BESSY VSR - Short X-ray pulse production Upgrade for BESSY II

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on behalf of the BESSY VSR project team

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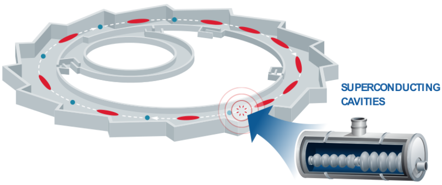
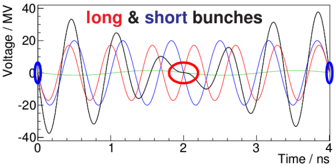
BESSY VSR: A Variable Pulse Length Storage Ring





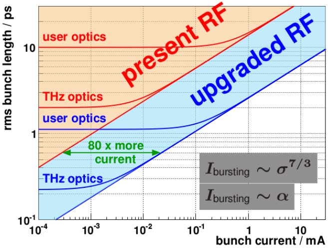
BESSY VSR cavity setup:

Fund.: 0.5 GHz at 1.5 MV

3rd: 1.5 GHz at 20 MV

3.5th: 1.75 GHz at 17 MV

Realized by four SC 5-cell cavitites:
2x 1.5 GHz and 2x 1.75 GHz

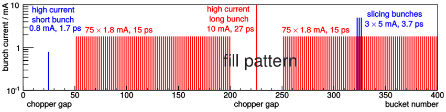


Bunch length:

$$\sigma \sim \delta_0 \sqrt{\frac{E_0}{f_0}\frac{\alpha}{U'}}$$

α - mom. compaction

$U' = dU/dt$ $\qquad U'_{\mathrm{VSR}} = 80 \cdot U'_{\mathrm{BII}}$



BESSY VSR - Short X-ray pulse production

1.) Bunch length limits, low α

Zero current bunch length σ_0:

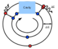
	standard optics	low α optics
ϵ	5 nm rad	40 nm rad
α	$7.3 \cdot 10^{-4}$	$3.5 \cdot 10^{-5}$
σ_0^{BII}	10 ps	2 ps
σ_0^{VSR}	1.1 ps	0.250 ps

Longitudinal quantum radiation excitation:

- Path length of a radiating electron depends on place s_i where photon emission took place
- It depends on the variance I_α of the partial momentum compaction $\bar{\alpha}$.
- Radiation excitation limit: $\sigma_{\mathrm{re}} = \frac{\delta_0 \sqrt{I_\alpha}}{f_0}$ with

$$I_\alpha = \langle[\bar{\alpha}(s_i) - \langle\bar{\alpha}\rangle]^2\rangle\,, \quad \bar{\alpha}(s_i) = \frac{1}{L_0}\int_{s_i}^{L_0} \frac{D(s)}{\rho(s)}\,ds$$

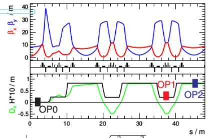
	standard	low α
I_α	$4.5 \cdot 10^{-8}$	$1.3 \cdot 10^{-8}$
σ_{re}	140 fs	70 fs



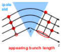
Transverse longitudinal coupling:

- Particles with horz. displacement pass dipoles on different trajectories, resulting in a long. displacement (rotation in x, z plane)
- Horizontal longitudinal coupling limit σ_{H}:

$$\sigma_{\mathrm{H}} = \sqrt{\epsilon H}/c\,, \quad H(s) = \gamma D^2 + 2\alpha D D' + \beta D'^2$$



	σ_{H}	$\sigma_{\mathrm{eff}} = \sqrt{\sigma_0^2 + \sigma_{\mathrm{H}}^2}$
OP0	–	250 fs
OP1	100 fs	270 fs
OP2	195 fs	320 fs

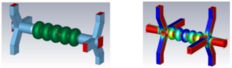


Bunch length limits: Bunch length in low α is limited by single particle effects and comparable with σ_0. $\sigma_{\mathrm{eff.}}^{\mathrm{straights}} = 330\,\mathrm{fs}$ and $\sigma_{\mathrm{eff.}}^{\mathrm{dipoles}} = 280\,\mathrm{fs}$.

2.) CBIs driven by HOMs

Novel technology: SC high frequency multi-cell cavities in CW operation in a high current storage ring!

Cavity design:
$E_{\mathrm{acc}} = 20\,\mathrm{MV/m}$, $Q_{\mathrm{loaded}} = 5e07$, $R/Q = 525\,\Omega$, $Q_0(1.8\,\mathrm{K}) = 8e09$ and HOM damped



Impedance threshold of CBIs:

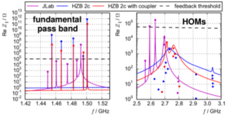
growth rate = damping rate

Even fill solution:

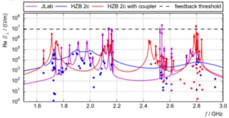
$$\tau^{-1} = \frac{f_{\mathrm{rev}} I}{2E/e} \times \begin{cases} \beta_{x,y}\,\mathrm{Re}(Z_{x,y}(f)) & \text{trans.} \\ f\,\alpha\,\mathrm{Re}(Z_{\parallel}(f))/f_s & \text{long.} \end{cases}$$

Damping rates at BESSY II:
Syn. rad. damping: $\tau_{x,y} = 16\,\mathrm{ms}$, $\tau_z = 8\,\mathrm{ms}$
BBFB damping: $\tau_{x,y} = 0.25\,\mathrm{ms}$, $\tau_z = 0.75\,\mathrm{ms}$

Longitudinal:

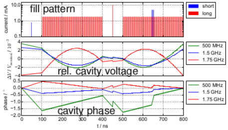


Transverse:

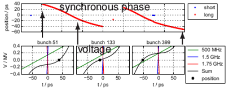


3.) Transient Beam Loading at BESSY VSR

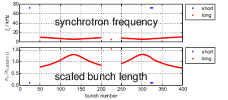
- Tracking code for longitudinal dynamics with one macro particle per bunch
- Slow feedback loop for cavities: Reacts only from one revolution to another



- All cavities operated close to zero crossing: Beam loading is mostly a phase shift
- Amplitude and phase variation is periodic with revolution → transient beam loading



- Little effect on short bunch but strong effect on long bunch (cancellation of gradients)
- Sum voltage significantly changed → shift of synchronous phase position
- Gradient at synchr. phase pos. different



- Consequently: Synchrotron frequency and bunch length different for each bunch