FIRST CONSIDERATIONS CONCERNING AN OPTIMIZED CAVITY DESIGN FOR THE MAIN LINAC OF BERLinPro

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Abstract

The Berlin Energy Recovery Linac Project (BERLinPro) 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 optimization of the cavities presented here is primarily based on a comparison of the JLab 1.5 GHz 5-cell high-current cavity design with a 7-cell Cornell design. While the JLab cavity was scaled to 1.3 GHz and extended to 7 cells, we integrated JLab HOM waveguide couplers into the Cornell structure. Modifications to the end group design have also been pursued, including the substitution of one waveguide by a HZB-modified TTF-III power coupler.

INTRODUCTION

HZB is building a demonstrator ERL facility that aims at low emittance and high current operation at 100 mA [1]. Preliminary results of the studies for the BERLinPro main linac are discussed. For ps long bunches HOM power in the order of 100 W/m can be generated in a frequency band up to $\approx 100\,\mathrm{GHz}$.

Optimizing cavity shape and cells per cavity is an important method to reduce HOM power beforehand. Since superconducting resonators are used, it is desirable to minimize $E_{\mathrm{surf}}/E_{\mathrm{acc}}$ by iris radius manipulation of base cells while maintaining sufficient intercell coupling to prevent HOMs being trapped inside the structure.

To maximize the average acceleration gradient of the main linac module, considerations are based on two different, existing cavities that were extended to 7 cells, which is a compromise between HOM extraction and acc. gradient (see Fig. 1). The remaining HOM power will be extracted with specialized waveguide couplers (see Fig. 2) that are hoped to provide efficient coupling while minimizing beam disturbance. The waveguide couplers should be effective up to high frequencies and require minimal space in longitudinal direction. Corresponding models of 7-cell cavities with waveguides, including a modified TTF-III power coupler [2], were evaluated in search for unwanted high-Q HOM resonances using wakefield and eigenmode solvers.

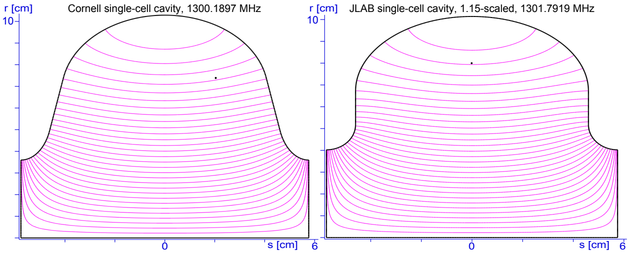

Figure 1: Comparison of Cornell (left) [3] and scaled JLab (right) [4] base cells with π-mode electric field lines [5].

In recirculating BBU theory for ERLs and for an uncoupled lattice, the current treshold for a single cavity roughly depends on $R_{\perp}/Q_{\mathrm{loss}} \cdot Q_{\mathrm{tot}}$ of the considered deflecting mode [6]. Unlike in storage rings with one eigenfrequency for each direction (betatron and synchrotron tunes), the HOM frequencies of all cavities form sidebands along the filling pattern, and the alternating stable and unstable frequency bands have a width of only a half circulation frequency (far-field wake). Therefore, every HOM has the high probability of $1/2$ to generate positive feedback, and the external quality factors of all TM-like dipole higher order modes need to be minimized to a sufficient extent. In addition, conventional linac BBU can occur at harmonics of the bunch repetition rate and must also be taken into account for all modes.

STRUCTURE DESIGN

E_{surf}/E_{acc} Optimization of Base Cells

Base cell studies with longitudinal π-periodic boundary conditions for the fundamental mode have been performed using the 2D code SUPERFISH [5] (see Fig. 3). The iris radius was gradually decreased from the (scaled) original radius (JLab 40.2 mm, Cornell $\approx$ 36 mm) to 30 mm. The design goal of 2.0 could not be reached by this decrease for the JLab standard cell.

Module Simulation Setup

For a first estimation of relevant HOM resonances, both multicell designs, consisting of the two different base cell designs with corresponding endcells, 5 waveguide couplers and one modified TTF-III power coupler, were simulated using a wakefield solver [7] to wake lengths of $\approx$ 500 m

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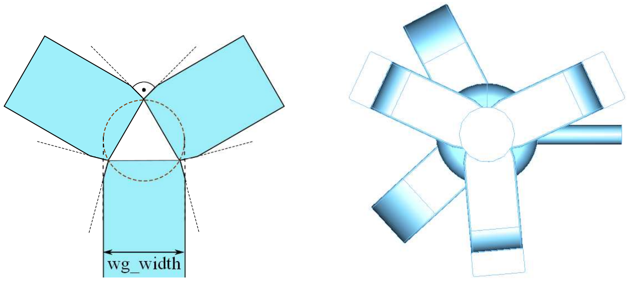

Figure 2: left: preliminary sketch of the 3-fold symmetric waveguide. right: asymmetric waveguides and power coupler in the Cornell-type model.

