Status of the BESSY VSR Project

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Advanced Low Emittance Rings Technology (ALERT) 2016 Workshop
ELETTRA, Trieste, Italy
14-16 September 2016
1. From BESSY II to BESSY VSR
   Present Machine
   Upgrade Concept

2. Timeline

3. Beam Dynamics
   Transient beam loading and lifetime
   Booster

4. Status R&D SRF Cavities
   Overview
   Cavity Design Specifications and Challenges
   End-groups and HOM Power
   Concatenation Studies
   Prototypes
   High Power Couplers
   Testing, Bead Pulls and Infrastructure

5. Summary
From BESSY II to BESSY VSR

Machine Parameters

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<tr>
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<td>5 nm rad</td>
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<td>300 mA</td>
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<td>17 MV</td>
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<td>1.7 ps</td>
</tr>
</tbody>
</table>

Bunch length:

\[ \sigma_0 \propto \sqrt{\frac{\alpha}{V'}} \]

\[ I_{CSR} \propto \alpha \]

<table>
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<tr>
<th>( f )</th>
<th>( V )</th>
<th>( V' = \frac{dV}{dt}/2\pi )</th>
</tr>
</thead>
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<tr>
<td>500 MHz</td>
<td>1.5 MV</td>
<td>0.75 MV GHz</td>
</tr>
<tr>
<td>1.5 GHz</td>
<td>20 MV</td>
<td>30 MV GHz</td>
</tr>
<tr>
<td>1.75 GHz</td>
<td>17.1 MV</td>
<td>30 MV GHz</td>
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- short, stable, high intensity bunches (1.7 ps, 0.8 mA)
- 300 mA basic operation maintained
- impedance heating / Touschek losses mitigated
Possible BESSY VSR operations

baseline fill pattern

high rep rate short pulses / THz
($\approx 5$ kW)

low-$\alpha$ short bunch: $I \approx 0.04$ mA, $\sigma \approx 0.3$ ps (rms)
Timeline:

- since 2013: VSR Science Workshops
- 03/2015: Technical Design Study completed
- 04/2015: successful review TDS BESSY VSR
- 06/2015: application to Helmholtz Association submitted (strategic investment, 19 Mio€ + 10 Mio€ HZB)
- 10/2015: scientific evaluation of application, result: “outstanding” project
- 2016/17: ranking of all applications from all research fields, decision about funding, available budget heavily “overbooked”
- 2018: first tranche of “fresh” Helmholtz money expected
- 2020/21: start of full user operation

- Two R&D projects started (total 3 Mio€ / 3a) + 15 FTE for the full project:
  - SRF cavity + auxiliary prototyping / bunch resolved diagnostics
  - preparatory phase = 1.5 GHz module @ BII planned for 2018/19
BESSY-VSR hybrid fill with two 100 ns gaps:

<table>
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<tr>
<th>bunch number</th>
<th>I/mA</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0.8mA, 1.7ps</td>
</tr>
<tr>
<td>1</td>
<td>10mA, 27ps</td>
</tr>
<tr>
<td>10</td>
<td>3 × 5mA, 3.7ps</td>
</tr>
<tr>
<td>75</td>
<td>1.8mA, 15ps</td>
</tr>
<tr>
<td>150</td>
<td>75 × 1.8mA, 15ps</td>
</tr>
<tr>
<td>200</td>
<td>75 × 1.8mA, 15ps</td>
</tr>
<tr>
<td>250</td>
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Phase transient and bunch length simulation:

Transient beam loading:

- Changes in beam current result in phase change that cannot be compensated by the RF (insufficient power, limited bandwidth)
- Focusing gradient (and hence bunch length) of long bunches varies along the bunch train, short bunches are nearly unaffected.

→ Long bunches are shortened: **Increased Touschek losses**

- Possible solution are investigated:
  Separation by resonant island buckets, optimization of fill pattern, ...

R&D project bunch resolved diagnostics addresses challenges of complex fill pattern
Status:

- Bunches from booster rather long (80 ps)
- Low injection efficiency into short buckets expected

Ongoing booster studies (T. Atkinson):

- Low-$\alpha$? (requires splitting)
- Cavity upgrade? (extra focusing)
- Longitudinal stability
- Diagnostics improvements

Injection efficiency; measurement and expectations: (courtesy T. Atkinson)
HZB SRF R&D project (budget: 2.5 M€):

- Design, fabrication and testing of fully dressed 1.5 GHz Nb cavities
- Development of HOM loads, tuners and necessary ancillaries
- Fabrication of copper and niobium prototypes to validate the proposed RF design techniques
- Design and fabrication of high power couplers
- Development of RF sources for cavity operation
- Prototype testing and commissioning: HoBiCaT and testing hall vertical test stand.

