Photoinjector SRF Cavity Development for BERLinPro

THPB066 (+ THPB069, T. Kamps et al.)

Axel Neumann
W. Anders, T. Kamps, J. Knobloch
E. Zaplatin (FZ Jülich)
LINAC12, 13.09.2012
Tel Aviv, Israel
(current) Layout of BERLinPro

<table>
<thead>
<tr>
<th>Basic Mode</th>
<th>Short Bunch Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch charge, pC</td>
<td>77</td>
</tr>
<tr>
<td>Bunch repetition rate, GHz</td>
<td>1.3</td>
</tr>
<tr>
<td>Max average current, mA</td>
<td>100</td>
</tr>
<tr>
<td>Beam kinetic energy, MeV</td>
<td>50</td>
</tr>
<tr>
<td>Transv. emitt., norm., mm mrad</td>
<td>~ 1</td>
</tr>
<tr>
<td>Bunch length, ps, rms</td>
<td>2.0</td>
</tr>
<tr>
<td>Relative energy spread, % rms</td>
<td>~ 0.5</td>
</tr>
</tbody>
</table>

- **Gun:**
  - 0.4-1.4 cell
  - SC cavity + NC cathode

- **Booster:**
  - 3 two cell
  - SC cavities

- **Main linac:**
  - 3 seven cell
  - SC cavities

- **Recirculator

- **Dump

- **Merger

LINAC12, 13.09.12, Tel Aviv, A. Neumann, THPLB12
Site for BERLinPro

2854,901 km North-West of Tel Aviv

Metrology Light Source

BERLinPro

HoBiCaT + Undulator development

BESSY II

BERLinPro LAGEPLAN
Stefan Heßler
Dipl. Ing. (FH)
Architekt
08.11.11

Lageplan Grundlage ist der Lageplan des Vermessungsbüros R&S, Rek & Dr. Schwenk vom Oktober 2011
BERLinPro: Cavity types and operating conditions

- **High beam power**
- **High beam current**
- **Intermediate field levels**

1. **SRF Photo-injector**
   - 1.5-2 MeV, 100 mA
   - High beam power
   - High beam current
   - Intermediate field levels
   - 12 MV/m

2. **SRF booster cavity (Cornell)**
   - High beam power
   - High beam current
   - Intermediate field levels
   - 10 MV/m

   → Beam pipe absorber

3. **SRF CW Mode machine**
BERLinPro: Cavity types and operating conditions

- High beam power
- High beam current
- Intermediate field levels

1.5-2 MeV, 100 mA
- High beam power
- High beam current
- Intermediate field levels
12 MV/m
→ Beam pipe absorber

SRF booster cavity (Cornell)
- High beam power
- High beam current
- Intermediate field levels
10 MV/m
→ Beam pipe absorber

SRF Photo-injector

+4.5 MeV (100 mA)

SRF CW Mode machine
BERLinPro: Cavity types and operating conditions

- High beam power
- High beam current
- Intermediate field levels 10 MV/m
  - Beam pipe absorber

Main linac cavity
- Low beam power
- High beam current
- Higher field levels 19 MV/m
- Multi-pass beam
  - JLAB style waveguide absorber

+45 MeV (2x 100 mA, recovered)

SRF booster cavity (Cornell)
- High beam power
- High beam current
- Intermediate field levels 10 MV/m
  - Beam pipe absorber

+4.5 MeV (100 mA)

SRF Photo-injector

- 1.5-2 MeV, 100 mA
  - High beam power
  - High beam current
  - Intermediate field levels 12 MV/m
  - Beam pipe absorber

Main linac cavity

THPB066
THPB069

MOPB067

SRF CW Mode machine

LINAC12, 13.09.12, Tel Aviv, A. Neumann, THPLB12
Requirements for BERLinPro: Staged approach

Gun 0: Objective: Beam dynamics studies
see T. Kamps et al. IPAC11, A. Neumann et al. IPAC11
Design: J. Sekutowicz (DESY)

Gun 1: What do we aim for?

Objective for peak brightness:
Insert a NC high QE cathode in a SC environment, demonstrate some mA beam current: Cathode studies, insert design, choke filter studies
→ 3-D RF and thermo-mechanical calculations, multipacting studies
→ Insert + choke layout (HZDR Design)

Objective for beam dynamics:
Optimize beam dynamics to meet BERLinPro requirements,
combined Superfish/CST design studies including feedback by ASTRA based beam dynamic calculations
→ Cavity shape

Followed by: Design coupler section, calculations of coupler kicks,
full 3-D studies with HOM and multipacting calculations
Tuning and field flatness studies (E. Zaplatin, FZ Jülich)
Some Limits and Objectives:

- Power limit about 230 kW by 2 FPCs (KEK style)
- Maximum field amplitude ≤ 40-45 MV/m ($E_{\text{peak}}$)?
- HOM damping

- $E_{\text{kin}}>2$ MeV, $I_b=100$ mA, $\varepsilon_n<1$ mm mrad

- **Aim at:**
  - $E_{\text{peak}}/E_0$ minimized (avoid Field emission)
  - $E_{\text{cathode}}<E_0$ (avoid Dark current)
  - $E_{\text{launch}}=E_{\text{cathode}} \cdot \sin(\Phi)$ maximized (avoid Space charge effects)
  - $\Phi$ close to on-crest
  - High $\Phi_{\text{opt}}$ reduces $E_0!$
Cavity design flow

Optimize for
1. Beam dynamics
2. HOM properties
3. SRF parameters

Tune frequency by Golden Section Search Optimizer

Calculate Cavity parameter

Energy-phase-field scan

Power limit met?