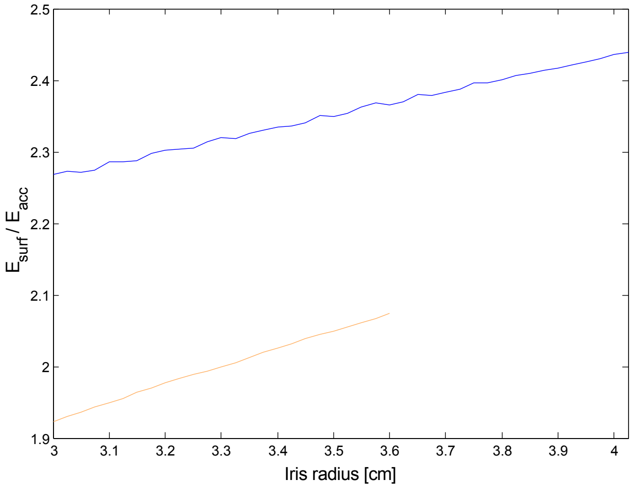

Figure 3: Surface-to-acc. gradient ratio for different iris radii of the 1.15-scaled JLab (blue) and Cornell cell (green). The maximum iris radius is the standard radius.

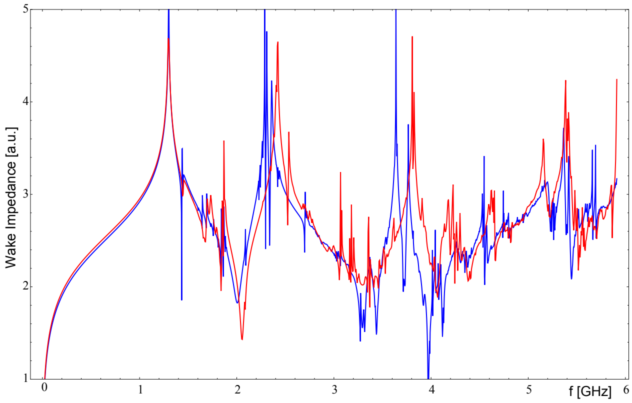

Figure 4: Comparison of longitudinal wake impedances of Cornell- (red) and Jlab-based (blue) cavities with modified TTF-III couplers and waveguides.

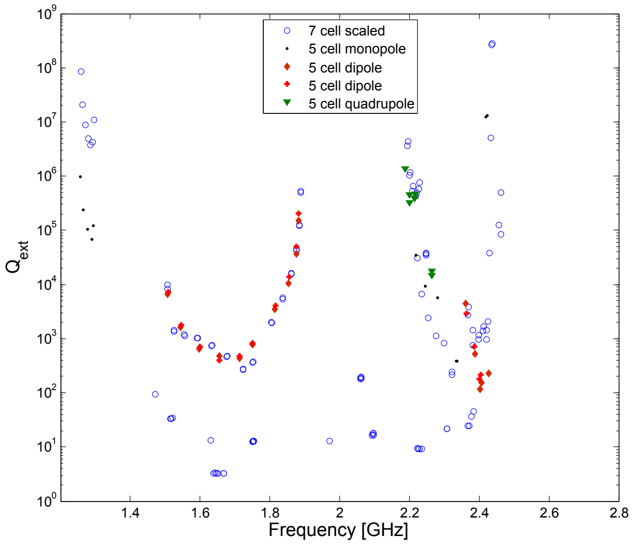

Figure 5: Results of eigenmode calculations for Q_{ext}. The 7-cell 1.15-scaled JLab-type cavity is compared to Q_{ext} data from the original 5-cell JLab-type cavity [4, 8].

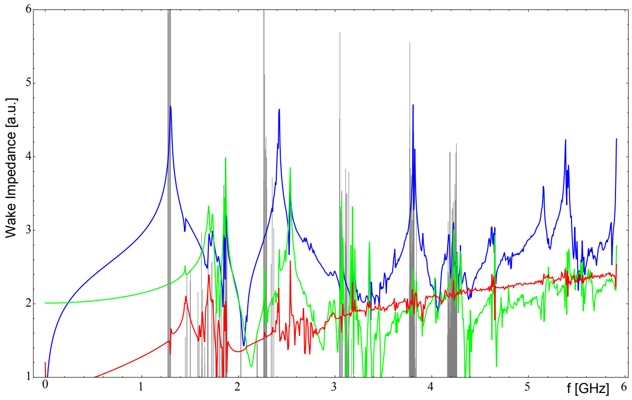

Figure 6: Wake calculation Results (blue: longitudinal, red/green: transversal) mixed with shunt impedances (maximum of longitudinal shunt impedances sampled on axis and two parallel off-axis paths) of eigenmode solvers (gray) for the Cornell-based model with modified TTF-III coupler and asymmetric waveguide configuration.

