ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPME017

STUDY OF HIGHER ORDER MODES IN MULTI-CELL CAVITIES FOR BESSY-VSR UPGRADE*

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Abstract

BESSY-VSR is a planned scheme to upgrade the existing BESSY II storage ring to support variable electron pulse lengths. In addition to the present 0.5 GHz energy replenishment cavity, two additional SRF bunch compressing cavities operating at 1.5 GHz (3rd harmonic) and 1.75 GHz (sub-harmonic), will be installed. These cavities are essential to produce short 1.5 ps bunches with a current of up to 0.8 mA per bunch. In order to achieve such high beam currents, higher order modes must be damped in the superconducting cavities. In this work we present analysis of higher order modes in cavities with different mid-cell shapes.

DESIGN OF CAVITY

BESSY-VSR superconducting radio frequency (SRF) cavities will run at two different frequencies to produce RF-voltage beating [1]. Design of the cavity used in this work is similar to the bERLinPro [2] energy recovery linac (ERL) main cavity [3], as shown in Fig. 1. The design uses

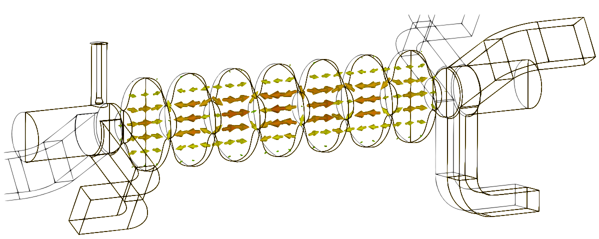

Figure 1: Fundamental π-mode in a 7-cell cavity with WG HOM couplers and coaxial input coupler.

the Cornell ERL mid-cell shape combined with JLab 3-fold symmetric waveguide higher order mode (HOM) couplers. One of the WG couplers is replaced by a coaxial TTF-III type fundamental power coupler. Waveguide (WG) couplers have cutoff frequency of the first mode $f_{c,\mathrm{WG}}$ at 1.578 GHz, above the fundamental accelerating mode frequency f_π at 1.3 GHz. Beampipes (BP), on both sides, are connected to the cavity cells by a narrowing nose with iris radius equal to the mid-cell iris radius. Cutoff frequency of the first BP mode $f_{c,\mathrm{BP}}$ at 1.597 GHz is also above the fundamental mode frequency and just below the first dipole band occurring above 1.6 GHz [3, 4]. In this preliminary study, in order to make a comparison with previous results obtained with similar numerical methods [5], cavities are modeled with geometries resulting in π-mode at 1.3 GHz.

* Work supported by Federal Ministry for Research and Education BMBF under contract 05K13HR1.
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These cavities in the future will be scaled down to the operational frequencies of 1.5 GHz and 1.75 GHz.

Mid-Cell Shapes

All cell shape designs and naming, except for the named here Cornell cell shape which will be used in bERLinPro [2], were discussed previously elsewhere [6]. Cells are described using iris radius R_{iris}, equator radius R_{eq}, and four elliptical parameters A, B, a and b [6]. Table 1 summarizes these parameters for cell shapes used in this study. It is worth to mention that Cornell cell shape is based on TESLA design, whereas NLSF and Ichiro designs are characteristic of Low-Loss like shapes [6].

Table 1: Cell Parameters

Parameters	Cornell	TESLA	NLSF	Ichiro
R_{iris} [mm]	36	35	32	30
R_{eq} [mm]	102.88	103.3	98.58	98.14
A [mm]	41.35	42	47.152	50.052
B [mm]	35.57	42	31.35	34.222
a [mm]	12.35	12	10.5	7.6
b [mm]	21.14	19	17	9.945

End-Group Optimization and Field Flatness

An optimization procedure was applied to tune the cavities' end-half-cells in order to obtain the best field flatness of the π-mode at 1.3 GHz, as reported previously [5]. Only cavities with BPs were used in optimization simulations, since the influence of HOM WG couplers on the axial electric field profile of the fundamental mode is negligible [5]. This allows for using symmetries and decreasing numerical effort. The goal function of the optimization algorithm, as implemented in CST Microwave Studio (MWS) [7], was set to aim for frequencies of the π-mode as close as possible to 1.3 GHz, maximized geometrical impedance R/Q and field flatness η_{ff} close to 100 %. Field flatness is defined as

$$\eta_{\mathrm{ff}} = \left(1 - \frac{\sigma_{\mathrm{E_{peak}}}}{\mu_{\mathrm{E_{peak}}}}\right) \times 100\%, \quad (1)$$

where $\mu_{\mathrm{E_{peak}}}$ is the mean value of the peak electric field component $E_z(z)$ on the beam axis in the direction of the beam in every cell and $\sigma_{\mathrm{E_{peak}}}$ is the standard deviation. Table 2 summarizes the values of field flatness for all cavity designs after the end-groups optimization. End-groups tuning requires a half-cell optimization over the length of the half cell L_{cell} and two elliptical parameters A and B, since two other elliptical parameters a and b are controlled by the iris,

