BESSY VSR 1.5 GHz CAVITY DESIGN AND CONSIDERATIONS ON WAVEGUIDE DAMPING

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Abstract

The BESSY VSR upgrade of the BESSY II light source [1] represents a novel approach to simultaneously store long (ca. 15ps) and short (ca. 1.5ps) bunches in the storage ring with the "standard" user optics. To this end, new high-voltage L-Band superconducting multi-cell cavities must be installed in one of the straights of the ring. These 1.5 GHz and 1.75 GHz cavities are based on 1.3 GHz systems being developed for the bERLinPro energy-recovery linac. This paper describes the baseline electromagnetic design of the first 5-cell cavity operating at 1.5 GHz as well different design approaches to ensure reliable operation.

INTRODUCTION

Simultaneous operation of long and short pulses by BESSY VSR represents a very attractive upgrade of the conventional storage ring operation concept. Nevertheless, very restrictive and challenging SRF cavity design requirements must be fulfilled in order to ensure stable operation [2]. High E_{acc} (20 MV/m) are needed and special attention must be paid to the damping of high order modes (HOMs) excited by the beam that may otherwise cause coupled bunch instabilities of the beam [3]. This paper shows the current status of the prototype design for this first 1.5 GHz cavity starting from the mid-cell to the 5 cell design including damping concepts. To this end, Q_{ext} calculations have been performed with Ansoft HFSS eigenmode solver [4] while the centre cell optimisation studies have been performed in COMSOL MULTIPHYSICS (eigenmode calculator) [5].

MID-CELL DESIGN

The first stage on a SRF high current cavity design consists on finding the centre cell parameters fulfilling RF specification and offering best possible performance. SRF requirements imposed by project boundary conditions are: a low E_{peak}/E_{acc} (<2.3), low B_{pk}/E_{acc} (<2.3 mT/(MV/m)) and large $R/Q_{\parallel}$ for TM_{010} (>95 Ω per cell). The present mid-cell design is depicted in figure 1 compared to the Cornell [6] and Jlab [7] designs. In order to avoid trapped modes the iris diameter has been set to a relatively high value (ϕ=71.34mm) and thus obtaining a high cell to cell coupling factor (K_c=3.3%) for the fundamental mode. A final set of mid-cell parameters fulfilling specifications has been obtained by performing a parametric analysis in COMSOL MULTIPYSICS with the main figures of merit (R/Q, G, E_{pk}/E_{acc} and B_{pk}/E_{pk}) as design goal (Table 1). This software has been chosen due to its good performance in 3D simulation and post-processing from 2D parameterized geometries.

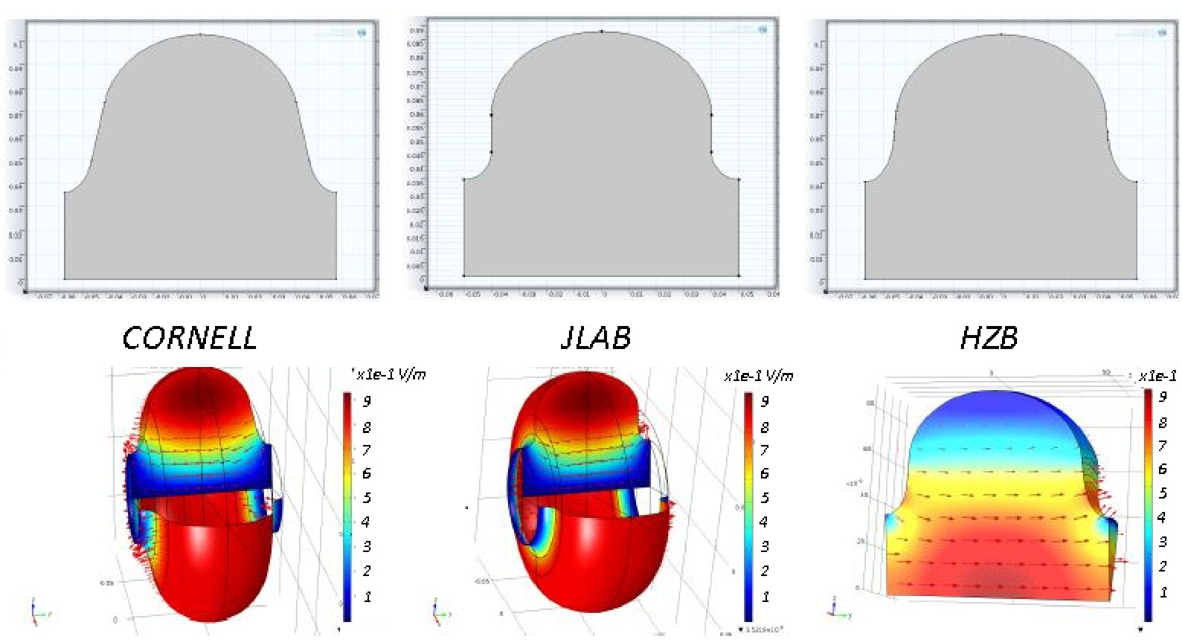

Figure 1: Layout of HZB Mid-cell geometry compared to Cornell and JLab base cell models.

