RF Electron Gun

Lecture No. 2:
Design, Simulation and Construction of RF Gun

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Lecture Outline

Lecture No. 1
- Electron accelerators and sources
- Types of electron guns
- Benefits of RF electron guns

Lecture No. 2
- Design and construction of RF gun
- Low power tests and tuning of RF gun
- RF power source and high power tests

Lecture No. 3
- Operation of RF electron gun
- Generation and applications of ultra short electron bunches produced by RF gun
Lecture No. 2

- **Design and Construction of RF Gun**
  - Design and simulation of RF gun
  - Fabrication of RF gun

- **Low Power Tests and Tuning of RF Gun**
  - Low power tests and RF measurements
  - Tuning of RF gun

- **RF Power Source and High Power Tests**
  - Introduction to RF source, transmission and coupling system required for RF gun
  - High power tests and conditioning of RF gun

- **High Power Tests and Commissioning of RF Gun**
  - Conditioning of RF gun
  - Cathode preparation
Steps of accelerator design:

1. Define basic parameters
2. Design machine layout and optics
3. Analysis of local and global properties
   Evaluation of performance
4. Stability of beams
5. Geometry and construction

Werner Herr, CERN, AB Department
➢ The cell radius cell \( r_{cell} \) is obtained from resonant frequency.
➢ The cell length \( l \) is calculated from RF wavelength.
➢ Introduce the cavity "reentrant" or "nose cone" with the gap width \( g \) and radius \( r_N \) to increase the transit time factor for better acceleration.
➢ The beam pipe radius \( r_b \) is determined from beam dynamics considerations.
➢ The rounded outer wall radius \( r_2 \) minimizes the ratio of cavity surface to volume and thus optimizes the Q-value.

Examples of RF coupling mechanism to $\text{TM}_{010}$ cavity

a) Aperture or electromagnetic coupling
b) Probe or electric coupling
c) Loop or magnetic coupling

RF Input Coupling (2)


http://pitz.desy.de/
- Half-cell and full-cell are $\pi$ excitation mode
- Side-coupling cavity leads the whole RF-gun to $\pi/2$ excitation mode
Femtosecond electron bunches from an RF-gun

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\textsuperscript{b}Laboratorio Nacional de Luz Sincrotron, LNLS, Campinas, Brazil
\textsuperscript{c}Applied Physics and SSRL, SLAC Stanford University, Stanford, CA, USA

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Available online 29 July 2004
SUPERFISH (LANL) was used to study:
- Shape optimization
- RF-parameters
- Accelerating field distribution

2D internal geometry and SUPERFISH computed electric field vectors of the one and half cells RF-gun (only half of the RF-gun cross-section is shown).
Parameters for the design RF-gun

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HC</th>
<th>FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity length (mm)</td>
<td>32.1</td>
<td>58.1</td>
</tr>
<tr>
<td>Effective length (mm)</td>
<td>25.1</td>
<td>38.7</td>
</tr>
<tr>
<td>Radius (mm)</td>
<td>24.64</td>
<td>24.64</td>
</tr>
</tbody>
</table>
Beam Dynamic Study

**PARMELA (LANL)**
- Track particles through RF-fields obtained from SUPERFISH
- Solve Maxwell’s equations for EM field including space charge effect
- Results show both longitudinal and transverse distributions

**BCompress (H. Wiedemann)**
- Study beam dynamics from gun exit to experimental stations
- Determine locations of experimental stations, electron bunch length, bunch charge, peak current

**Beam Optics (H. Wiedemann)**
- Simulate beam optics in the alpha magnet, linac and other components
- Used to optimize the electron beam size through the beam line

S. Rimjaem et al., Nucl. Inst. And Meth. A 533, 2004
In a **thermionic RF gun**, electrons are continuously emitted by the cathode but can only be extracted and accelerated during half an RF cycle with a large phase.

