

# HOM DAMPING OPTIMIZATION DESIGN STUDIES FOR BESSY VSR CAVITIES

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## Abstract

The BESSY VSR project is a future upgrade of the 3rd generation BESSY II light source. By using the same "standard" user optics, simultaneously long (ca. 15ps) and short (ca. 1.5ps) bunches will be stored. Thus, SRF higher harmonic cavities of the fundamental 500 MHz at two frequencies need to be installed in the BESSY II storage ring. This work describes the optimization studies for the waveguide-based HOM dampers and the adjustable fundamental power coupler for the 1.5 GHz first SRF cavity prototype.

## INTRODUCTION

Simultaneous operation of long and short pulses by BESSY VSR represents a very attractive upgrade of the conventional storage ring operation concept. As described in [1] the addition to the 500MHz signal of two higher harmonics cavities and operating at zero crossing will lead to the desired combination of compressed and long bunches. Therefore 4 new SRF cavities (2x1.5 GHz and 2x1.75 GHz) need to be designed. These cavities will operate in CW at high field levels ( $E_{acc} = 20$  MV/m). The combination of these factors with high beam current ( $I_b = 300$ mA) makes the cavity design a challenging goal since stable operation must be ensured [2]. Thus special attention must be paid to the damping of high order modes (HOMs) excited by the beam that may otherwise cause coupled bunch instabilities (CBIs) [3]. In order to avoid possible CBIs a stability condition is established imposing HOM impedances to be below feedback threshold both for longitudinal and transverse modes ( $5e4\Omega \cdot 1e7\Omega/m$ )[4]. This paper shows the current status of the design for the first 1.5 GHz cavity with special attention devoted to the optimization of the waveguide-based HOM damping technique [5,6]. To this end, EM calculations have been performed with both Ansoft HFSS and CST Microwave Studio [7,8] in order to compute the HOM-damped cavity spectrum

## WAVEGUIDE HOM-DAMPING (WG-D)

The proved efficiency of WG-D absorbers [5] offers the capability to handle high power while offering very high damping levels. In addition the WG-D close distance to the cavity shows a better performance when propagating possible trapped modes as compared to beam-pipe ferrite absorbing solutions. The present designed WG-D end-groups consist on a 2 Y-shape beam-pipe section loaded with 3 equally spaced waveguides (120°). Both input and output WG-D are shifted 60° in order to cover for

different mode polarisations. The length of the waveguides is set to 400 mm ensuring enough isolation for the fundamental  $TM_{010}$   $\pi$ -mode ( $Q_{ext}=5e10$ ) while reducing the risk of dust contamination.

## Damping Studies

In order to avoid CBIs the limit on the feedback threshold forces the model to push the limits of the damping technique. As it is well known TM modes more often present higher  $R/Q^*Q$  values and therefore represent the highest risk when dealing with CBIs. However a few TE modes with impedances in the order of the present threshold limit can be found due to band superposition effects and asymmetries (with coax coupler) [4]. Therefore the damping system must be optimized in a way that both TE and TM modes can be propagated.

Two main approaches are used on the damping optimization for the cavity prototype: extended WG (HZB.x.b) and enlarged beam-pipe (HZB.2.x).

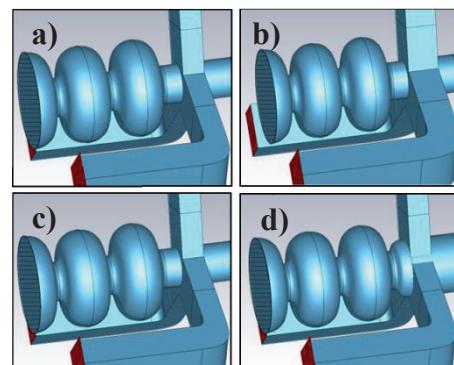


Figure 1: Layout of the two techniques applied on the optimization of the Y-shape waveguide absorbers. Extended WG-D (a~b). Enlarged beam-pipe (c~d).

In the first one, the beam-pipe diameter is equal to the iris (71mm) but the height (H) of the waveguide is increased from 50mm (HZB1a) to 60 mm (HZB1b). Therefore the propagated waveguide TE-like modes benefit from a lower cut-off (i.e.  $f_c$  TE<sub>011</sub>=2.50GHz) and are allowed to propagate through the WG-D. This effect is depicted in Fig 2 for the TE<sub>111</sub>, TE<sub>011</sub> and TE<sub>211</sub> modes. However, in contrast to the enlarged beam-pipe, this approach is not as effective when damping most of the TM modes. On the other hand the enlarged beam-pipe approach benefits from the beam-pipe cut-off reduction due to the increase of its diameter (71mm~110mm). Therefore the beam-pipe cut-off for the first propagated mode is reduced to 1.65 GHz offering a great

improvement over the first to dipole bands ( $TE_{111}$ ,  $TM_{110}$ ). As expected, an overall  $Q_{ext}$  decrease is induced being TM modes the most affected. Nevertheless modes such as the monopole  $TE_{011}$  remain almost unaffected.

