STATUS OF THE HOM CALCULATIONS FOR THE B*ERL*inPro MAIN LINAC CAVITY*

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Abstract

The Berlin Energy Recovery Linac Project (B*ERL*inPro) is designed to develop and demonstrate CW LINAC technology and expertise required to drive next-generation Energy Recovery Linacs (ERLs). Strongly higher order mode (HOM) damped multicell 1.3 GHz cavities are required for the main linac. The cavity under study is an integrated design of the Cornell base cell with JLab HOM waveguide couplers. Modifications to the end group design have also been pursued, including the substitution of one waveguide by a HZB-modified TTF-III power coupler. In this paper the progress in HOM calculations to avoid beam-breakup instabilities for the favored cavity structure will be presented.

INTRODUCTION: THE B*ERL*inPro PROJECT

The B*ERL*inPro ERL will be a CW driven machine accelerating a 100 mA beam to 50 MeV while preserving a normalized emittance of better than 1 mm mrad at a pulse length of 2 ps [1]. For the different sections of the superconducting accelerator -SRF photo-injector, booster module and main linac in the recirculator- the operating boundary conditions for the cavity design vary from high current, high beam loading to a high current, zero net beam loading environment. Thus the requirements for quality factor and peak fields are quite different for these three cavity types as well as the HOM damping technique applied. Main emphasis of this paper will be the calculations for the main linac cavity.

The main linac cavity has to have strong HOM damping as it accelerates the beam during the first passage and decelerates the recirculated beam for energy recovery thus interacting with two 100 mA beams. The beam may excite a transverse acting mode, e.g. a TM_{110} dipole mode, which deflects a following bunch. After recirculation, this bunch will arrive within the same structure affected now by an offset and, depending on the phase advance, possibly further exciting this dipole mode.This effect may add up from bunch to bunch until the beam will be lost - the so called beam break up (BBU) [2]. Equation 1 describes the dependance of the threshold current I_{th} for one cavity HOM on the mode's transverse shunt impedance $R/Q_{\perp}$, its external quality factor Q_{ext}, frequency ω and the beam's energy γ, recirculating time t_{r} and the transfer matrix of the linear beam optics M_{12}:

$$I_{\text{th}} = -\frac{2\gamma}{e}\frac{c}{\frac{R}{Q}_{\perp} Q_{\text{ext}}\omega M_{12}}\frac{1}{\sin(\omega t_{\text{r}})}. \qquad (1)$$

From the viewpoint of cavity design it means to minimize the HOM's $R/Q_{\perp}$ and Q_{ext}. The HOM's spectrum and dispersion relation is mainly influenced by the mid-cell design, especially the cell-to-cell coupling via the iris diameter. By tuning the end-cells one achieves first of all field flatness for the fundamental TM_{010}-π mode and may avoid trapped modes within the center cells. The end-cell is mainly responsible to couple the HOMs to the loads or damping structures.

In this paper an update of the HOM calculations of the main linac cavity is given which was already introduced in [3]. Further a short outlook on ongoing activities is given of which more is described in [4].

STRUCTURE DESIGN AND EIGENMODE CALCULATIONS

The baseline design so far consists of a seven cell structure using the Cornell's ERL design [5] and combining it with JLab style symmetric assembled waveguide HOM couplers [6] (see Figure 1). To allow for a flexible coupling, one group of HOM couplers is broken in symmetry by replacing one waveguide with a TTF-III type coaxial fundamental power coupler. This design combines the good peak field properties of the Cornell design with the advantage of waveguide couplers having a natural cutoff above the fundamental and further limiting the possibility of dust from ferrite beam tube absorbers propagating in the SC cavity.

