BESSY-VSR

A novel application of SRF for Synchrotron Light Sources

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OUTLINE

• BESSY VSR
  – The BESSY VSR concept

• BESSY VSR challenges

• SRF Systems
  – Cavity design status
  – Module arrangement
  – Cryogenics
  – RF power

• Prototypes and measurements

• Future work and Conclusions
• 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 has ben developing a comunity of user performing dynamic measurements in ps and fs range „functional materials“
• Pioneer in offering low α and femtoslicing facility

In order to remain competitive among the international synchrotron sources a superconducting upgrade is undergoing

BESSY III
Third generation light sources move in the direction of minimizing beam emittance

ESRF (Grenoble), Spring-8 (Japan), APS (USA) → DLSR by multi-bend achromats (MBA)

- Complete new ring
- New magnet/vacuum system
- Long dark time (1 year ESRF)
- Very expensive

BUT ...

Short pulse experiments represent one of the strong fields at HZB (low-Alpha, femtoslicing).

Such a pitty to lose!

A complementary approach to DLSRs

BESSY VSR
The concept of BESSY VSR

BESSY II @ present

Normal conducting cavity system

- Limited pulse length in storage ring
  \[ \sigma \propto \sqrt{\frac{\alpha}{V_{rf}}} \]
  \( \rightarrow \) Machine optics
  \( \rightarrow \) Hardware (RF cavities)

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

- Low alfa 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?
The concept of BESSY VSR

**BESSY II @ present**

- Limited pulse length in storage ring
  \[ \sigma \propto \sqrt{\frac{\alpha}{V_{\text{rf}}}} \]
  - Machine optics
  - Hardware (RF cavities)
- At high current beam becomes unstable
- For ps pulses, flux is reduced by nearly 100

Supply short pulses down to 1.5 ps

100× more bunch current

Low \( \alpha \) permits few 100 fs

**Configure BESSY\textsuperscript{VSR} so 1.5 ps and 15 ps bunches can be supplied simultaneously for maximum flexibility and flux!**
The concept of BESSY$^{\text{VSR}}$

BESSY II, SC Upgrade

Present

- Voltage: 1.5 MV @ 0.5 GHz
- Time: ~4.2 m

Phase I

- Voltage: 20 MV @ 1.5 GHz
- Time: ~4.2 m

Impedance heating problems

Touschek lifetime issues

J. Feikes, P. Kuske and G. Wüstefeld.
"Towards Sub-picoseconds electron bunches: Upgrading ideas for BESSY II"
EPAC2006
The concept of BESSY VSR

BESSY II, SC Upgrade

cavity $V_1, f_1$

cavity $V_2, f_2$

• 1.5GHz and 1.75GHz ---- RF beating (modulate RF focusing)
• Odd (voltage cancelation, 15 ps bunches)
• Even (voltage addition, long focussing, 1.7 ps)

Voltage: 1.5 MV @ 0.5 GHz

Voltage: 20 MV @ 1.5 GHz

Voltage: 20 MV @ 1.5 GHz + 17.1 MV @ 1.75 GHz

G. Wüstefeld et al.
“Simultaneous long and short electron bunches in the BESSY II storage ring”
IPAC2011
The concept of BESSY $^V_{SR}$

**BESSY II, SC Upgrade**

**BESSY VSR filling pattern**

- High concentration of long bunches populated with high current (flux hungry users)
- Few short bunches placed at will (high current short bunches, slicing bunches ...)

**Present**

- Voltage: $1.5 \text{ MV @ } 0.5 \text{ GHz}$

**Phase I**

- Voltage: $20 \text{ MV @ } 1.5 \text{ GHz}$

**Phase II**

- Voltage: $20 \text{ MV @ } 1.5 \text{ GHz} + 17.1 \text{ MV @ } 1.75 \text{ GHz}$
**BESSY II, SC Upgrade**

**BESSY VSR filling pattern**
- High concentration of long bunches populated with high current (flux hungry users)
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**Chopper Wheel**

**Resonance Islands**

**Incoherent excitation**

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M. Cammarata et al. “Chopper system for time resolved experiments with synchrotron radiation”. In: *Review of Scientific Instruments*


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A.Velez, SRF15 Whistler CA
The concept of BESSY\textsuperscript{VSR}

BESSY II , SC Upgrade

\textbf{BESSY VSR filling pattern}

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

- Few short bunches placed at will (high current short bunches, slicing bunches ...)

