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FIRST CAVITY DESIGN STUDIES FOR THE BESSY-VSR UPGRADE PROPOSAL*

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Abstract

Recently HZB proposed an upgrade of the 3rd generation synchrotron light source BESSY II allowing simultaneous long and short pulse operation [1]. For this scheme superconducting higher harmonic cavities of the fundamental 500 MHz at two frequencies need to be installed in the BESSY II storage ring. Given an appropriate choice of the higher harmonics the resulting gradient leads to a beating effect of the effective longitudinal focusing voltage at the stable fix points resulting in different bunch lengths in subsequent buckets. This project places stringent requirements on the cavity performance, as high accelerating fields, excellent HOM damping capabilities and high reliability as they will operate in a 300 mA 24/7 user facility. In this paper we describe the requirements for the cavity design and first design steps.

INTRODUCTION

The BESSY-VSR proposal is a planned upgrade of the existing BESSY II storage ring. By inserting two higher harmonic cavity systems at the 3rd and 3.5th harmonics of the fundamental 500 MHz cavity a beating of the total voltage as seen by the beam can be created. By this RF buckets are formed which experience different voltage gradients and thus different bunch lengths of the beam using standard beam optics. The working principle is displayed in Figure 1.

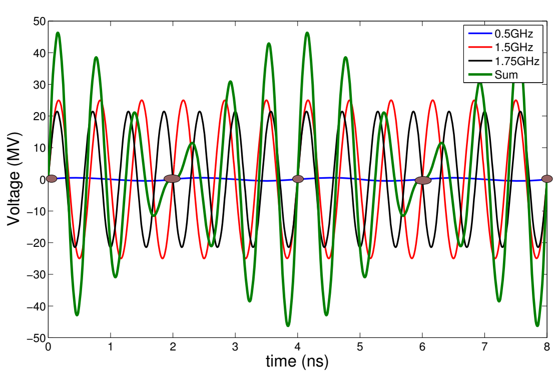

Figure 1: Voltage beating by the three cavity system in time domain for a factor 10 bunch shortening. The long bunches are placed within the low gradient buckets, while the short bunches appear 2 ns shifted.

Presently, it is foreseen to sacrifice one low $\beta_{x,y}$ straight section to fit a cryomodule with both frequency systems into the ring. For this 5m long section optimizations were first done taking the avoidance of trapped cavity higher order modes (HOM) and an optimized real estate gradient into account to limit the peak fields within the cavities. This resulted in using two 5-cell 1.5 GHz and three 4-cell 1.75 GHz cavities or a more symmetric system with higher peak fields for the 1.75 GHz system consisting of two 5-cell units. Table 1 lists the required RF parameters of the two higher harmonic systems for a more relaxed scenario of a factor nine in bunch length reduction. The quoted mean accelerating fields are within reach of such class of cavities as demonstrated at e.g. JLab for a 1.5 GHz high current cavity design [2].

Table 1: Required SRF cavity parameters of the higher harmonic systems for a factor 9 reduction in bunch length and assuming an even filling of the high current long pulse buckets

RF frequencies	1.5, 1.75 GHz
Voltage at 1.5 GHz	20.25 MV
Voltage at 1.75 GHz	17.36 MV
Mean acc. gradient at 1.5 GHz	20.25 MV/m
Mean acc. gradient at 1.75 GHz	16.88 MV/m
Cell number at 1.5 GHz	2x5 cell
Cell number at 1.75 GHz	3x4 cell
$I_{avg,beam}$	300 mA
Cavity detuning for beam loading	+11.5 kHz
at even filled buckets 1.5, 1.75 GHz	−18.9 kHz
$P_{forward}$ per cavity (1.5, 1.75 GHz)	2.7, 0.9 kW
Q_{loaded}	$5 \cdot 10^7$
R/Q per cell $TM_{010,\pi}$	≥105 Ω
Φ_{acc}	-90, 90 deg

RF REQUIREMENTS FOR THE SC CAVITIES

Fulfilling the RF requirements set by the boundary conditions of this project combining high current operation at high peak field with excellent HOM damping is quite an endeavor. In addition we face challenges in operating SRF systems in a storage ring not originally designed for such devices.