Table 1 summarizes the figures of merit of the field-flatness tuned seven cell structure. The main task of this adapted design was to calculate its performance with respect to BBU, identify limiting HOMs and find means to tune them to lower Q_{ext} while preserving the fundamental's RF properties. Because of the influence of the couplers on the field distribution, most calculations done so far were carried out in 3D with CST MWS [7] making use of the given symmetry plane at the coaxial coupler and using both mesh types, tetrahedral and hexahedral, where the latter had to be used to calculate the Q_{ext}. In all results shown here mainly the Jacobi-Davidson-Method (JDM) was used. Figure 2 shows the calculated spectrum up to 3 GHz, mainly limited by mesh size versus computing power and time. Figure 3 depicts the corresponding Q_{ext}, demonstrating a rather good damping of the lowest order dipole

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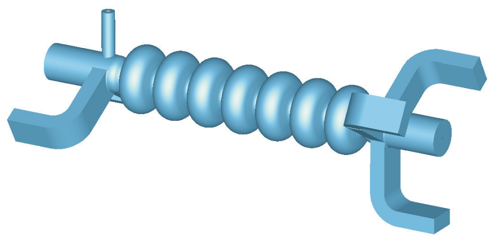

Figure 1: Drawing of the cavity design under consideration for B*ERL*inPro. It combines the Cornell ERL base cell with JLAB style waveguide HOM dampers and a tuneable TTF-III fundamental power coupler (FPC). This design features one symmetry axis in the FPC plane.

band, but some weak coupling to some of the quadrupole modes.

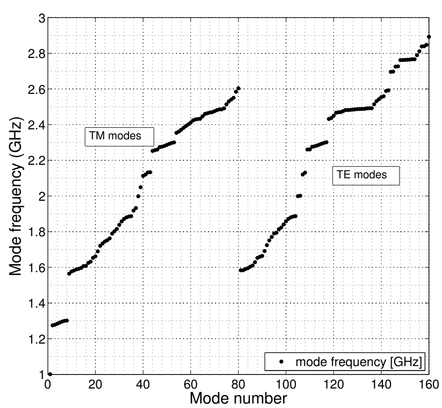

Figure 2: Frequency of all TE/TM modes up to 2.85 GHz, about the lower range of the 4$^{\text{th}}$ dipole band. All the modes were calculated using the 3-D eigenmode solver of CST MWS$^{\text{TM}}$.

The final goal will be to minimize the product $R/Q_\perp \cdot Q_{\text{ext}}$ for all HOMs. The $R/Q_\perp$ was directly evaluated making use of the Panofsky-Wenzel theorem by integrating the transverse Lorentz forces along the beam path. The resulting $R/Q_\perp$ is shown in Figure 4. Again the dipole modes seem sufficiently damped while some quadrupole modes due to their high Q_{ext} and some unexpected non-zero shunt impedance on axis show to be the most harming modes concerning BBU. An example of a strongly localized HOM with high Q_{ext} is given in Figure 5. The question arised whether these remnant on-axis fields are due to meshing and thus numerical inaccuracies of the method used or due to some shift of the quadrupole fields by the influence of the FPC.

TRANSVERSE SHUNT IMPEDANCE

To investigate the possible shift of quadrupole modes a calculation of $R/Q_\perp$ along circular distributed integration paths at an arbitrary offset of 5mm was done using the following approximation to mitigate numerical meshing errors:

$$R_{\perp x} \approx \left| \frac{c}{\omega} \frac{\sqrt{R_\parallel(x_2)} - \sqrt{R_\parallel(x_1)}}{x_2 - x_1} \right|^2 . \qquad (2)$$

Figure 6 shows the distribution of $R/Q_\perp$ versus the polar angle of the integration paths for a quadrupole mode. Obviously the mode is shifted along the vertical axis (FPC axis).

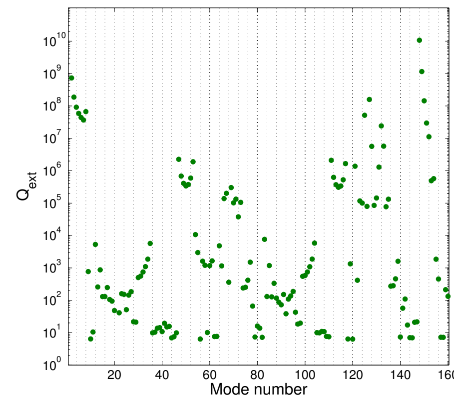

Figure 3: External Q of all TM/TE modes up to 2.85 GHz. While the dipole modes are sufficiently damped, some quadrupole modes exhibit large $Q_{\text{ext}} > 1 \cdot 10^6$.