Table 1: RF current parameters

Param.	Units	Goal	Mid-Cell	5 Cell
Epk/Eacc	-	≤ 2.3	2.29	2.29
Bpk/Epk	mT/(MV/M)	≤ 2.3	1.816	1.91
R/Q	(Ω)	≥ 95	100.7	105*5
G	(Ω)		280.05	279

MULTI-CELL CAVITY DESIGN

Once the centre cell geometry is fixed, the next step consists of creating a multi-cell prototype and tailoring the end-half cells shape to ensure field flatness. By this procedure a correct field distribution along the whole cavity is guaranteed minimizing the risks of quenching by undesired localized high peak fields. To this end, a 3D parametric tuning of the end-cells for the five cell model has been performed both in COMSOL and ANSOFT HFSS. In this case HFSS is introduced due to the accurate performance when applying perfect matching layers (PMLs) for computing losses on waveguide ports and thus Q_{ext}. In addition, since HOM dampers will be present in the final design the proper minimum distance end-cell-damper has been determined. This has to be done in order to perform a good HOMs propagation with no power leakage from the fundamental accelerating mode while protecting field from being affected by the vicinity of the dampers. To the present state only waveguide dampers are considered. As a result a field flatness value of 98.2% is obtained according to the general definition [8]. After this first optimization step, all the SRF goal parameter are fulfilled both for the mid-cell and the 5 cell cavity , as summarized in Table 1.

HOM Damping

A Y-shape waveguide system for HOM damping has been studied and is presented in this paper. On the present design, both end-groups are identical with 3 waveguides each (120° separation) and shifted 60° in order to cover for all polarisations. Two different waveguide damping schemes are presented. Each one is divided in two categories (Standard or tuned waveguide):

- HZB 5 cells-
  Standard and Tuned WG.
- HZB 5 cells enlarged beam pipe-
  Standard and Tuned WG.

The main difference between them is on the beam pipe cut-off frequency. On the first approach (HZB 5 cells), the cut-off frequency for the beam pipe is chosen to lay above the first dipole band (2.46 GHz). This design ensures no power from the fundamental accelerating mode (TM_{010}) to be lost by leakage on the dampers but might imply a worse HOM damping behaviour. For the second scheme, the beam pipe diameter is enlarged so the first dipole band can also be propagated ($f_{cut\text{-}off}$=1.67GHz).

In addition, two different scenarios have been considered for both cases: The Waveguide HOM dampers dimensions are set to standard waveguide with H=W/2 (44mmx88mm) and the height of the waveguide is slightly increased (H=60mm) (tuned waveguide).

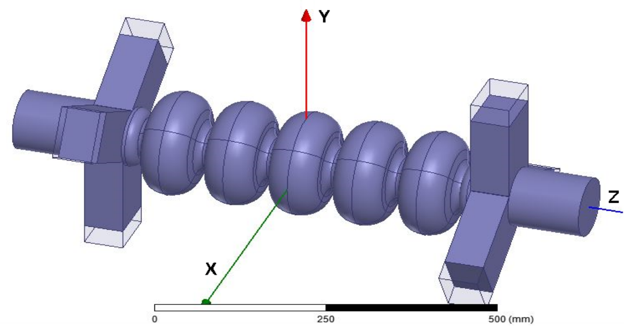

Figure 2: Layout for the HZB enlarged beam pipe design with enlarged WG (a).

The reason for this variation is based on the field distribution in transitions from the end-cell to the beam pipe for some modes such as the quadrupole TM_{211}. On the equator of the last cell, being a TM mode, the magnetic field rotates around Z axis with pure transverse orientation. Nevertheless, in the transition to the beam pipe, H field orientation changes gaining an important longitudinal component. Thus, the damping of this type of mode is compromised since the cut-off frequency for the HOM waveguide damper is no longer only defined by the waveguide width (W, transversely oriented) but also by its height (H, longitudinally oriented). This effect is depicted in figure 3.

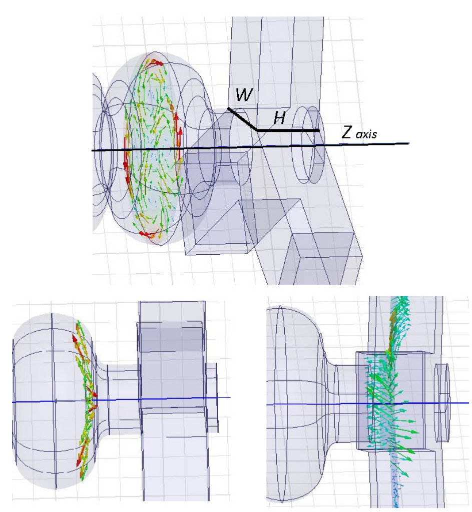

Figure 3: Magnetic field distribution for the TM_{211} mode in the transition from last cell to damping region.

