ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB021

FIRST CONSIDERATIONS ON HZB HIGH FREQUENCY ELLIPTICAL RESONATOR STIFFENING

E. Zaplatin, Forschungszentrum Juelich, Germany
H-W. Glock, J. Knobloch, A. Neumann, A. Velez, Helmholtz-Zentrum Berlin, Germany

Abstract

There are two projects that currently are under development and construction at HZB which utilize high frequency elliptical resonators – Energy Recovery Linac Prototype (bERLinPro, 7-cell, 1300 MHz, β=1) and BESSY Variable pulse-length Storage Ring (VSR, 5-cell, 1500/1750 MHz, β=1). A critical issue of both projects is small effective beam loading in cavities operating at high CW fields (Eacc of 20 MV/m) with a narrow bandwidth. This necessitates precise tuning and therefore good compensation of microphonics and coupled Lorentz-force detuning driven instabilities. Motivated by this we present a conceptual study of an integrated SRF resonator and helium vessel structure design to ensure a reduced resonance frequency dependence on pressure and Lorentz forces to minimize their impact on the accelerating field profile.

PRESSURE RESPONSE OF MID-CELL

In the accelerator facilities (such as Cornell ERL, the KEK ERL and bERLinPro) that plan to use SRF cavities in the continuous wave (cw) operation with low effective beam loading and thus a narrow band width, the Lorentz force detuning becomes the factor that should be taken into account during structural design. Additionally, the peak fluctuations in the helium bath pressure are the source of the cavity resonance frequency shift.

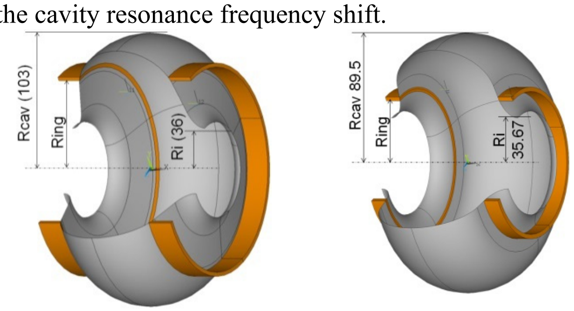

Figure 1: HZB bERLinPro (1300 MHz, β =1) and BESSY VSR (1500 MHz, β =1) mid-cell simulation models.

The bERLinPro elliptical 7-cell cavity and the original BESSY VSR 5-cell cavity RF designs were reported elsewhere [1-2]. (Note that the latest BESSY VSR resonator design is 4-cell cavity). Initial investigations of the cavity mechanical properties were performed on middle cell geometries (Fig. 1). The simulations were made with the cell-to-cell junction constrained by symmetry. The procedure of middle cell stiffening optimization was similar like used in [3]. The main goal was to find the stiffening ring positions to balance resonator frequency shifts caused by the change of the magnetic and electric stored energies. The summaries of numerical simulations are presented on Figs. 2-3.

The best stiffening ring positions in terms of df/dp minimization are the large ring radius (R_{ing}/R_{cav}=0.77) or no rings at all (R_{ing}/R_{cav}=0.35 corresponds to no rings case) for both resonators. The last case of results without rings repeats the similar investigations for other 1300 MHz, β=1 elliptical structures like TeSLA, Cornell re-entrant, ICHIRO "low-loss" and MSU half re-entrant cavities [4].

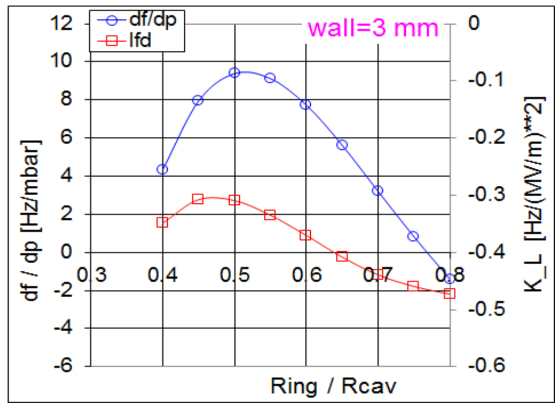

Figure 2: bERLinPro 1300 MHz, β =1 middle cell simulation summary (red curve – Lorentz force sensitivity, blue curve – pressure sensitivity).

