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# STUDY ON RF COUPLER KICKS OF SRF CAVITIES IN THE BESSY VSR MODULE

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*Abstract*

The BESSY VSR project implies installation of four L-band SRF cavities in the BESSY II storage ring to achieve high overvoltage necessary for bunch compression down to ps levels. Those cavities are equipped with strong waveguide HOM dampers necessary for stable operation. The expected RF coupler kicks has been studied for design accelerating gradients of each cavity. The resulting net coupler kicks from the four cavity chain are discussed.

## INTRODUCTION

The BESSY Variable pulse length Storage Ring (BESSY VSR) is an upgrade of the BESSY II light source representing a novel application of superconducting cavities in a storage ring [1-3]. This upgrade will allow to store simultaneously long (ca. 15 ps) and short (ca. 1.7 ps) bunches with the "standard" user optics. This challenging goal requires installation of four new high harmonics SRF multi-cell cavities (2x1.5 GHz and 2x1.75 GHz) equipped with waveguide HOM dampers ensuring tolerable beam coupling impedance, necessary for stable operation [4-10].

These cavities will operate at 20MV/m in CW mode and at the zero-crossing phase according to the accelerating voltage. Consequently the transverse voltages will be maximum and can impact the transverse beam dynamics. The asymmetric character of those transverse kicks are caused by cavity fundamental power couplers (FPC) [7] with strong monopole terms, introducing transverse kick to on-axis particles. Different FPC orientations were analyzed to optimize the net coupler kick from the four cavity chain. Corresponding beam dynamic studies are presented in [8]. The coupler kick strength of each cavity is estimated taking into account accelerating mode amplitudes and phases required for operation in VSR mode. In this paper we focus on computational aspects of coupler kicks.

## THE DESIGN OF SRF CAVITIES

The realisation of the BESSY VSR project implies installation of a single superconducting module with four SRF cavities in one of the low beta straight sections of the existing BESSY II ring.

Each of those superconducting 4-cell elliptical cavities are equipped with five waveguide dampers and one coaxial FPC as depicted in Fig.1. The cross sections of the waveguide dampers are design to have cut-off frequencies above the fundamental $TM_{010}$ mode frequencies (1.5 GHz & 1.75 GHz) and the different orientations ensures optimum HOM damping for different polarisations. Since the cavities will

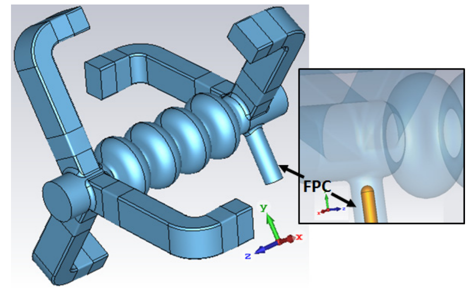


Figure 1: BESSY VSR SRF cavity layout.

operate in a storage ring, the cavity HOM spectrum was designed to fulfil off-resonance condition with respect to the circulating beam harmonics located at multiples of 1.25 MHz revolution frequency [4-6].

Table 1: RF Parameters of SRF Cavities

| Simulation Results ($TM_{010}$ $\pi$-mode) | | |
|---|---|---|
| **Cavity type** | **1.5 GHz** | **1.75 GHz** |
| Number of cells | 4 | |
| Active length | 0.4 m | 0.344 m |
| Frequency [GHz] | 1.4990 | 1.7489 |
| $Q_{ext}$ | $5*10^7$ | $4.3*10^7$ |
| Geometry factor – G [Ω] | 277 | 275 |
| $E_{peak}$ / $E_{acc}$ | 2.32 | 2.30 |
| $B_{peak}$ / $E_{acc}$ [mT/(MV/m)] | 5.05 | 5.23 |
| R/Q [Ω] | 386 | 380 |
| Field flatness - $\mu_{ff}$ | 97 % | 99 % |

In Table 1 the accelerating mode properties are summarized. Main contribution to particle acceleration or bunch compression occurs within the so-called cavity active length which includes the space restricted only to the elliptical cells (Fig. 2). While the evanescent field penetration in both end-groups will reduce the accelerating voltage, i.e. the effective voltage and shunt impedance will be reduced.