Figure 4 shows a comparison between modal spectrums for the HZB 5 cell case with both scenarios (standard and enlarged waveguide). As depicted on this figure, the Q_{ext} values of some modes such as TE_{011} and TM_{211} drop considerably from the standard case to the WG tuned case. Also, damping for the TE_{211} quadrupole mode (2.5 GHz band) is slightly improved. Nevertheless, the TM_{011} monopole mode which seems to be a limiting band for stability reasons can't be improved by this technique.

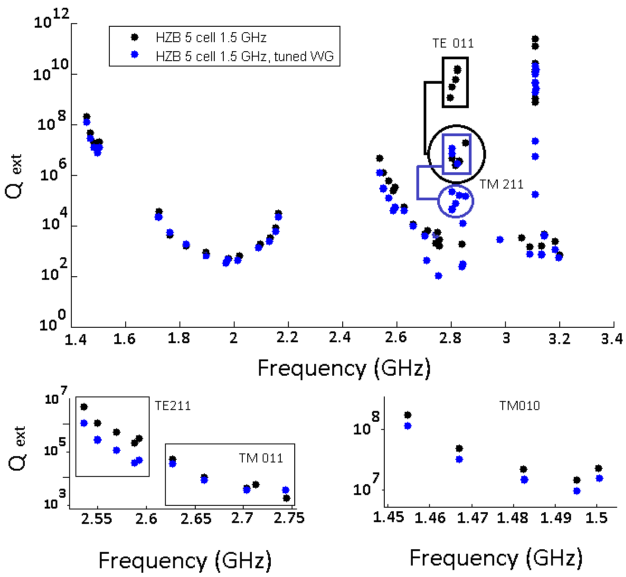

Figure 4: Qext vs Frequency for the HZB 5 cell model with normal waveguides (black) and tuned waveguides (blue).

Figure 5 shows HOM damping enhanced by lowering the cut-off for the beam pipe by means of enlarging the diameter as in the bERLinPro case [9] ($\phi_{HZB5\text{-}cells}$=71.34mm, $\phi_{HZB5\text{-}cells\ enlarged\_beampipe}$=105mm). In this model all the bands experiment a significant drop in their Q_{ext}, and especially the TE_{211} (2.5 GHz band) quadrupole mode. At the same time, the limiting TM_{011} monopole mode (2.6 GHz band) damping is slightly increased when compared to the HZB 5 cells case. Nevertheless this mode is not affected and thus can't be damped further away by any variation on the waveguide size. A comparison with standard beam pipe (HZB 5 cell) is depicted on this plot. The HZB enlarged beam pipe model shows a better performance regarding higher order bands while limiting the damping of the fundamental TM_{010} mode. Loading for the fundamental mode has been arbitrarily set to a value of 1e8 in order to perform a proper damping comparison for different techniques.

CONCLUSIONS

A detailed study of the future 1.5GHz 5 cell cavity prototype to be built for the BESSY VSR upgrade has been presented on this paper. Special emphasis has been put on developing different waveguide damping procedures due to its crucial role on beam stability. As a

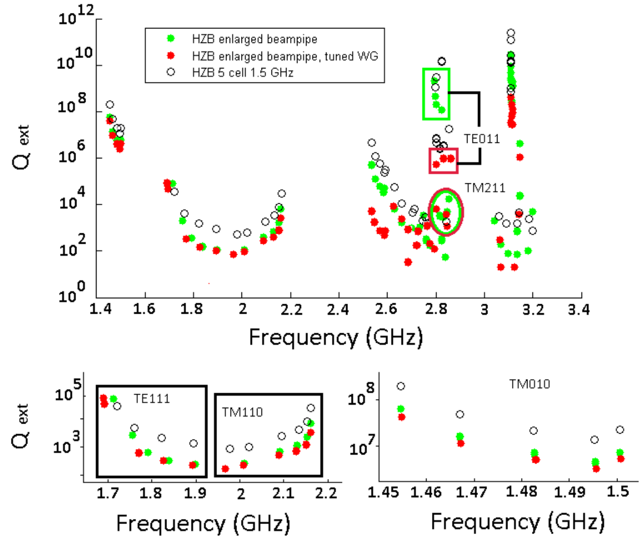

Figure 5: Q_{ext} vs Frequency for the HZB enlarged beam pipe model with normal waveguides (green) and tuned waveguides (red). The HZB 5-cell results with the smaller beam pipe are shown in black.

result, widening the beam pipe diameter has been proved to significantly help on damping dipole modes such as the 1.7-2.2 GHz band without compromising the field response or fundamental power. In addition, this technique has been proved to be a good tool in order to reduce the effect of the TM_{011} dangerous monopole mode. Also, any possible impact on beam stability due to the high Q of some longitudinal modes around 2.8 GHz has been drastically reduce by applying the tuned waveguide technique. Nevertheless, this work represents just a first step in the design of the final 1.5 GHz cavity prototype. It is necessary to accurately evaluate the damping level needed for every HOM in order to ensure stable operation without severe influence on the beam performance. To this end, coupled beam instabilities (CBI's) will be next studied as described in [3] on the basis of the longitudinal and transverse impedance values with special attention to the longitudinal modes.

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