→ The electron pulse that can exit the cavity is long (~1/4 of RF period) and has a very large energy spread.
Longitudinal Beam Dynamics (1)

Electron distribution @ Cathode (100% particles)
Electron distribution @ End of HC (~25.7% particles available)
Electron distribution @ Gun Exit (22.7% particles available)
Nose-cone @ cathode
- divergence ~10 mrad
- limit bunch length ~120 fs

CMU RF-gun
- flat cathode
- bigger iris radius
- divergence ~1 mrad
- $\epsilon_{n,rms} \sim 3.8$ mm-mrad
- bunch length ~53 fs
Gun design + Beamline design

Main keys for gun design
- Flat cathode, increase iris aperture for reduction of beam divergence
- Increase HC length

Other main keys
- Magnetic bunch compressor
- Optimization of beamline specifications
Optimization for Production of Short Bunches (2)

RF Electron Gun
S. Rimjaem

Experimental station
Linear accelerator (linac)

1-1/2 cell RF gun
RF input port

Alpha magnet
Energy slits

Thermionic cathode

100,000 simulated macroparticles per bunch with cathode current of 2.9 A and each macroparticle represents a charge of 10.15 fC or $6.34 \times 10^4$ electrons

at experimental station ($l_b \sim 53$ fs)

at RF-gun exit ($l_b \sim 10$ ps)

at $\alpha$-magnet exit
## RF Gun & Beam Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design RF-gun</th>
<th>RF-gun as built</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity length of HC/FC (mm)</td>
<td>32.1 / 58.1</td>
<td>31.6 / 57.2</td>
</tr>
<tr>
<td>Effective length of HC/FC (mm)</td>
<td>25.1 / 38.7</td>
<td>24.9 / 39.2</td>
</tr>
<tr>
<td>$f_{\text{rf}}$ of HC/FC (MHz)</td>
<td>2863.6 / 2825.0</td>
<td>2880.6 / 2868.8</td>
</tr>
<tr>
<td>$Q_0$ of HC/FC</td>
<td>15263 / 13022</td>
<td>15692 / 13343</td>
</tr>
<tr>
<td>$\beta = \frac{v}{c}$ at gun exit</td>
<td>0.9851</td>
<td>0.9849</td>
</tr>
<tr>
<td>Max. kinetic energy (MeV)</td>
<td>2.45</td>
<td>2.44</td>
</tr>
<tr>
<td>Ave./max. field in HC (MV/m)</td>
<td>23.9 / 29.9</td>
<td>22.7 / 28.7</td>
</tr>
<tr>
<td>Ave./max. field in FC (MV/m)</td>
<td>45.0 / 67.6</td>
<td>46.9 / 68.5</td>
</tr>
<tr>
<td>Ave. field ratio</td>
<td>1.88</td>
<td>2.07</td>
</tr>
<tr>
<td>Max. field ratio</td>
<td>2.26</td>
<td>2.39</td>
</tr>
<tr>
<td>Cathode radius (mm)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Cathode emission current (A)</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Cathode current density (A/cm²)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Charge per bunch @ experiment (pCb)</td>
<td>94</td>
<td>94</td>
</tr>
<tr>
<td>Peak current @ experiment (A)</td>
<td>707</td>
<td>682</td>
</tr>
<tr>
<td>Bunch length, rms @ experiment (fs)</td>
<td>53</td>
<td>55</td>
</tr>
</tbody>
</table>
SUPERFISH 7.19: 2D simulations

CST Microwave Studio 2012@: 3D simulations

PARMELA distribution @ gun exit

5 cm after gun exit
RF study and 3-D simulations of a side-coupling thermionic RF-gun

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\textsuperscript{b} Thailand Center of Excellence in Physics (ThEP), Commission on Higher Education, Bangkok 10400, Thailand
### Electric field distributions