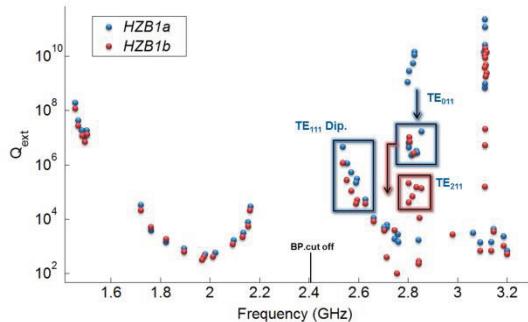


Figure 2:  $Q_{ext}$  calculations on the models loaded with standard beam-pipes. Standard beam-pipe+standard WG-D (87mmx50mm), HZB1. Standard beam-pipe+extended WG-D (87mmx60mm), HZB1b.

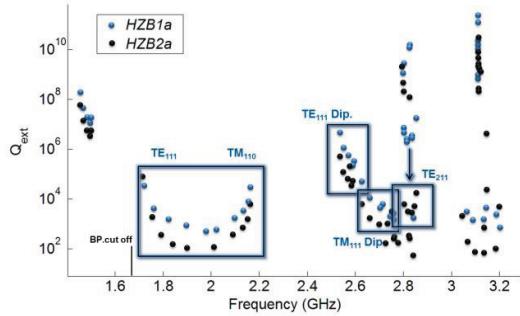


Figure 3:  $Q_{ext}$  calculations on the models loaded with standard WG-D. Standard beam-pipe (71 mm), HZB1a. Extended beam-pipe (104 mm), HZB2a.

### Combined Techniques and Coaxial Coupler

After both techniques have been independently tested, the 6 waveguide-loaded model is modified to include extended WGs and enlarged beam-pipes at the same time (HZB2b). The damping technique must be refined as much as possible since the introduction of the coaxial fundamental power coupler (FPC) might worsen the response introducing asymmetries on the model. Thus fine tuning of the geometry is performed in order to achieve the required damping specifications. Results on this model show a significant improvement in damping both for longitudinal and transverse impedances as it is depicted in Figure 5 (HZB2c). The next step is replacing one of the waveguide dampers by the coaxial FPC (HZB2c-coax.coupler). This coupler is inspired by the Cornell booster coupler since the required power specifications  $< 15\text{kW}$  and adjustable capabilities accurately match to this coupler design [9].

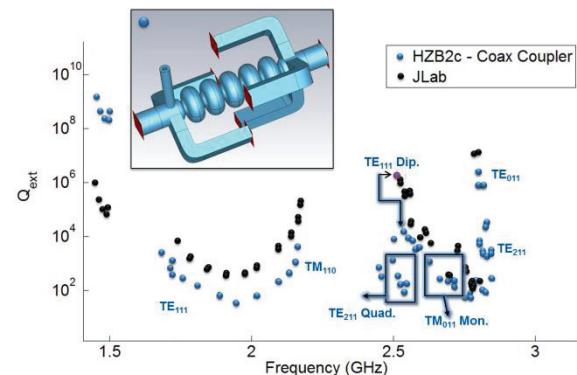


Figure 4: Layout of the HZB 1.5 GHz prototype model loaded with WG-D and coaxial FPC. Enlarged beam-pipes are used ( $\phi=110\text{mm}$ ) (a). Comparison between the “HZB2c-coax coupler” model after tuning with respect to the JLAB “High current” simulation results (b) [10].

As expected, the insertion of the FPC perturbs the symmetrical mode distribution and therefore the overall damping response is slightly degraded. Although most of the modes still remain safely below the feedback threshold the desired specification is not fulfilled by a  $TM_{111}$  and  $TM_{011}$  being this last one very limiting in terms of  $R/Q^*Q$ . A second optimization was performed increasing the beam-pipe diameter to 110mm. As it is depicted in Figures 4 and 5, all the computed HOMs over the analysed frequency range remain below the impedance limit with the only exception of the one  $TE_{111}$  dipole after this optimization step. However, being the impedance of this single TE mode slightly above the threshold limit ( $3.5e7\Omega/\text{m}$ ) and presenting a very narrow bandwidth characteristic it does not represent a major risk and can be assumed as part of the impedance budget.