Results

2-D studies: 0.X-cell

Change geometry parameter

Analyze results, Parameter scan Optimizer

External ASTRA scans beam dynamics group T. Kamps

Need for?
- RF focusing
- Launch phase
- Launch field

Field distributions

\( E_z, E_r \)

Results 2D studies: 0.X-cell

T. Kamps

External

Beam dynamics

HOM properties

SRF parameters

Results

Need for?
- RF focusing
- Launch phase
- Launch field

Field distributions

\( E_z, E_r \)
Half-cell optimization: Length scan, velocity and transit time effects

Operating conditions: 0.4 cell

- Launch phase 18 degrees, $E_0 = 30$ MV/m, $E_{cathode} = 24$ MV/m
- Energy gain 1.2 MeV, $E_{acc} = 26$ MV/m
- Launch field $E_{launch} = 24$ MV/m $\times \sin(18) = 7.42$ MV/m
- $E_{peak} = 30$ MV/m $\times 1.35 = 40.5$ MV/m
- $P_{forward} = 120$ kW at minimum
Optimized half-cell: 0.4 cell vs. 1.4 cell

Design field

- Phase with max. energy gain

Even under limited RF power boundary condition:
1. X beats 0. X cell design
Operating conditions: 0.4 cell vs. 1.4 cell

Typical design parameters:

- $R/Q = 90 \ \Omega$
- $H_{\text{peak}}/E_{\text{peak}} = 2.3 \ \text{mT}/(\text{MV/m})$
- $E_{\text{peak}}/E_0 = 1.3$
- $E_{\text{cath}}/E_0 = 0.7-0.9$

with operating parameters:

- $E_{\text{kin}} = 1.2 \ \text{MeV}$ at:
  - $E_0 = 30 \ \text{MV/m}$
  - $\phi_{\text{launch}} = 18 \ \text{deg}$
  - $E_{\text{launch}} = 7.4 \ \text{MV/m}$
  - $E_{\text{cathode}} = 24 \ \text{MV/m}$

at best:

- $E_{\text{kin}} = 1.6 \ \text{MeV}$ at:
  - $E_0 = 40 \ \text{MV/m}$
  - $\phi_{\text{launch}} = 24 \ \text{deg}$
  - $E_{\text{launch}} = 13.0 \ \text{MV/m}$
  - $E_{\text{cathode}} = 32 \ \text{MV/m}$

Typical design parameters:

- $R/Q = 150 \ \Omega$
- $H_{\text{peak}}/E_{\text{peak}} = 2.2 \ \text{mT}/(\text{MV/m})$
- $E_{\text{peak}}/E_0 = 1.5$
- $E_{\text{cath}}/E_0 = 0.7-0.9$

with operating parameters:

- $E_{\text{kin}} = 2.4 \ \text{MeV}$ at:
  - $E_0 = 30 \ \text{MV/m}$
  - $\phi_{\text{launch}} = 50 \ \text{deg}$
  - $E_{\text{launch}} = 18.4 \ \text{MV/m}$
  - $E_{\text{cathode}} = 24 \ \text{MV/m}$

**Decision:** First cavity design will be a 1.4 cell cavity

**High launch field at lower peak and cathode field, higher energy**
Design for next Gun

CW-modified TTF/XFEL Coupler (coupling compromise between 4 mA and “Q₀ operation”)

1.4 cell gun cavity

HZDR-style choke with modified cathode holder

SC Solenoid

DESY style absorber using SiC (courtesy J. Sekutowicz)

T. Noll, HZB

J. Sekutowicz
Ongoing: 3-D studies: HOM, tuning, field flatness

<table>
<thead>
<tr>
<th>$f$ (MHz)</th>
<th>$R/Q_{\parallel} (\beta = 1)$</th>
<th>$R/Q_{\parallel}$</th>
<th>$R/Q_{\parallel}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1270</td>
<td>59</td>
<td>4.9</td>
<td>0.51</td>
</tr>
<tr>
<td>1300</td>
<td>150</td>
<td>125</td>
<td>147</td>
</tr>
<tr>
<td>2403</td>
<td>16.1</td>
<td>3.0</td>
<td>14.8</td>
</tr>
<tr>
<td>2510</td>
<td>49</td>
<td>24.9</td>
<td>20.8</td>
</tr>
<tr>
<td>2663</td>
<td>36.8</td>
<td>3.5</td>
<td>0.9</td>
</tr>
<tr>
<td>2750</td>
<td>28.6</td>
<td>3.5</td>
<td>0.04</td>
</tr>
</tbody>
</table>

HOMs: Loss factor and BBU: $R/Q_{\parallel}$ and $R/Q_{\perp}$ depend on $\beta(E_0, \Phi)$!
That’s it

Thank you for your attention and many thanks to all people involved with BRLinPro:


and

A. Arnold (HZDR), P. Kneisel (JLAB), R. Nietubyc (NCBJ), J. Sekutowicz (DESY), J. Smedley (BNL), J. Teichert (HZDR), V. Volkov (BINP), I. Will (MBI), E. Zaplatin (FZ Jülich) + co-workers

For discussion visit: THPB066+THPB069 right after the exit of the Plenary Hall A