#### 3-D CST MWS RF-gun Model (1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>3-D model</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{\pi/2}$</td>
<td>2856.4 MHz</td>
<td>2856 MHz @ 27.5°C</td>
</tr>
<tr>
<td>$Q_o$</td>
<td>15272</td>
<td>12979</td>
</tr>
<tr>
<td>$Q_l$</td>
<td>2074</td>
<td>1586</td>
</tr>
<tr>
<td>$Q_{ext}$</td>
<td>2400</td>
<td>1741</td>
</tr>
<tr>
<td>$\beta_{rf}$</td>
<td>6.36</td>
<td>7.3</td>
</tr>
<tr>
<td>$E_{p2}/E_{p1}$</td>
<td>1.98</td>
<td>2.00</td>
</tr>
<tr>
<td>$&lt;E_2&gt;/&lt;E_1&gt;$</td>
<td>1.69</td>
<td>1.73</td>
</tr>
</tbody>
</table>
Magnetic field distributions in xy-plane @ $z = 0, 20, 41, 58$ mm

@ gun exit (emit. Increases 10.8%)

@ 5 cm after gun exit (emit. Increases 17.2%)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>SUPERFISH field</th>
<th>MWS field</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. field in half cell ($E_1$)</td>
<td>25.91</td>
<td>25.91</td>
<td>MV/m</td>
</tr>
<tr>
<td>Max. field in half cell ($E_{p1}$)</td>
<td>31.91</td>
<td>31.80</td>
<td>MV/m</td>
</tr>
<tr>
<td>Ave. field in full cell</td>
<td>44.82</td>
<td>43.78</td>
<td>MV/m</td>
</tr>
<tr>
<td>Max. field in full cell</td>
<td>64.29</td>
<td>62.86</td>
<td>MV/m</td>
</tr>
<tr>
<td>Ave. field ratio ($E_2/E_1$)</td>
<td>1.73</td>
<td>1.69</td>
<td></td>
</tr>
<tr>
<td>Max. field ratio ($E_{p2}/E_{p1}$)</td>
<td>2.00</td>
<td>1.98</td>
<td></td>
</tr>
<tr>
<td>Ave. beam kinetic energy</td>
<td>1.96</td>
<td>1.94</td>
<td>MeV</td>
</tr>
<tr>
<td>Max. beam kinetic energy</td>
<td>2.53</td>
<td>2.49</td>
<td>MeV</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>0.21</td>
<td>0.21</td>
<td>nC</td>
</tr>
<tr>
<td>Horizontal centroid position</td>
<td>0.028</td>
<td>0.846</td>
<td>mm</td>
</tr>
<tr>
<td>Vertical centroid position</td>
<td>−0.032</td>
<td>−0.575</td>
<td>mm</td>
</tr>
<tr>
<td>Horizontal rms beam size</td>
<td>1.145</td>
<td>1.154</td>
<td>mm</td>
</tr>
<tr>
<td>Vertical rms beam size</td>
<td>1.146</td>
<td>1.183</td>
<td>mm</td>
</tr>
<tr>
<td>Horizontal rms emittance</td>
<td>16.25</td>
<td>17.79</td>
<td>mm · mrad</td>
</tr>
<tr>
<td>Vertical rms emittance</td>
<td>16.25</td>
<td>18.21</td>
<td>mm · mrad</td>
</tr>
</tbody>
</table>
On-axis electric field distributions

Longitudinal particle distributions
Rotate side-coupling cavity from horizontal coupling to be vertical coupling
Vertical On-axis Side-coupling Cavity RF-gun (1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant frequency in $\pi/2$-mode ($f_{\pi/2}$)</td>
<td>2855.8 MHz</td>
</tr>
<tr>
<td>Unloaded quality factor ($Q_0$)</td>
<td>15,271</td>
</tr>
<tr>
<td>Loaded quality factor ($Q_l$)</td>
<td>2053</td>
</tr>
<tr>
<td>External quality factor ($Q_{ext}$)</td>
<td>2372</td>
</tr>
<tr>
<td>RF-coupling coefficient ($\beta_{rf}$)</td>
<td>6.44</td>
</tr>
<tr>
<td>Peak electric field ratio ($E_{p2}/E_{p1}$)</td>
<td>2.00</td>
</tr>
<tr>
<td>Average electric field ratio ($E_2/E_1$)</td>
<td>1.72</td>
</tr>
</tbody>
</table>
Magnetic field distributions in xy-plane @ z = 0, 20, 41, 58 mm