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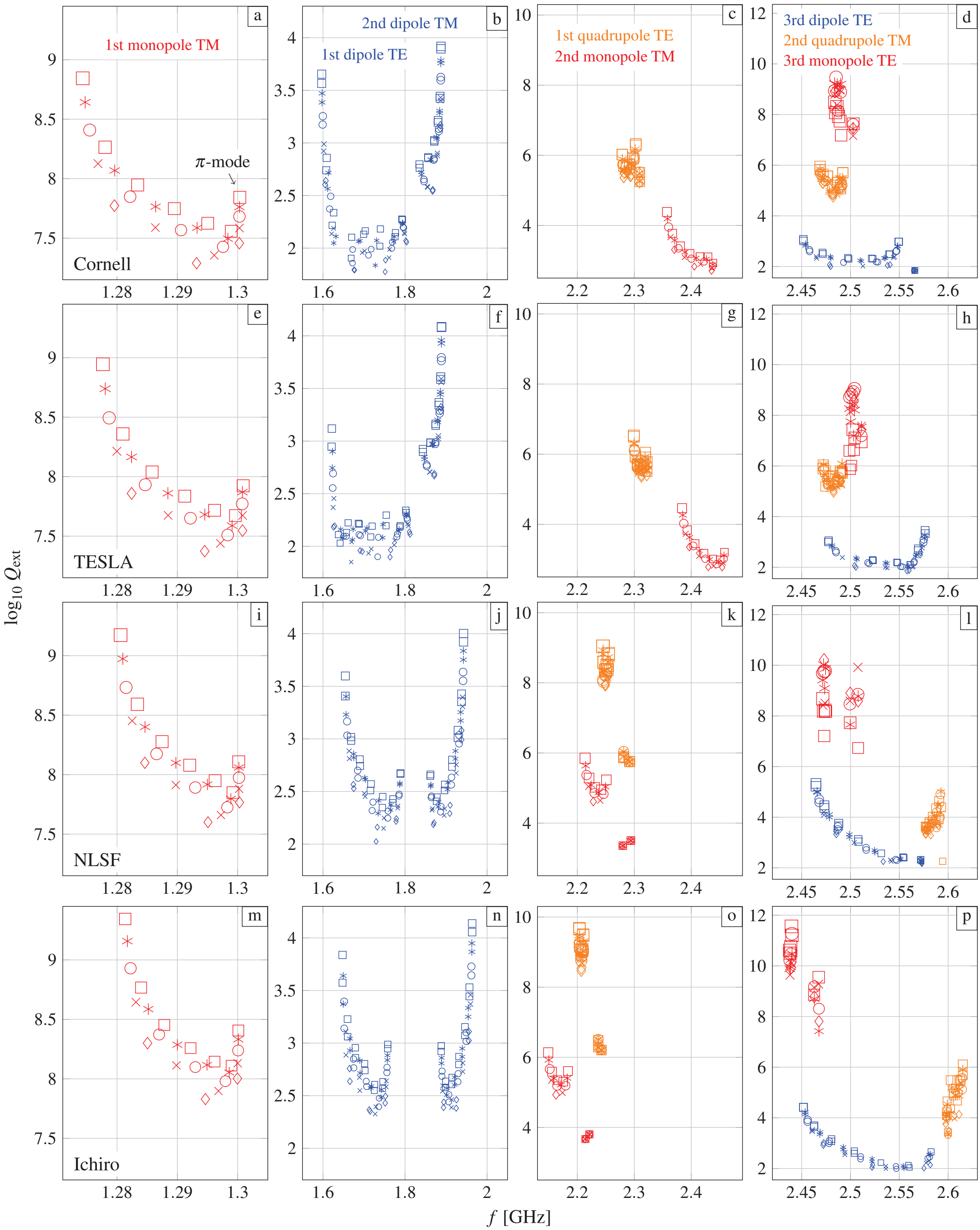