The major design issue is to avoid a longitudinal or transverse instability (coupled bunch instability, see [3]) of the beam by interaction with the cavity's higher order modes,

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but as well as the same order modes of the fundamental TM_{010} passband, as described in [4]. Besides the high average current, the beam's spectrum is populated by different effects, e.g. synchrotron sidebands which increase an interaction probability with the HOMs. By the beam's revolution frequency the cavity impedance spectrum is sampled every 1.25 MHz by a 300 mA beam. Taking the natural frequency spread of HOMs by the cavity production process into account, a variation of the HOMs frequency by 5 MHz rms and a variation of the mode's external Q by a factor of three [5] may occur. As thus a prediction of cavity performance by simulation and design to tune modes off the beam spectral content is rather uncertain, the main goal would be in damping all HOMs to a Q_{ext} as low as possible.

The same-order modes by the TM_{010} passband should have a rather high cell-to-cell coupling and a cell number ≤5 is preferred to avoid overlaps of these modes (e.g. $1/5\pi$-$4/5\pi$) with the beam harmonics and synchrotron sidebands at 8.0 kHz for the long bunches [3]. Typically the next passband to the π-mode is shifted by an order of 1 MHz for current designs. With the bERLinPro ERL project [6] there is

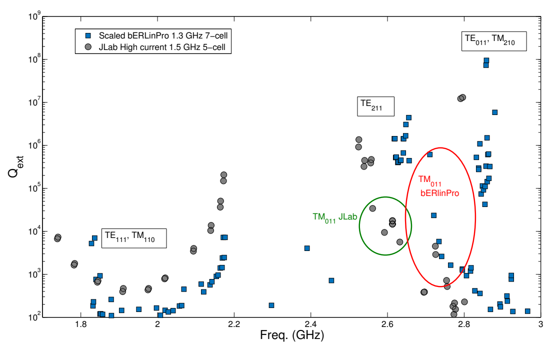

Figure 2: Comparison of the calculated Q_{ext} for the JLab high current design and the 1.3 GHz bERLinPro design scaled to 1.5 GHz. Marked is the area of the TM_{011} limiting the VSR concept.

already in-house experience with designing cavities for high current machines. Figure 2 displays a comparison between the achieved Q_{ext} of the JLab design [2] and the bERLinPro ERL 7-cell design scaled in frequency [7]. Both designs use the JLab approach of rectangular waveguide HOM dampers. Whereas the JLab design extends the iris diameter to the beam tube, the bERLinPro design uses also a nose transition to an enlarged beam tube, similar to the Cornell ERL design [8]. Both design shown here exhibit a strong damping of the dipole modes, which contribute mostly to the one-pass beam break-up instability. However, calculations presented at this conference [3] show, that for the BESSY II ring the longitudinal modes appear more harmful and limit the VSR concept. The damping of the TM_{011} modes is about a factor 3 too low for the current BESSY II longitudinal feedback and synchrotron frequency.

Thus, besides optimization of the damping by waveguides or beam tube HOM absorbers, strong emphasis has

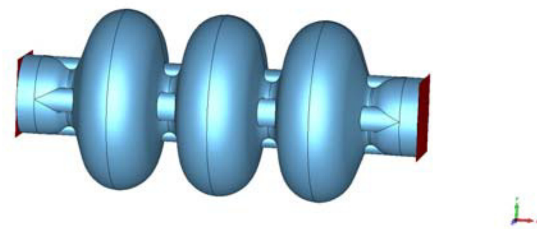

Figure 3: Example for design studies based on TESLA cells to increase the cell-to-cell coupling and HOM propagation by fluted iris.

to be placed on increasing the HOM's cell-to-cell coupling, especially for TM_{0np} type of modes. Figure 3 shows first design approaches under study to increase the HOM's propagation. Besides those more exotic approaches work is also done on optimizing classic elliptical cavity designs and further ideas, which will be published in the near future. Fig-

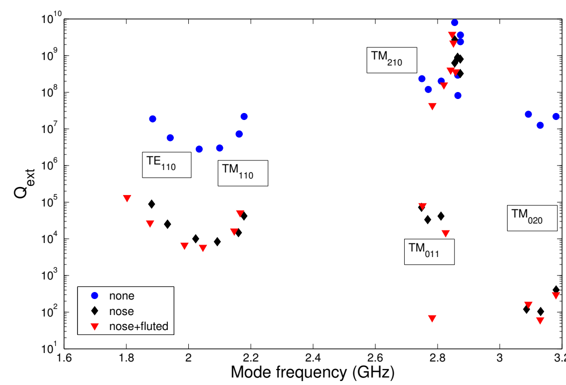

Figure 4: Comparison of Q_{ext} achieved with a 3-cell TESLA cavity to study different cell-to-cell coupling and damping concepts.