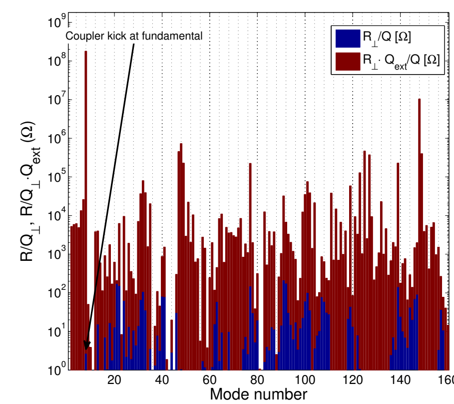

Figure 4: Transverse $R/Q_\perp$ and $R/Q_\perp \cdot Q_{\text{ext}}$ for all TM and TE modes up to 2.85 GHz (beginning of 4$^{\text{th}}$ dipole band). The arrow marks the coupler kick by the TTF-III power coupler at the fundamental mode.

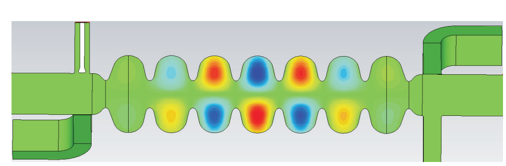

Figure 5: Example of strongly localized quadrupole mode at 2.3 GHz. This mode exhibits a high external Q with only low coupling to the waveguide dampers.

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Table 1: Cavity Figures of Merit for the TM_{010}-π Mode of the Tuned Structure

Parameter	Value
$R/Q(\Omega)$	754
E_{surf}/E_{acc}	2.07
$\Delta\nu$ (MHz)	1.54
Q_{ext}	$5 \cdot 10^7$
Geometry factor $G(\Omega)$	272.7

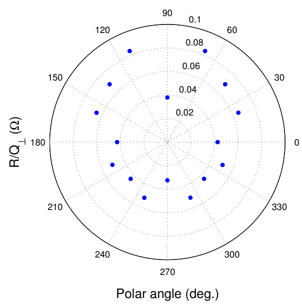

Figure 6: Polar plot of transverse R/Q determined on circularly arranged integration paths at 5mm offset from beam axis for a quadrupole mode.

Figure 7 shows the shift of the first dipole and quadrupole mode bands versus the beam axis. Most modes of these bands are shifted more than the expected vertical beam size in the linac and thus quadrupole modes may exhibit a dipole component. This effect needs to be investigated in

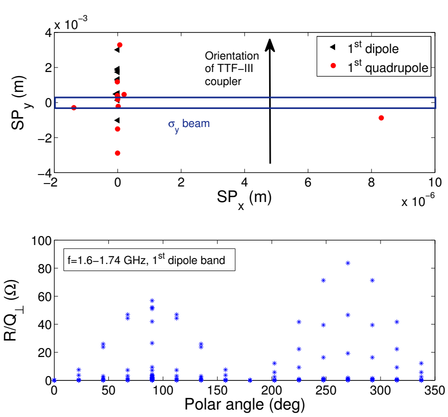

Figure 7: The upper plot shows the shift of the dipole and quadrupole modes of the first bands mainly in direction of the FPC. The blue square denotes the transverse beam size. The lower plot depicts the $\frac{R}{Q}_{\perp}$s of the first dipole band versus polar angle at a distance of 5mm from the beam axis.

more detail and it has to be understood how much the coupler's position influences this effective dipole component of the quadrupole modes.

OUTLOOK

The calculations using 1.5-3M mesh cells are too time consuming and cumbersome to become the core of an optimizer routine for tuning the end-cells to lower the Q_{ext} for the dangerous HOMs. In the next steps the authors will combine Coupled S-parameter Calculations [8] of the segmented structure with 2-D eigenmode calculations of the rotationally symmetric cavity cells to create a set of field-flat cavity designs and run an optimizer loop for minimizing $R/Q_{\perp} \cdot Q_{ext}$ [4]. Once a sufficiently performing design is found, these calculations will be extended to the full three cavity string, as already the lowest order dipole modes propagate along the beam tube and thus also couples to the waveguides of the next cavity.

Also a more detailed investigation of the FPC's influence of the HOM's center shift is planned by changing the coupler's position. As a side-effect the coupler kick of the fundamental mode will be calculated for different Q_{ext}.

Recently the bead pull and RF measurement of an aluminium model of the base cell design was started at TU Dortmund. After fabrication of the end groups, this model may be used to validate some of the findings of the calculations presented within this paper.

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