gun exit (emit. Increases 0.9%) 5 cm after gun exit (emit. Increases 0.7%)
### Improvement of Transverse Phase Space Distribution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SUPERFISH</th>
<th>H-coupling</th>
<th>V-coupling</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{E_{p2}}{E_{p1}} )</td>
<td>2.00</td>
<td>1.98</td>
<td>2.01</td>
<td></td>
</tr>
<tr>
<td>( \frac{\langle E_2 \rangle}{\langle E_1 \rangle} )</td>
<td>1.73</td>
<td>1.69</td>
<td>1.72</td>
<td></td>
</tr>
<tr>
<td>( \langle E_1 \rangle )</td>
<td>25.91</td>
<td>25.91</td>
<td>25.91</td>
<td>MV/m</td>
</tr>
<tr>
<td>( \langle E_2 \rangle )</td>
<td>44.82</td>
<td>43.78</td>
<td>44.56</td>
<td>MV/m</td>
</tr>
<tr>
<td>( E ) @ cathode</td>
<td>31.91</td>
<td>31.80</td>
<td>31.41</td>
<td>MV/m</td>
</tr>
<tr>
<td>Max. kinetic energy</td>
<td>2.53</td>
<td>2.49</td>
<td>2.51</td>
<td>MeV</td>
</tr>
<tr>
<td>Mean kinetic energy</td>
<td>1.96</td>
<td>0.94</td>
<td>1.96</td>
<td>MeV</td>
</tr>
<tr>
<td>X-centroid position</td>
<td>0.028</td>
<td>0.846</td>
<td>0.027</td>
<td>mm</td>
</tr>
<tr>
<td>Y-centroid position</td>
<td>-0.032</td>
<td>-0.575</td>
<td>0.250</td>
<td>mm</td>
</tr>
<tr>
<td>Xrms beam size</td>
<td>1.145</td>
<td>1.154</td>
<td>1.163</td>
<td>mm</td>
</tr>
<tr>
<td>Yrms beam size</td>
<td>1.146</td>
<td>1.183</td>
<td>1.118</td>
<td>mm</td>
</tr>
<tr>
<td>X-emittance @ gun exit</td>
<td>16.25</td>
<td>17.79</td>
<td>15.80</td>
<td>mm-mrad</td>
</tr>
<tr>
<td>Y-emittance @ gun exit</td>
<td>16.25</td>
<td>18.21</td>
<td>17.22</td>
<td>mm-mrad</td>
</tr>
<tr>
<td>X-emittance @ 5 cm</td>
<td>10.89</td>
<td>12.07</td>
<td>10.25</td>
<td>mm-mrad</td>
</tr>
<tr>
<td>Y-emittance @ 5 cm</td>
<td>10.82</td>
<td>12.68</td>
<td>11.33</td>
<td>mm-mrad</td>
</tr>
</tbody>
</table>
Lecture No. 2

- **Design and Construction of RF Gun**
  - Principle, design and simulation of RF gun
  - **Fabrication of RF gun**
- **Low Power Tests and Tuning of RF Gun**
  - Low power RF measurements
  - Tuning of RF gun
- **RF Power Source and High Power Tests**
  - Introduction to RF source, transmission and coupling system required for RF gun
  - High power tests and conditioning of RF gun
- **High Power Tests and Commissioning of RF Gun**
  - Conditioning of RF gun
  - Cathode preparation
Normal conducting RF cavities are typically made of Oxygen Free High Conductivity copper (OFHC copper) due to its strength, hardness, high conductivity.