\textbf{BESSY II is a low energy machine (1.7GeV)}

The whole BESSY VSR installation fits into a single low $\beta$ straight

No changes is the BESSY optics are needed !!
Project challenges

Bunch length: theory v. reality
- Reality: bunch lengthening due to CSR-driven instabilities at high current

High-gradient SRF cavities
- 20 MV/m CW operation
- Particulate free vacuum \((10^{-10} \text{ mbar})\) in an otherwise “dirty” machine.

Transparent “parking” of cavities in case VSR needs to be “switched off”

Coupled-bunch instabilities
- Higher-order modes in SRF systems in relation to beam spectrum
- Very strong damping of HOMs
- Sufficiently strong bunch-by-bunch feedback to suppress instabilities

Transient beam loading due to fill pattern & Robinson instabilities
- RF and tuning control parameters for the cavities
- Proper choice of bandwidth and available RF power
- Changing bunch profile along bunch train

Injection, top-up operation and lifetime issues
- Injection of long booster bunches into short BESSY-VSR buckets
- Reduced Touschek lifetime

Technical realization
- Integration in a single straight
- Cryogenic installation
- Required infrastructure for system development and tests

Technical design study
SRF Systems challenges

- CW operation @ high field levels $E=20$ MV/m
- On the edge field values on the surface (discharges, quenching)
- High beam current ($I_b=300$ mA)
- Cavities must be highly damped (CBIs)
- Imposed design restrictions: iris diameter, beam-pipe diameter ...

The combination of **CW operation, high voltage** and **high beam current** in a storage ring make the design a challenging goal to achieve.

2@1.5 GHz  2@1.75 GHz
1.5 GHz Cavity design

Stage 1: Cavity geometry

Design specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{acc}}$</td>
<td>20 MV/m</td>
</tr>
<tr>
<td>$I_{\text{beam}}$</td>
<td>$\leq$ 300 mA</td>
</tr>
<tr>
<td>$E_{pk}/E_{\text{acc}}$</td>
<td>$\leq$ 2.3</td>
</tr>
<tr>
<td>$B_{pk}/E_{\text{acc}}$</td>
<td>$\leq$ 5.3 mT/(MV/m)</td>
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<tr>
<td>$R/Q$</td>
<td>$\geq$ 100 $\Omega$</td>
</tr>
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<td>$K$ for TM$_{010}$</td>
<td>$\geq$ 3%</td>
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1.5 GHz design

SRF Specifications fulfilled

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<th>HIZB</th>
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<td>$\leq$ 2.3</td>
<td>2.29</td>
</tr>
<tr>
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<td>4.4 mT/(MV/m)</td>
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<td>$R/Q$</td>
<td>$\geq$ 500 $\Omega$</td>
<td>525 $\Omega$</td>
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<tr>
<td>$K$ for $\pi$-TM$_{010}$</td>
<td>$\geq$ 3%</td>
<td>3.3%</td>
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Operation problems derived from high field values prevented
1.5 GHz Cavity design

Stage 1: Cavity geometry

Base models
- Cornell 1.3 GHz (scaled)
- Jlab 1.497 GHz

Big iris diameter for high cell-cell coupling
Φ = 71.34 mm

1.5 GHz design

HZB optimized model

SRF Specifications fullfilled

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Operation problems derived from high field values prevented

A.Velez, SRF15 Whistler CA
### 1.5 GHz Cavity design

#### Stage 1: Cavity geometry

**Base models**
- Cornell 1.3 GHz (escaled)
- Jlab 1.497 GHz

Big iris diameter for high cell-cell coupling  
\( \Phi = 71.34 \text{mm} \)