Table 1: BESSY VSR Filling Pattern with Calculated Loss factor for the Different Bunch  $\delta$

N	I(mA)	$\delta(\text{mm})$	$k//, a=4/3$	$k//, a=0.59$
1	0.8	0.51	48	13
150	1.65	4.5	2.6	3.55
150	0.18	0.33	85.8	16.9
1	10	8.1	1.21	2.45
3	5	1.11	17	8.18

Table 2: Calculated HOM Power for Different Scaling of the Loss Factor ( $k(\delta)$ ) for the BESSY VSR Filling Pattern

$\sum n$	$\sum I$	$\sum (p\text{C})$	$P_{HOM, a=4/3}$	$P_{HOM, a=0.59}$
305	300.3	2.4e5	1.2kW	0.98kW

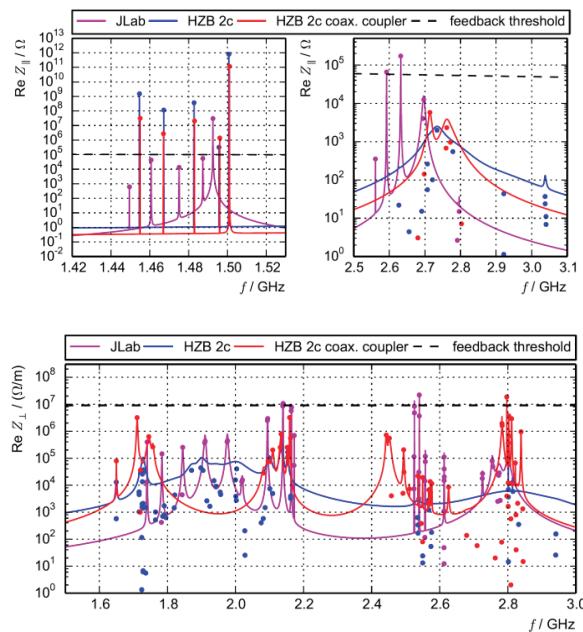


Figure 5: Longitudinal and transverse impedance spectrum representation for the optimized HZB2c model (6 WG dampers) and the FPC loaded HZB2c.coax coupler (M.Ruprecht et al, [3]).

### HOM Power and Damping Performance

In order to have a complete view on the distribution of the power lost by the beam (300mA) when passing through the cavities and the amount of power needed to be taken by the loads, CST wake-field calculations have been performed. Simulations were run with on/off axis excitation up to a frequency of 35 GHz for a bunch sigma of 3mm ( $\delta$ ). Due to the complexity of the BESSY-VSR filling pattern (see Table 1) and the single  $\delta$  bunch runs performed in CST, the calculated  $\delta=3$ mm loss factor ( $k_{||}$ ) has been scaled in order to account for the all different bunch patterns (see Eq. 1). The scale factor (a) on this equation is initially set to 4/3 based on BeRLiNPro experience [11].

$$k(\delta)_{||} = \frac{k_{||}(CST, \delta = 3\text{mm})}{a} \quad (1)$$

However, a second CST run for a different sigma ( $\delta=4.5$ mm) was performed in order to cross-check this number. Simulations show a lower scale factor ( $a=0.599$ ) and therefore some improvement in terms of damped power. Then both values are used to compute the single-bunch HOM power and shown as a best/worst case scenario (Table 2). As a result of the computed wake-field spectrum it is inferred that 51.5% of the energy lost by the bunch is properly damped into HOMS. Therefore the amount of expected HOM power per cavity fluctuates in the range between 1kW~1.2kW. From this HOM power 67,6% of the energy is damped into the WG-D while 32,4% is propagated though the beam-pipes to the next cavity. This beam-pipe propagated power is a direct consequence of the increased beam-pipe. As a

consequence special attention needs to be put into the travelling power through beam-pipes. Possible heat extractions problems will be addressed as well as the effect of the transitions from enlarged beam-pipe to standard beam-pipe. As it is known a transition from a wide beam-pipe section to a narrower one might induce an important increase in the loss factor and needs to be evaluated. However this effect can be counter-acted by finding the correct damper-transition distance so energy can be effectively reflected back into the dampers.

### CONCLUSION

A complete detailed study of the different waveguide damping approaches to be applied on the design of the final 5 cell 1.5 GHz SRF cavity is presented on this work. The use of the WG size tailoring technique combined with the extended beam-pipe has been refined and is proved as an effective tool when high damping efficiency is required. Both techniques combined have demonstrated excellent performance when damping both TE/TM-like modes. In addition, a good damping performance has been recovered after removing one of the WG dampers and addition of the fundamental power coupler. As it is proved the worsening in damping introduced by the increased asymmetry induced by the FPC can be counteract with the proper optimization procedures.

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