The main deformations caused by the Lorentz force pressure occur at the iris section of the cell geometry. Hence, the main part of the frequency shift resulted by electrical field region deformations that in turn always results in the negative frequency shift.

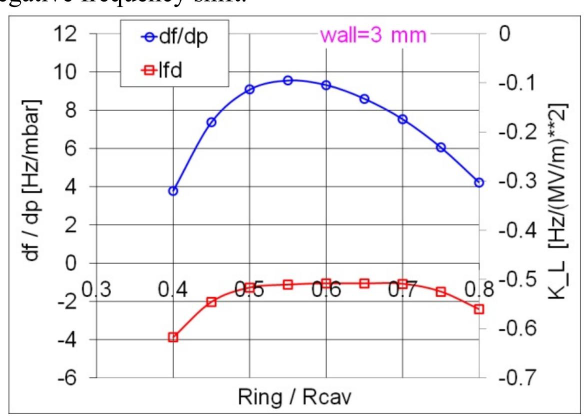

Figure 3: BESSY VSR 1500 MHz, β =1 middle cell simulation summary.

Small BESSY VSR cavity dimensions resulted in higher Lorentz force frequency sensitivity dependence on resonator wall deformations with low dependence on ring positions.

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MULTI-CELL CAVITY STIFFENING

The simulation model of bERLinPro 7-cell elliptical cavity (1300 MHz, β = 1.0) in provisional helium vessel (HV) (Fig. 4) consists of the cavity surrounded by the cylindrical helium vessel. The structure includes coaxial tuner, power coupler and six (three on each side) HOM waveguides that are connected to the beam pipes close to their transition with the cavity. The use of the sixth waveguide instead of the power coupler simplifies the simulation model but does not change structure mechanical properties. All waveguides firmly join the outer HV cylinder. The same design concept was accepted to the BESSY-VSR resonator helium vessel (Fig. 5).

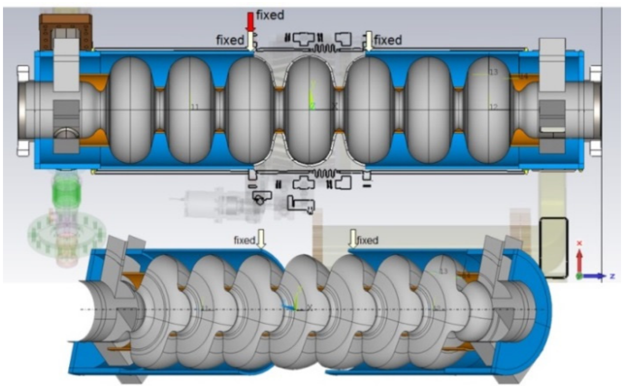

Figure 4: bERLinPro 7-cell elliptical cavity simulation model in provisional helium vessel (stiffening rings are brown).

The inner stiffening rings are installed between cavity cells while end-cell's outer stiffening rings connect these with waveguides. Such design ensures very rigid end parts of the structure. Both beam pipe ends are supposed to be completely free.

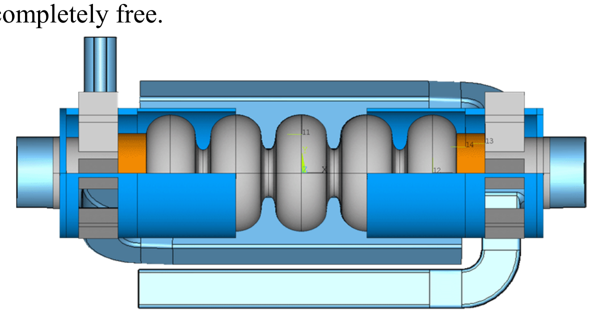

Figure 5: BESSY VSR 5-cell elliptical cavity simulation model in provisional helium vessel.