($\Delta\nu \approx 600\,\text{kHz}$, $\nu_{\text{max}} = 6\,\text{GHz}$, see Fig. 4) with a bunch path parallel to the design axis. The endcells were taken from the original geometries, e.g. JLab endcells are 4,2% shorter than base cells.

This approach allows to observe dipolar and higher modes and to separate most spectral lines. Additional field probes were included for localization of modes (see Fig. 8). Subsequently, small frequency bands with considerable wake impedances are investigated using Jacobi-Davidson and Krylov-subspace eigenmode solvers [7], retrieving Q_{ext} (see Fig. 5) and R/Q of the relevant modes (until now up to 4.3 GHz, see Fig. 6).

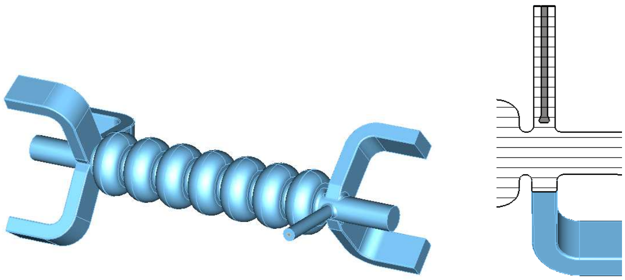

Figure 7: Overview and detail of the modified 7-cell JLab cavity with one modified TTF-III coupler. Note that for technical reasons the waveguide couplers are bent outwards, while they will be bent inwards inside the cryomodule.

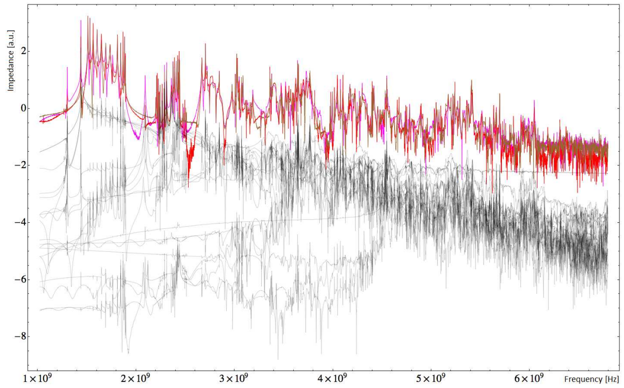

Figure 8: Field intensity in cell probes of JLab-type model with modified TTF-III coupler (colors) and corresponding outgoing port power (black).

Modified TTF-III Coupler and Waveguide Modifications

The HZB-modified TTF-III power coupler works with high input power up to 10 kW and allows adjustment of Q_{ext} in operation [2]. Thus it was included in both cavities, substituting one of the six waveguides, and the remaining two waveguides were adjusted to create a right angle (see Fig. 7).

Studies of introducing more asymmetric features to the waveguide angles are in progress to further account for the substitution of one waveguide (see Fig. 2).

To find the right antenna position, the surface distance of the antenna from the beam axis was manually optimized to yield $Q_{\mathrm{ext}} \approx 4 \cdot 10^7$. The corresponding surface distance is 58mm.

Choice of Tuner

It was considered to move the waveguides away from the endcell for installation of a Saclay-type tuner. For the JLab-type cavity, this would result into a decrease of HOM coupling by four orders of magnitude because many HOMs are evanescent for the given beam tube radius. Therefore, blade tuners will be used which do not require any additional space between endcells and waveguides.

OUTLOOK

The results of this study will be used for BBU calculations with different lattice configurations. Based on the outcome of this calculations, a decision will be made which of both cavity designs will be further developed. This cavity will be used for construction of a modular, normal-conducting brass model consisting of lateral half cell brass elements (cut in half along an axis parallel to beam path) and different endgroups. The model will be characterized using a bead-pull measurement stand at TU Dortmund University.

SUMMARY

We have started design considerations for the BERLinPro main linac on basis of two known linac cavity designs that were changed for high acc. gradient, flexible input power coupling and higher order mode damping with waveguides.

The first results obtained by electromagnetic simulations (base cell optimization, external quality factors of HOMs, shunt impedances, power coupling) have been presented and act as input to further numerical studies.

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