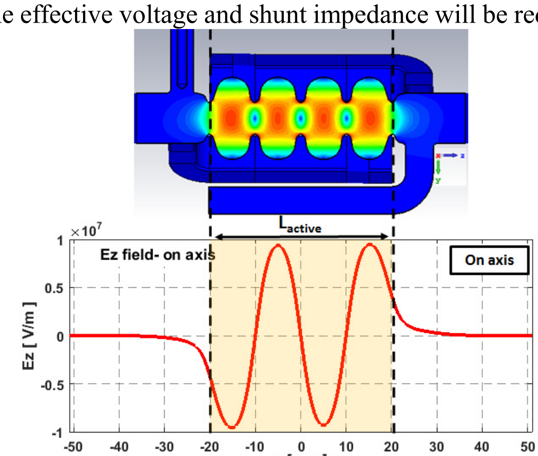


Figure 2: 1.5 GHz cavity accelerating mode field profile.

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Following [3] the induced voltages at both frequencies (1.5 GHz and 1.75 GHz) are modulated in amplitude to reach cancelation or amplification at even or odd buckets correspondently (Fig. 3). This will allow to store long and short bunches simultaneously in the storage ring.

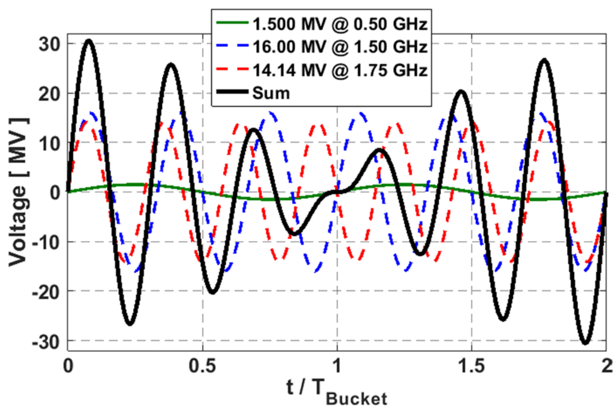


Figure 3: RF voltages of 1.5GHz (blue), 1.75GHz (red) cavities and superposition (black) required for BESSY VSR.

Each of the four cavities will operate in CW mode with maximum 8MV voltage corresponding to 20MV/m accelerating gradient. At zero-crossing of cavity accelerating voltages resulting energy spread of the particles within the bunch will lead to length compression [1-3].

## SIMULATION OF COUPLER KICKS

The $TM_{010}$ fundamental mode traverse field components close to the cavity axis are typically several orders of magnitude smaller than the longitudinal ones. Thus to accurately simulate the field response a local fine mesh around the cavity axis is required. To this end a mesh refinement within a 1cm on-axis cylinder (Fig. 4) is used. This results into about 2 million tetrahedrons for the entire model and is at the limit of available hardware. The simulations have been performed by CST Microwave Studio [11].

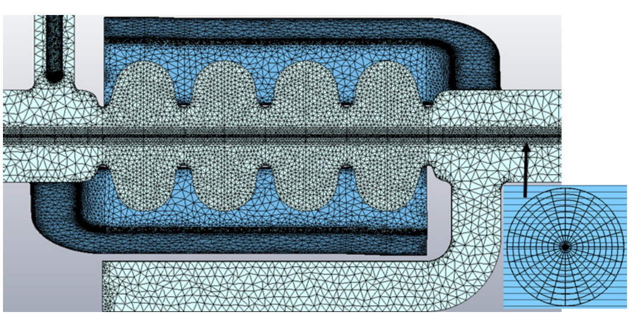

Figure 4: CST tetrahedral mesh with local refinement regions and control nodes in meshing.

The resulting transverse field profiles are shown in Fig. 5. As it can be seen, horizontal field components ($E_y$, $cB_x$) corresponding to particle kicks are mainly located at the FPC end-group (coupler kicks) and its penetration within the elliptical cell region is proved to be very week. The computed profiles of the vertical field components ($E_x$, $cB_y$) are indicate some numerical noise level. The asymmetric location of the corresponding horizontal field components are illustrated in Fig. 6. As can be seen, the mode symmetry distortion is mainly located at the FPC end-group while in the opposite end-group the field remains symmetric.