Connections, flanges and vacuum components

- Stainless steel
- Copper plating of stainless steel (for area where contact to the RF field)

Superconducting RF cavities are made of Niobium

Table 1: Some characteristics of metals

<table>
<thead>
<tr>
<th></th>
<th>el. cond.</th>
<th>density</th>
<th>yield strength ($R_p \ 0.2%$)</th>
<th>tensile strength</th>
<th>Brinell hardness</th>
<th>melting temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MS m$^{-1}$</td>
<td>g/cm$^3$</td>
<td>MPa</td>
<td>MPa</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>Ag</td>
<td>62.6</td>
<td>10.5</td>
<td>30</td>
<td>130…160</td>
<td>15…36</td>
<td>960.5</td>
</tr>
<tr>
<td>Cu soft</td>
<td>59</td>
<td>8.94</td>
<td>100…150</td>
<td>200 … 250</td>
<td>40 … 50</td>
<td>1083</td>
</tr>
<tr>
<td>Cu hard</td>
<td>55</td>
<td>8.8</td>
<td>300…450</td>
<td>400 … 490</td>
<td>80 … 120</td>
<td></td>
</tr>
<tr>
<td>Cu-OF</td>
<td>58</td>
<td>8.92</td>
<td>70…360</td>
<td>220…450</td>
<td>50…100</td>
<td>1083</td>
</tr>
<tr>
<td>CuZr</td>
<td>53.8</td>
<td>8.89</td>
<td>42…500</td>
<td>200…530</td>
<td></td>
<td>980</td>
</tr>
<tr>
<td>Cu-Al$_2$O$_3$</td>
<td>49.3</td>
<td>8.8</td>
<td>410…560</td>
<td>480…580</td>
<td></td>
<td>1080</td>
</tr>
<tr>
<td>Au</td>
<td>45.4</td>
<td>19.29</td>
<td>100…300</td>
<td>13…75</td>
<td></td>
<td>1063</td>
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<tr>
<td>Al</td>
<td>38</td>
<td>2.7</td>
<td>25…200</td>
<td>70…250</td>
<td>15 … 70</td>
<td>658</td>
</tr>
<tr>
<td>Mo</td>
<td>20.8</td>
<td>10.2</td>
<td>400</td>
<td>700…1200</td>
<td>150</td>
<td>2630</td>
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<tr>
<td>W</td>
<td>18.2</td>
<td>19.3</td>
<td>1500</td>
<td>400…4000</td>
<td>250</td>
<td>3380</td>
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<tr>
<td>Pd</td>
<td>9.8</td>
<td>11.97</td>
<td>200…400</td>
<td>40…100</td>
<td></td>
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<td>Nb</td>
<td>6.6</td>
<td>8.57</td>
<td>500</td>
<td>120</td>
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<td>2477</td>
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<tr>
<td>SS 316LN</td>
<td>1.1</td>
<td>7.9</td>
<td>300</td>
<td>600</td>
<td>180</td>
<td>1350</td>
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</tbody>
</table>

There are several techniques for machining the RF gun and its components. → To choose the technique, one should consider required surface properties, e.g. tolerance, surface finish, contamination from other materials.

<table>
<thead>
<tr>
<th>Surface finish</th>
<th>N8</th>
<th>N7</th>
<th>N6</th>
<th>N5</th>
<th>N4</th>
<th>N3</th>
<th>N2</th>
<th>N1</th>
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<tbody>
<tr>
<td>$Ra$ (μm)</td>
<td>3.2</td>
<td>1.6</td>
<td>0.8</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
<td>0.05</td>
<td>0.025</td>
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<td>polishing</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rule of thumb: $Ra$ should not exceed a quarter of the skin-depth.

Example: Fabrication of CMU RF-gun

RF cavities and related components

- Oxygen Free High Conductivity copper (OFHC copper)
- CNC machining
Joining Techniques

- **TIG (tungsten inert gas)** welding is characterized by the use of an inert gas (Ar) flow to shield the heated area around the joint from the oxidizing atmosphere.
- **EBW (electron-beam welding)** uses a finely (sub mm) focused electron beam to vaporize the work-piece near the joint to be.
- **Diffusion bond** is created between smooth surfaces.
- **Vacuum brazing** is the preferred brazing technique.
  - Different brazing alloys behave differently when becoming liquid.

Cells of an S-band structure being stacked inside a vacuum brazing furnace.