Collaboration partners

- Helmholtz Association POF-III Topic “Accelerator Research and Development”
- External: Jefferson Lab (USA), TU Dortmund and Uni Rostock
Cavity design challenges:

- CW operation at high field levels $E = 20 \text{ MV/m}$
- Edge field values on the surface (discharges, quenching)
- High beam current (300mA), reactive beam loading
- High HOM damping (CBIs)
- Cavity fabrication processes not mature
Basic design:

Damping Technique

Choice for Waveguide Dampers:
- High power capabilities
- Natural cut-off
- Damping efficiency
- Long distance to loads (dust contamination)
- Compact option

General constraints:
- High HOM damping level required to avoid Coupled Bunch Instabilities (CBIs)
Major steps towards high HOM damping:

- Enlarged beam tubes
- Modified wave guide cross sections

Resulting impedance spectrum

\[
\frac{Z_0}{\Omega} \quad |Im| \quad Re
\]

\[
10^{-2} \quad 10^0 \quad 10^2 \quad 10^4 \quad 10^6 \quad 10^8 \quad 10^{10}
\]

\[
\frac{Z_1}{(\Omega/m)} \quad |Im| \quad Re
\]

\[
10^{-1} \quad 10^0 \quad 10^1 \quad 10^2 \quad 10^3 \quad 10^4 \quad 10^5 \quad 10^6 \quad 10^7
\]

\[
\frac{Z_2}{(\Omega/m^3)} \quad |Im| \quad Re
\]

\[
10^3 \quad 10^4 \quad 10^5 \quad 10^6 \quad 10^7 \quad 10^8 \quad 10^9 \quad 10^{10} \quad 10^{11} \quad 10^{12}
\]

\[
f/GHz
\]

\[
m = 0 \text{ (monopole)}
\]

\[
m = 1 \text{ (dipole)}
\]

\[
m = 2 \text{ (quadrupole)}
\]
Major steps towards high HOM damping:

- Enlarged beam tubes
- Modified wave guide cross sections

Coupled bunch instability thresholds

Monopole HOMs ($m = 0$)

Dipole HOMs ($m = 1$)
End-group design considerations:

- Long waveguide needed in order to avoid Q dropping ( > 400 mm )
- Waveguide tapered to reduce a localized end-group mode
Energy going to HOMs:

- HOM power = 1.3 kW (5 waveguides) + 800 W (up/downstream)
- Maximum power on load = 300 W

Waveguide power:
HOM dampers:

- Specifications scaled to max. values on WG + BP power (460W per load)
- Water-cooled
- Collaboration with Jefferson Lab

First load designs for bERLinPro

VSR design ongoing: Stronger cooling, single plate with ferrit tiles

3 prototype loads (Q4 2016) + series of 15 (2017)
- Dust production test (particle counting)
- Low power + High Power tests @ JLab
First power calculations of complete cold string (very preliminary) 1.5 GHz + 1.75 GHz:

Challenges:
- Limited length
- Different frequencies, different sizes
- Extra beam pipe absorbers needed?

Tasks:
- Confirm HOM load specifications
- Validate impedance budget
- Coupler kicks, orientation

→ work in progress!
WG loaded cavity with copper WG extensions

- Under fabrication by Research Instruments (RI)
- To be delivered by October 16
- Validate fabrication techniques, relatively new development (deep drawing, spring backs, weld shrinkage)
- Validate EM design
- 1.75 GHz prototype foreseen
Niobium single-cell with one sided WG end-group loaded with 2 WG + 1 FPC + 100 mm beam-pipe extension

- Ordered at RI, delivery expected in December
- 150 mm extended beam-pipe on the other side (same diameter as copper model)
- Fabrication drawings based on the existing copper model
- Chemical surface treatment
- WG flanges closed with an Nb sealing (space constraint in vertical test stand)

Primary goals:
- Validate multipacting
- Validate Nb fabrication process
16 kW CW couplers @ 1.5 GHz

- Close to 0 beam loading expected, high $Q_{\text{ext}} > 10^7$ with low power $< 10$ kW
- Adjustable coupling is required due to parking (different temperature) and impedance control (within power budget)
- Design based on the Cornell 60kW injector coupler

→ Work in progress!
Warm bead-pull

Cold bead-pull:

- Novel design
- Inside HoBiCaT (horizontal test module)
- Evaluates field profile of cavities in SC state
- Commissioned with a 9 cell Tesla cavity
- Able to characterize HOMs
- Results to be published (Adolfo Vélez)
Summary of planned tests

1.5 GHz and 1.75 GHz 5-cell Copper Cavities:
  ▶ To be tested in new RF Lab (Schwarzschildstraße)

1.5 GHz Single-cell Niobium Cavity:
  ▶ To be tested in small VTS, minor modifications

1.5 GHz 5-cell Niobium Cavities
  ▶ Undressed cavities: To be tested in large VTS, Testing Hall 1 in operation by Q2 2017
  ▶ Dressed cavities: To be tested in HoBiCaT (horizontal)
  ▶ Low power tests: 500 Watts broadband Amp @1.5 GHz+1.75 GHz
  ▶ High power Tests: 16kW transmitter, SSA. RF infrastructure: WGs, circulator, water loads etc. Installation in HoBiCaT
Concept:

- Combines high brilliance with short pulses
- Opens a new regime for storage ring operation
- Is the ideal and cost effective upgrade of BESSY II

Status:

- Two R&D projects started:
  - SRF cavity and auxiliary prototyping
  - Bunch resolved diagnostics
- Application process for full funding ongoing
Acknowledgment: The BESSY VSR team at HZB and all collaboration partners.