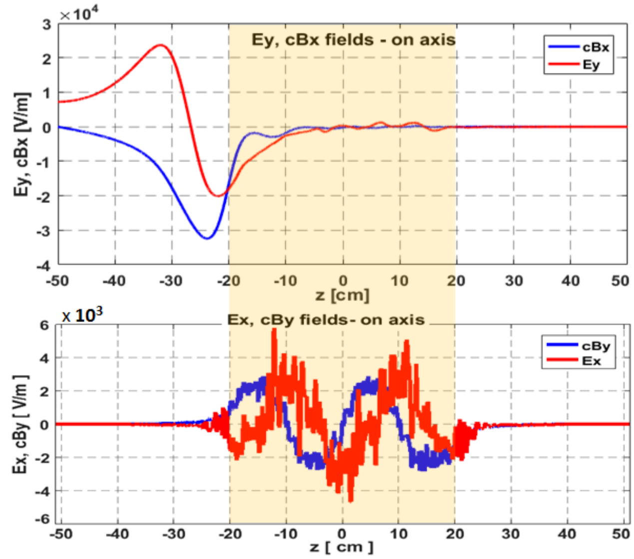


Figure 5: On axis transverse field profiles of $TM_{010}$ π-mode contributing to horizontal (top) and vertical (bottom) kicks.

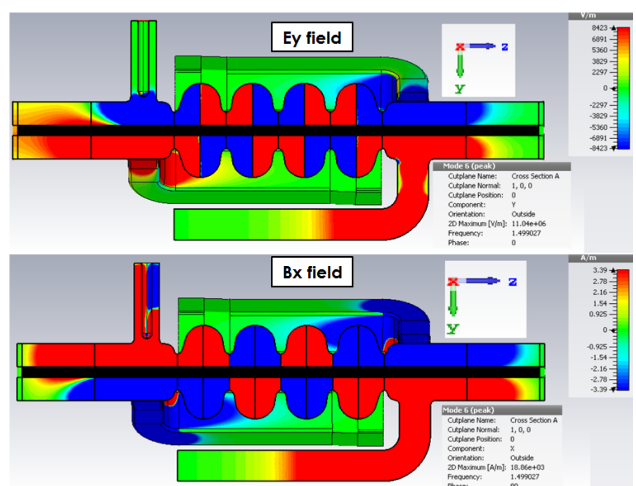


Figure 6: 2D field plots of transverse electric and magnetic fields.

Further, the longitudinal voltages were scanned with respect to the different transverse offsets (Fig. 7). The active voltage is then defined as the field integral taken in the elliptical cell region only, while the effective voltage stays for the complete integration range (including end-groups). As can be seen (Fig. 7), the active voltage is in good agreement with the known analytical solution where no symmetry brake is expected. According transverse voltages are calculated using the Panowsky-Wenzel theorem

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$$\vec{V}_{\perp}(\vec{r}) = \frac{1}{\omega/c} \cdot \vec{\nabla}_{\perp} V_{//}(\vec{r}) \ ,$$

where the voltage derivatives are obtained by finite-difference technique. As expected this indicates that the field symmetry brake is located outside the region of the elliptical cells.

In the case of the effective horizontal voltage a combination of coupler kicks and RF focusing fields can be observed. Nevertheless these two effects tend to compensate each other keeping the net kick bounded (Fig.7).

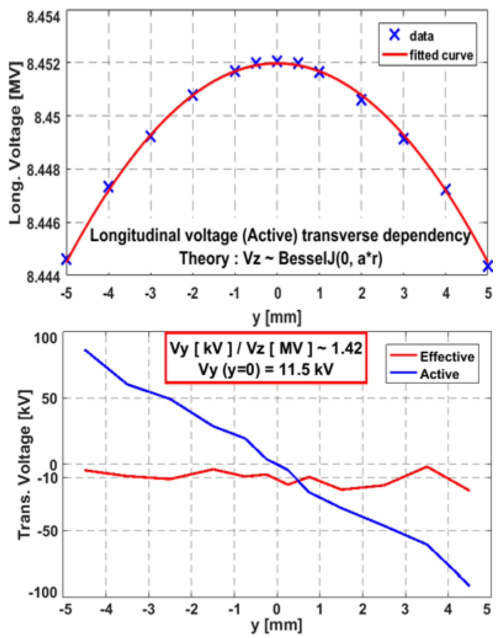


Figure 7: Longitudinal (top) and transverse (bottom) voltages for the 1.5 GHz cavity.

The same procedure was applied to the 1.75 GHz cavity showing similar behaviour.

## MONOPOLE KICK OF FOUR CAVITY CHAIN

A detailed analyses of the coupler kicks for each cavity results into the following relation between accelerating and horizontal voltages for both 1.5 GHz and 1.75 GHz cavities

$$\frac{|V_y|}{|V_z|} \approx 1.5 \cdot 10^{-3}$$

This relations corresponds to the monopole term of coupler kick. It is obtained by direct evaluation of the on axis fields and is cross checked by evaluating the transverse derivative of longitudinal voltage.