ure 4 compares achieved damping for a field flat tuned 3-cell TESLA type cavity without any modification but increased beam tubes and a cell-to-cell fluted iris to increase the damping via the beam tubes only. Note, that for the latter the electric peak field ratio is increased. So far these two concepts demonstrate good propagation of the next higher monopole HOMs.

The HOM damping and the further requirements can be summarized as follows:

- $E_{peak}/E_{acc} \leq 2.3$ as the cavities operate at high fields to avoid field emission (FE) and FE driven quenches
- To limit the probability of trapped modes with high Q_{ext} the cell number should be ≤5.
- $R/Q_{TM_{010}\pi} \geq 95\,\Omega$ per cell
- High cell-to-cell coupling to allow propagation of HOMs and to widen the TM_{010} passband.
- A large enough iris diameter to avoid cavity heating by beam halo or beam loss.

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- The geometry constant $G = R_{\text{surface}} \cdot Q_0$ should not be larger by 20 % than current designs, even though RF losses are not a major design goal

CHALLENGES FOR EXPECTED MODES OF OPERATION

Besides the impedance requirements these SRF structures have to handle different modes of operation of the storage ring. BESSY II is operated in top-up mode and it was demonstrated [9] that injection in short bunches will not be possible, requiring the SC cavities to be ramped down. Assuming the top-up mode fill period can be extended to 1 s, it was already experimentally shown, that a fast field ramp within that range is possible [10]. However the strong detuning needed for the beam-loading will not be able to be set on that time scale using mechanical tuners. Piezos usually offer only limited range of $\leq$1 kHz [11]. Thus more power reserve has to be accounted for the top-up mode and a rather lower Q_{ext} of the order of 10^6.

A very important issue is to handle the case of a failure of the SRF systems by quench, cryo-plant malfunction or controlled "parking" of the cavities in the case of long pulse mode only. In all conceivable failure scenarios it has to be made sure, that the cavity can be detuned such to be invisible for the beam. Detuning by mechanical means can achieve a level of about $\pm$300 kHz, whereas from 1.8 K to room temperature the cavity detunes by -2.5 MHz and by typically $\approx$100 Hz/mbar helium pressure.

We calculated the impedance spectrum of the cavity for different conditions including the following effects (see Figure 5):

- Frequency shift by thermal shrinkage
- Frequency shift by helium gas pressure level
- Temperature (and frequency) dependent normal conducting surface resistance
- Temperature (and frequency) dependent superconducting RF BCS surface resistance

The mode's frequency first increases with temperature by the helium pressure, but for higher temperatures the thermal expansion dominates. Any interaction of this passband has to be avoided by proper passband's frequency control as proposed in [4] as it has the highest impedances.

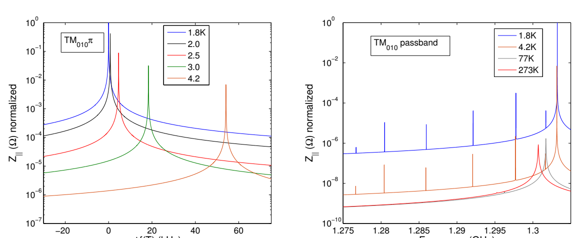

Figure 5: Impedance of the TM_{010}-π mode (left) and the TM_{010} passband for different temperature level accounting for frequency shifts by helium pressure and thermal shrinkage/expansion for the bERLinPro design.

Ongoing, but yet not completed studies are performed with respect to a non-uniform filling of the RF buckets, e.g. for ion clearing or single reference pulse. The resulting 100 buckets gap will cause a fast repetitive transient beam-loading on a time-scale faster than usual LLRF's and tuner system's response time. Further, because of the possibility, that one specific HOM leads to coupled bunch instabilities, it is thought of extending the capabilities of the mechanical tuner for a kind of 2D tuning scheme.

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