RF-gun forming
- Welding (SST components)
- High temperature brazing in free-O$_2$ environments

SST welding

High temperature brazing

Lower temperature brazing

completed RF gun
Example: **CMU Cathode Assembly**

![Diagram of CMU Cathode Assembly with a length of 53 mm]
Fresh cathode

**Thermionic cathode** *(Heat Wave Labs, Ins)*
- Dispenser tungsten cathode coated with Os/Ru
- Flat circular emitting surface of 3 mm radius

Used cathode
(Some damage from electron back-bombardment)
Lecture No. 2

- Design and Construction of RF Gun
  - Principle, design and simulation of RF gun
  - Fabrication of RF gun
- Low Power Tests and Tuning of RF Gun
  - Low power RF measurements
  - Tuning of RF gun
- RF Power Source and High Power Tests
  - Introduction to RF source, transmission and coupling system required for RF gun
  - High power tests and conditioning of RF gun
- High Power Tests and Commissioning of RF Gun
  - Conditioning of RF gun
  - Cathode preparation
RF frequency measurements
- Using network analyzer
- Typical input RF-power level = 1 dB

Field ratio measurement & tunings (for multicell RF gun)
- Field ratio between each cell is defined according to the application goals.
Field Ratio Optimizations

Semi-monochromatic beam (good for application which required low energy spread)

Energy-time linear correlation (good for bunch compression in alpha magnet)
Example: RF gun tuning @ PITZ, DESY: Tuning device can be used to push and pull the cavity walls.
RF-measurements
- Before and after the RF-gun brazing process
- Using network analyzer
- Input RF-power level = 1 dB (10 mW)
- RF-power input port → waveguide at FC
- Output pick up port → vacuum port at HC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{rf}$ of HC/FC (MHz)</td>
<td>2854.6 / 2858.3</td>
</tr>
<tr>
<td>$f_{rf}$ of whole gun (MHz)</td>
<td>2855.3</td>
</tr>
</tbody>
</table>
Identification of the half-power points from the Smith Chart representation showing seven frequencies \( (f_0, f_1, f_2, f_3, f_4, f_5 \text{ and } f_6) \). \( Q_0 \) locus is given by \( x = r \), \( Q_L \) by \( x = r \pm 1 \) and \( Q_{\text{ext}} \) by \( x = \pm 1 \).

The quality factors are

\[
Q_0 = \frac{f_0}{f_1 - f_2}, \quad Q_{\text{ext}} = \frac{f_0}{f_3 - f_4}, \quad Q_L = \frac{f_0}{f_5 - f_6}
\]

The RF coupling coefficient can be calculated from

\[
\beta_{rf} = \frac{Q_0}{Q_{\text{ext}}}
\]
Results of RF Measurements Using Smith Chart

Unloaded quality factor ($Q_0$)                             12,979
Loaded quality factor ($Q_l$)                              1586
External quality factor ($Q_{ext}$)                        1741
RF-coupling coefficient ($\beta_{rf}$)                      7.3

\[ Q_0 = \frac{f_0}{f_1 - f_2}, \quad Q_{ext} = \frac{f_0}{f_3 - f_4}, \quad Q_L = \frac{f_0}{f_5 - f_6} \]

\[ \beta_{rf} = \frac{Q_0}{Q_{ext}} \]
Schematic diagram of the bead-pull set-up.

**Slater’s Perturbation**

$$\frac{\Delta \omega}{\omega} = \frac{\Delta U_M - \Delta U_E}{U} = \frac{\int_V (\mu H^2 - \varepsilon E^2) dV}{\int_V (\mu H^2 + \varepsilon E^2) dV}$$

**Bead-pull measurement**

- 2.36 mm diameter dielectric bead
- Resonant frequency shift: $E_z \alpha \sqrt{\Delta \omega} = \sqrt{f - f_0}$
Field Ratio Adjustment

On-axis RF gun (adjusting the length of both cells)

Separate RF input ports
e.g., Tohoku RF gun

e.g., PITZ RF gun

Side-coupling RF gun

e.g., CMU RF gun
Measured on-axis electric field distribution inside the RF-gun.