#### Stage 2: HOM damping

- Analyze HOM in relation to beam spectrum
- Provide strong HOM damping in order to avoid CBIs
End-groups and Damping

Calculations show high HOM damping level required to avoid CBI’s

- 5e4 Ω, longitudinal modes
- 1e7 Ω/m, transverse modes

Modified WG. Damping (b ≠ a/2)

Enlarged beam-tubes

- f = 2.755 GHz
- 4xTE_{01}
- 2xTE_{10}

A.Velez et al. WEPMA013
IPAC15
A.Velez et al. MOPP071, LINAC’14
End-groups and Damping, adding a coaxial coupler

Heavily damped 1.5 GHz prototype (with FPC+WG dampers)

All analyzed modes except 1 are below the Impedance threshold (with feedback)

Table 1: BESSY VSR filling pattern with calculated loss factor for the different bunch δ

<table>
<thead>
<tr>
<th>n</th>
<th>I (mA)</th>
<th>δ (mm)</th>
<th>k/l, α=4/3</th>
<th>k/l, α=0.59</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8</td>
<td>0.51</td>
<td>48</td>
<td>13</td>
</tr>
<tr>
<td>150</td>
<td>1.65</td>
<td>4.5</td>
<td>2.6</td>
<td>3.55</td>
</tr>
<tr>
<td>150</td>
<td>0.18</td>
<td>0.33</td>
<td>85.8</td>
<td>16.9</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>8.1</td>
<td>1.21</td>
<td>2.45</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>1.11</td>
<td>17</td>
<td>8.18</td>
</tr>
</tbody>
</table>

Table 2: Calculated HOM power for different scaling of the loss factor (k) for the BESSY VSR filling pattern

<table>
<thead>
<tr>
<th>Σn</th>
<th>Σl</th>
<th>Σ(C) P_{HOMA}=4/3</th>
<th>P_{HOMA}=0.59</th>
</tr>
</thead>
<tbody>
<tr>
<td>305</td>
<td>300.3</td>
<td>2.4e5</td>
<td>1.2kW</td>
</tr>
</tbody>
</table>

HOM power of 1 KW need to be damped with the most possible compact design (module length limitation)

Courtesy of M.Ruprecht

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1.75 GHz Cavity design

- Design work started with a scaled version of the 1.5 GHz 5-cell cavity.
- The RF and HOM damping techniques developed on the 1.5 GHz cavity can be implemented in order to fine tune the design (if needed).
1.75 GHz Cavity design

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- The RF and HOM damping techniques developed on the 1.5 GHz cavity can be implemented in order to fine tune the design (if needed).

Concatenation of cavities

- Different iris sizes. Tapered transitions are needed to avoid modal overlapping between cavities and fundamental power leakage (TM_{010}).
- Possible high Q trapped modes generated in the tapered transitions (CBIs).
- Limited module space (4.2m).
- Possible heating on belows, HOM dampers ...
- In case higher damped needed beam-tube dampers might not be feasible.
- Concatenation studies currently undergoing

T. Flisgen et al.
IPAC2014 TUNAB01 (2014)
Prototypes and Measurements

Copper prototype (1.5GHz)
(5 WG+1 FPC) with Rotary mechanical flanges
To be measured in standard bead-pull test-bench

A new cold-bead-pull test stand has been developed by HZB in order to measure field characteristics of Nb prototypes in SUPERCONDUCTING STATE at HoBiCat

First results obtained from 1.8K measurements of a 9 cell Tesla Cavity

A.Velez et al, TUPB078, this proceedings
Future work and conclusions

Work in progress ...

• Study effects of undamped energy propagated through the beam-pipes to the ring. Heating issues.

• Concatenation studies. Cavity-cavity coupling, energy damping and impedances.

• Thermal studies (waveguides, flanges...).

  • Studies on tuning HOMS

  • FPC Coupler design.

• Multipacting on transitions (iris-damper, damper-B.P)

  • Fabrication of prototypes.

Poster
TUAA03
Thank you for your attention