Higher Harmonic SRF Cavities for BESSY II Upgrade

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BESSY II Storage Ring

- BESSY II is a 1.7 GeV synchrotron radiation source operating for 20 years in Berlin.
- Core wavelength in the range from Terahertz region to hard X rays.

### BESSY II Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Lattice</td>
<td>DBA</td>
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<tr>
<td>Circumference</td>
<td>240 m</td>
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<tr>
<td>Energy</td>
<td>1.7 GeV</td>
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<tr>
<td>Current</td>
<td>300 mA</td>
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<tr>
<td>RF Frequency</td>
<td>500 MHz</td>
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<tr>
<td>RF Voltage</td>
<td>1.5 MV</td>
</tr>
<tr>
<td>Bunch Length</td>
<td>15 ps</td>
</tr>
<tr>
<td>Emittance</td>
<td>6 nm rad</td>
</tr>
</tbody>
</table>
The Concept of BESSY VSR

BESSY II @ present
Normal conducting cavity system

- **Low alpha operation only 12 days/year (all beamlines) ------ Low flux**
- **Femtoslicing is continuously operated (only 1 beamline) -- Low flux**

Can we design a system offering both possibilities simultaneously?

- **Limited pulse length in storage ring**
  \[ \sigma \propto \alpha \sqrt{\frac{\alpha}{V_{tf}}} \]

  - Machine optics
  - Hardware (RF cavities)

- **At high current beam becomes unstable**
- **For ps pulses, flux is reduced by nearly 100**

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**Graph:**

- **User optics**
- **Low alpha optics**

**Legend:**

- **Bursting mode begins**

**Axes:**

- **RMS bunch length (ps)**
- **Bunch current (mA)**

**Range:**

- **10^{-4}** to **10^{-1}**
- **0.1** to **10**
The Concept of BESSY VSR

BESSY II @ present
Normal conducting cavity system

- Supply short pulses down to 1.5 ps (100 × more bunch current)
- Low α permits few 100 fs pulses
- Configure BESSY VSR so 1.5 ps and 15 ps bunches can be supplied simultaneously for maximum flexibility and flux!

- Limited pulse length in storage ring
  \[ \sigma \propto \frac{\alpha}{V} \]
- At high current beam becomes unstable
- For ps pulses, flux is reduced by nearly 100

Machine optics
Hardware (RF cavities)

Bunch current (mA)
RMS bunch length (ps)

- User optics
- Low alpha optics

Bunched length is highly proportional to \( V \times \alpha \)

80 × more voltage gradient

Bunch current (mA)
RMS bunch length (ps)
BESSY II, SC Upgrade – BESSY VSR

G. Wüstefeld et al. „Simultaneous long and short electron bunches in the BESSY II storage ring“, IPAC2011

- 1.5GHz and 1.75GHz ---- RF beating (modulate RF focusing)
- Odd (voltage cancelation, 15 ps bunches)
- Even (voltage addition, 1.5 ps)
BESSY VSR Filling Patterns

- **High concentration of long bunches populated with high current**
  (flux hungry users)

- **Few high current - short bunches**
  (slicing bunches ...)

**More short bunches ( Extended )**

- **High Population of long & short bunches at the same time**
Simultaneous Store of long & short bunches

**SRF SYSTEM:** 2@1.5 GHz & 2@1.75 GHz

**CHALLENGES**
- CW operation @ high field levels $E=20\text{MV/m}$
- Peak fields on surface (discharges, quenching)
- High beam current ($I_b=300\text{mA}$)
- Cavity HOMs must be highly damped (CBIs)
- Exotic cavity design (damping end-groups)
- Integrating in existing storage ring
- Transparent Parking of SRF Module.

**BESSY II SC Upgrade – BESSY VSR**
- Tune fundamental mode: field flatness, R/Q …
- Control cavity HOM spectrum (off-resonance condition) during the design.

Strong HOM Damped SRF Cavity Concepts

Cavity with HOM WG Dampers

- 5 x Waveguide dampers, HOM loads (warm)
- Large beampipe radius – better HOM propagation
- Waveguides are below cutoff for fundamental → can be moved close to the cavity for heavy damping.
During cavity design additional to standard parameters (peak fields, field flatness ...), HOM spectrum should be controlled to avoid any resonances with circulating beam harmonics.

- Both cavities are not hitting any of beam resonances that are multiple of 250MHz.

- Cornell's ERL cavities are designed to run at about 100-200W HOM Power.
- Water-cooled HOM loads (room temperature 300K)
- Specifications: 460W per load
- Design, fabrication and tests @ JLab

- Low reflection (broadband) from the WG bend is for bending radius $= 30\text{mm}$ or $bR \geq 100\text{mm}$.

- TE10 mode couples into different modes after bend: TE10, TE11, TM11..., depending on excitation frequency & the cutoff of each WG mode!

- At high frequencies the TE10 is scattered from the bend into several modes, i.e. acts as mode mixer.

- At optimized 30mm inner bending radius the reflection is minimal in broadband frequency sense.

Courtesy of Jefferson Lab
Bakering temperature ~ 700°C, because of Helium-vessel parts.

- Nb inner surface removal ~ 200µm total is planned with BCP. The homogeneity of removal in HOM dampers should be checked.
- In waveguide NbTi flanges VATSEAL gaskets will be used – cold test is planned. At all other flanges – diamond gaskets.
- Looking solutions for cooled WG-flange concept.
BESSY VSR: Cavity Prototypes

1.5 GHz 5-cell Copper prototype

1.5 GHz Single-cell Nb prototype

- No multipacting or quenching
- Field emission - Measurement will be repeated after rinsing.
Wakefield Simulations

- Long Range Wakes~ 20m
- Spectral Weighting of all Port Signals with Beam Spectrum
- Expected HOM Power Levels & Spectrum
- Efficiency of HOM Damping

- Analyze different cavity arrangements in the module to reach optimal operation conditions with equally distributed power portions in warm HOM loads.
- Study on different FPC locations (Upstream - Downstream) to minimize the flown HOM powers & redirect to wavguide dampers. (RF window issues)
HOM Power Levels in SRF Module

BESSY VSR – SRF Module Setup – LSSL2

1.75 GHz Cavities

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Total: 4245 W  4225 W  4457 W  4432 W
Shielded bellows are required due to the cavity fundamental mode losses.

Beampipe-Absorbers for more HOM damping, especially excited by interaction with warm components.

Synchrotron light collimating bellow is required at module center.

Thank You for Your Attention!