The horizontal voltage time profile corresponding to four cavity chain is presented in the Fig. 8. It is constructed taking into account the design accelerating gradients for each cavity (Fig.3). According to the Panofsky-Wenzel theorem for each cavity, the transverse voltage at zero-crossing associated to its longitudinal component will be maximum. Thus for expected BESSY VSR voltages the 1.7GeV short bunches will see the highest kick of about 27µrad in each turn corresponding to 45kV a net horizontal voltage. Here the assumption that the fundamental power couplers of all four cavities have same orientation is made, i.e. the coupler kicks are accumulated.

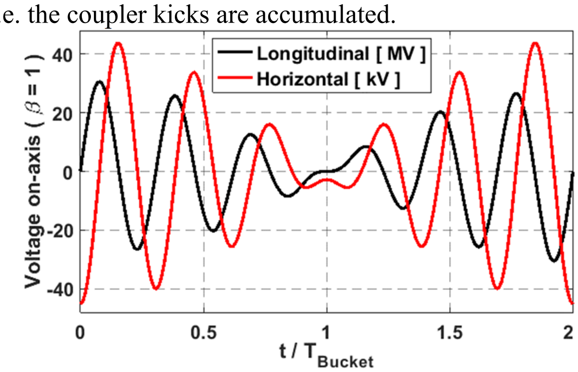


Figure 8: Superposed on-axis longitudinal (black) and horizontal (red) voltages of the four cavity chain.

A natural compensation of the coupler kicks can be reached by installing the FPCs of identical cavities in opposite orientations. This is challenging task for SRF module integration, because of space constrains in the existing BESSY II storage ring.

## CONCLUSION

In this paper we have presented the results on the coupler kick calculations for the BESSY VSR superconducting cavities. It was shown that the brake down of the cavity EM field symmetry occurs mainly at FPC location outside of the elliptical cell region. The BESSY VSR superconducting module will contain one pair of each 1.5 GHz and 1.75 GHz cavities. Thus a natural compensation of coupler kicks is possible by installing cavities with horizontally opposite oriented couplers for each system. Based on obtained coupler kick levels beam dynamic studies [8] are performed where different orientations of the couplers have been considered.

## REFERENCES

[1] A. Jankowiak, J. Knobloch *et al.*, Technical Design Study BESSY VSR, Helmholtz-Zentrum Berlin, 2015.

[2] A. Jankowiak, J. Knobloch *et al.*, "The BESSY VSR Project for Short X-Ray Pulse Production", in *Proc. IPAC'16*, Busan, Korea, 2016, pp. 2833-2836.

[3] G. Wüstefeld *et al.*, "Simultaneous Long and Short Electron Bunches in the BESSY II Storage Ring", in *Proc. IPAC'11*, paper THPC014, San Sebastian, Spain, 2011.

[4] A. Velez *et al*, "HOM Damping Optimization Design Studies for BESSY VSR Cavities, in *Proc. IPAC'15*, Richmond, VA, USA, 2015, pp. 2774-2776.

[5] A. Velez *et al*, "The SRF Module Developments for BESSY VSR", in *Proc. IPAC'17*, paper MOPVA053, Copenhagen, Denmark, 2017, doi:10.18429/JACoW-IPAC2017-MOPVA053

[6] A. Tsakanian *et al*, "Study on HOM Power Levels in the BESSY VSR Module", in *Proc. IPAC'17*, paper MOPVA052, Copenhagen, Denmark, 2017, doi:10.18429/JACoW-IPAC2017-MOPVA052

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[7] E. Sharples, A. Velez, M. Dirsat, J. Knobloch, "Design of the High Power 1.5 GHz Input Couplers for BESSY VSR", in *Proc. IPAC'17*, paper MOPVA051, Copenhagen, Denmark 2017, doi:10.18429/JACoW-IPAC2017-MOPVA051

[8] T. Mertens *et al.*, "Impact of RF Coupler Kicks on Beam Dynamics in BESSY VSR", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, Apr.-May 2018, Paper THPAF084, this conference.

[9] A. Tsakanian *et al*, "HOM Power Levels in the BESSY VSR Cold String", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, Apr.-May 2018, Paper WEPML048, this conference.

[10] H.-W. Glock *et al*, "Design of the Beamline Elements in the BESSY VSR Cold String", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, Apr.-May 2018, Paper THPMF033, this conference.

[11] CST Studio Suite is a trademark of CST GmbH, Bad Nauheimer Str. 19, 64289 Darmstadt, Germany (www.cst.com).