Figure 2: External quality factors Q_{ext} in frequency range from 1.27 GHz to 2.65 GHz for four different mid-cell shape designs: Cornell (a, b, c, d), TESLA (e, f, g, h), NLSF (i, j, k ,l) and Ichiro (m, n, o, p). For each cavity design five cases are shown with following number of cells: three (diamond), four (cross), five (circle), six (asterisk) and seven (square). Bands are colored according to the type of the modes: monopole (red), dipole (blue) or quadrupole (orange). Character of the modes is either transverse electric (TE) or transverse magnetic (TM).

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which connects the beampipe and cavity cells. The need for asymmetrical end-groups increases to six the total number of parameters over which the optimization has to be performed.

Table 2: Field Flatness η_{ff} [%]

Cells	Cornell	TESLA	NLSF	Ichiro
3	99.43	99.42	98.49	98.12
4	99.66	99.53	97.88	97.11
5	99.63	99.56	97.26	96.46
6	99.48	99.33	96.89	95.78
7	99.68	97.70	96.03	95.16

RESULTS

The SRF cavities were investigated in frequency range from 1.25 GHz to 2.65 GHz using an eigenmode solver and a tetrahedral mesh in MWS. First, only single cells were investigated with periodic boundary conditions with cell-to-cell phase advance of 0° and 180°, as described previously [5]. Initial frequency bands of interest were calculated and used in subsequent simulations of full cavity models with BPs, WG HOM couplers and input coupler.

The resulting Q_{ext} values grouped in bands are presented in Fig. 2 for all cell shapes and cavities. Bands of modes appearing in the frequency range used in simulations, are described with the types of modes i.e. monopole, dipole or a quadrupole, with modes either transverse electric (TE) or transverse magnetic (TM). Additionally, designs with the highest and the lowest value of R_{iris} are presented at the top and at the bottom of Fig. 2, respectively. In Fig. 2 it can be seen that in the studied designs higher values of Q_{ext} are attributed to designs with smaller iris radius. It is worth mentioning that Cornell cell shape design with R_{iris} of 36 mm has relatively lower Q_{ext} values for almost all bands than Ichiro cell shape design with R_{iris} of 36 mm (Fig. 2).

Moreover, due to extensive geometrical modifications of the end-half-cells for the NLSF and Ichiro shape designs, a band splitting can be observed. In these two cases, geometrical parameters of the end-half-cells were modified during the optimization process to fulfill the condition for field flatness of the π-mode at 1.3 GHz. However, after the optimization of NLSF and Ichiro shape designs, the end-groups do not retain the Low-Loss like shape [6], they rather exhibit TESLA like shape. In the investigated cell shapes some mode bands experience band splitting, where two modes are separated from others of the same type by frequency shifts bigger than the shifts between particular neighboring modes. This indicates highly localized modes characteristic of lower Q_{ext} values and associated with end-group cells, as shown in Fig. 3.

CONCLUSIONS

The presented preliminary study of new SRF cavity designs is focused on investigating HOMs behavior in the frequency range from 1.25 GHz to 2.65 GHz. In future, the frequency range will be extended to include more HOMs and the use of automatic mode recognition procedures, as described elsewhere [8]. Further studies will also include more cell designs, like Reentrant shapes [6], as well as promising novel cell shapes [9]. Furthermore, the influence of different end-group geometries on the band splitting, and on the overall performance of HOMs, is to be studied. Additionally, to confirm the results of the eigenmode simulations, frequency domain solvers combined with pole fitting of transmission S-parameter spectra [5], will be used.

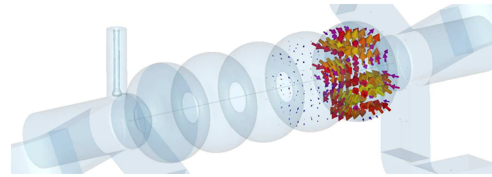

Figure 3: Localized TE quadrupole mode at 2.2425 in one of the end-cells of Ichiro shape 5-cell cavity.

ACKNOWLEDGMENTS

The collaboration with Dr. Axel Neumann from Helmholtz-Zentrum Berlin and M.Sc. Bernard Riemann from Technical University Dortmund is acknowledged. Also the authors would like to thank M.Sc. Thomas Flisgen from Universität Rostock for fruitful discussions.

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