\[ E_{p2} \over E_{p1} = 2.00 \quad \frac{E_{\text{ave,2}}}{E} = 1.73 \]

Measured field ratio vs. the tuning rod position.
Summary of RF Parameters of RF Gun

Measured RF-parameters of the RF-gun in $\pi/2$ operation mode obtained from the low-power RF-measurements. The measurements were performed at the room temperature of 25 °C and in ambient air.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant frequency in $\pi/2$- mode ($f_{\pi/2}$)</td>
<td>2855.3 MHz</td>
</tr>
<tr>
<td>Frequency separation between $\pi/2$ and $\pi$ modes</td>
<td>7.9 MHz</td>
</tr>
<tr>
<td>Unloaded quality factor ($Q_o$)</td>
<td>12,979</td>
</tr>
<tr>
<td>Loaded quality factor ($Q_l$)</td>
<td>1586</td>
</tr>
<tr>
<td>External quality factor ($Q_{ext}$)</td>
<td>1741</td>
</tr>
<tr>
<td>RF-coupling coefficient ($\beta_{rt}$)</td>
<td>7.3</td>
</tr>
<tr>
<td>Peak field ratio ($E_{p2}/E_{p1}$)</td>
<td>2.00</td>
</tr>
<tr>
<td>Average field ratio ($E_2/E_1$)</td>
<td>1.73</td>
</tr>
</tbody>
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- **Commissioning of RF Gun**
  - Conditioning of RF gun
  - Cathode preparation
RF System for CMU RF Gun

- Oscillator
- Tank
- 90° hybrid directional coupler
- Phase shifter

Diagram:
- Oscillator
- -3dB Hybrid directional coupler
- Amplifier
- Klystron
- Modulator+PFN
- 5 MW peak power
- Circulator
- Waveguides
- Oscilloscope
- Crystal detector
- Attenuator
- RF Gun
- Directional coupler

Equations:

- Oscillator
- Tank
- 90° hybrid directional coupler
- Phase shifter
High Power RF Source

RF out
Absorber
Output cavity
Modulated electron
Bunching cavity
Electron gun

www2.slac.stanford.edu/vvc/accelerators/klystron.html

Gun PFN
RF Gun Klystron
Linac PFN
Linac Klystron
Main Power Supply

www2.slac.stanford.edu/vvc/accelerators/klystron.html
RF-gun Temperature and Thermal expansion

RF power signal vs. time at different gun temperatures.

Cavity absorption power $\sim 1.46$ MW

Frequency de-tuned of 362 kHz (small cavity absorption)

\[ \frac{\Delta f}{\Delta T} \approx -\frac{2.405 c}{2\pi a} \alpha \]
\[ \approx -48.3 \text{ kHz/}^\circ\text{ C} \]
The RF-coupling coefficient ($\beta_{rf}$) can be determined from the input ($P_i$) and reflected ($P_r$) power measurements in the steady state as in formula:

$$\beta_{rf} = \frac{1 \pm \sqrt{P_r/P_i}}{1 \mp \sqrt{P_r/P_i}}$$

RF signal in the first cell of Tohoku RF gun
The RF-coupling coefficient ($\beta_{rf}$) can be determined from the input ($P_i$) and reflected ($P_r$) power measurements in the steady state as

$$
\beta_{rf} = \frac{1 \pm \sqrt{P_r/P_i}}{1 + \sqrt{P_r/P_i}}
$$

High-power RF parameters, typical operating condition and electron beam-loading parameters of the PBP-CMU RF-gun.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant frequency in $\pi/2$-mode</td>
<td>2856</td>
<td>MHz</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>27.5</td>
<td>°C</td>
</tr>
<tr>
<td>Input RF peak power</td>
<td>3.55</td>
<td>MW</td>
</tr>
<tr>
<td>Dissipation RF power</td>
<td>1.36</td>
<td>MW</td>
</tr>
<tr>
<td>External RF-coupling coefficient</td>
<td>8.3</td>
<td></td>
</tr>
</tbody>
</table>

Questions
&
Discussion