table>
Treatment and test of the cavity

Tests in the vertical cryostat (1.8 K) at DESY in 2007

HPR cleaning very difficult, surface damaged after 4 vertical test at DESY improvement not expected cavity used as it was, assembly continued
3½ CELL CAVITY

Cavity performance in the gun

- maximum achievable field only 1/3 of the designed value of $E_{\text{peak}} = 50$ MV/m,
- measured $Q_0$ is 10 times lower than in all vertical tests,
- gradient is limited by field emission
- no $Q$ degradation found since the 1st measurement in 2007,
- Improvement by (9th test) high power processing (HPP) results 3 MeV operation
- After warming-up or cathode exchange the HPP must be repeated

$\frac{E_{\text{peak}}}{E_{\text{acc}}} = 2.7$
Energy and energy spread @ 5 pC (w/o space charge)
He pressure effect on cavity frequency

SRF-gun ~230 Hz/mbar
ELBE module ~35 Hz/mbar

Lorentz force detuning

SRF-gun $K = 0.69 \text{ Hz/(MV/m)}^2$
ELBE module $K = 0.25 \text{ Hz/(MV/m)}^2$
(with respect to peak fields)
New “High Gradient” Cavity

**Improvements**
- higher stiffness of the half-cell back wall microphonics, Lorentz force detuning
- larger opening in choke and partly in half-cell better HPR cleaning
- new pick-up antenna design, etc.
- simpler clean-room assembly
New “High Gradient” Cavity

Fabricated in collaboration with JLab, thanks to P. Kneisel

now: warm tuning @ JLab
next: warm rf measurements @ FZD
    cleaning & test @ JLab
Cs₂Te PHOTO CATHODES

Photo Cathode Transfer System

Photo cathode preparation equipment at FZD

Ø10 mm Cs₂Te cone for positioning & thermal contact

bayonet fixing

pressure spring

Institute of Radiation Physics • Jochen Teichert • www.fzd.de • Forschungszentrum Dresden-Rossendorf
Use of semiconductor photo cathodes like Cs$_2$Te requires a UHV exchange system with $<10^9$ mbar
UV CW Laser system delivered by MBI

Laser upgrade 2010
(0.5 W @ 262 nm)

Two oscillators
13 MHz:
Nd:glass oscillator (26 mHz)
3 ps FWHM Gaussian
500, 250, 125 kHz:
Nd:YLF oscillator (26 mHz)
14 ps FWHM Gaussian

one amplifier
Nd:YLF multipass amplifier
10-20 W

two UV converters
two-stage frequency converters (LBO, BBO)
Upgrade of the laser beam line & virtual cathode

remote-controlled laser spot size setting (telescope & aperture)
Measurement of laser profile, position, and power on the virtual cathode screen
Radiation Source ELBE
diagnostics beamline designed and built by HZB (BESSY) Berlin
- Laser input port, Solenoid
- Current & Charge (Faraday-cup & ICTs)
- Transverse Emittance (slit mask, solenoid scan)
- Energy and $\Delta E$ (C-bent)
- Bunch length (Cherenkov radiator with optical beamline and streak camera, electro-optical sampling)
Installation of electron beamline to ELBE was finished in winter shutdown 2009/10

First accelerated SRF gun beam at ELBE on Febr. 5, 2010
5 MeV energy increase
Compared to thermionic injector
3 MeV from SRF gun,
2 MeV from on-crest injection
SUMMARY

In 2009

• Upgrade of the cathode transfer system: sufficient vacuum, backing during ELBE operation
• Installation of the beam line to ELBE
• Commissioning of the Cherenkov station for bunch length measurements
• Spectrometer for slice emittance measurements delivered
• Design upgrade and fabrication of two new “high gradient” cavities

Outstanding and planned for 2010

• Demonstration of ELBE injection
• Preparation and Test of the new cavities at JLab
• Demonstration of high-current operation with 13 MHz laser & PC >1% QE
• Systematic experimental studies of HOM excitation in the gun
• Measurements & Optimization to find the bunch charge limit at 3 MeV
• First ELBE user beam with SRF gun
Acknowledgement

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