The outer HV cylinder is split in two halves. The gap between these halves simulates the place of the tuner installation. The left half of HV outer wall where the tuner is supposed to be connected to the external cryomodule structure is fixed. The right part of the tuner gap is also fixed for df/dp and LFD simulations since the tuner stiffness is not taken into account in simulations. The cavity and cryostat are under vacuum and the helium vessel volume was set at 1 bar in simulations, the pressure differential is exerted not only on the cavity walls, but also on the inside surfaces of the helium vessel, including end flanges. Several options of the cavity stiffening were investigated.

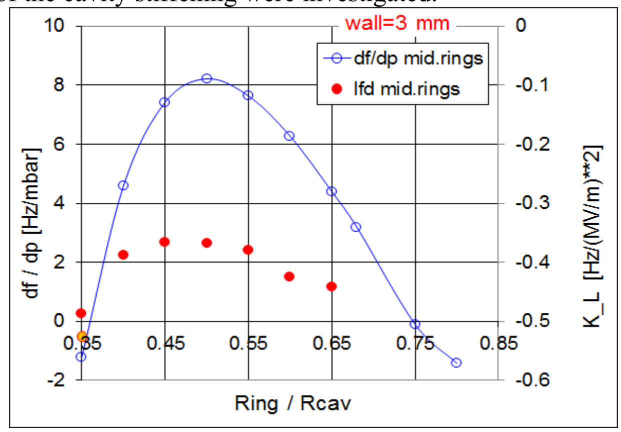

Figure 6: bERLinPro 7-cell cavity in helium vessel simulation results of df/dp and LFD with middle rings position variation.

The simulation results in dependence of stiffening ring positions for the project cavity wall thickness 3.0 mm are shown on Figs. 6-7. There are two df/dp=0 stiffening ring positions for bERLinPro cavity that is similar to the single middle cell calculations and the naked cavity simulation model. A preferable choice is no ring option (R_{ing}/R_{cav}=0.35) since using the installation of rings close to the dome would result in a high tuning pressure. This is defined by very rigid end groups. The same results were also reported in [5] for Cornell ERL 7-cell resonator.

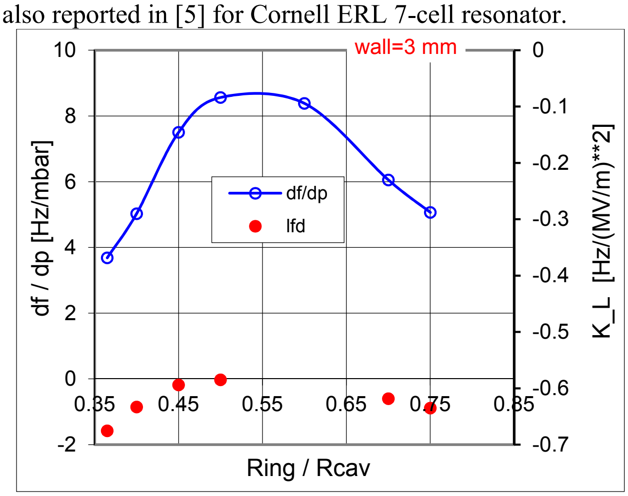

Figure 7: BESSY VSR 5-cell cavity in helium vessel simulation results of df/dp and LFD with middle rings position variation.

However, the operation helium pressure in bERLinPro HoBiCaT is 16 mbar and pressure stability on the level of 30 μBar. That would result in the frequency detuning of at most 0.24 Hz and ensures a free choice for the stiffening ring positions.

The calculations of LFD for BESSY VSR cavity (Fig. 7) repeat the previous simplest simulation model results – rather low absolute value and weak dependence on ring po-

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sitions because of the resonator inherent high rigidity satisfying df/dp optimization at R_{ing}/R_{cav}=0.35 (R_{ing_end}/R_{cav} =0.65).

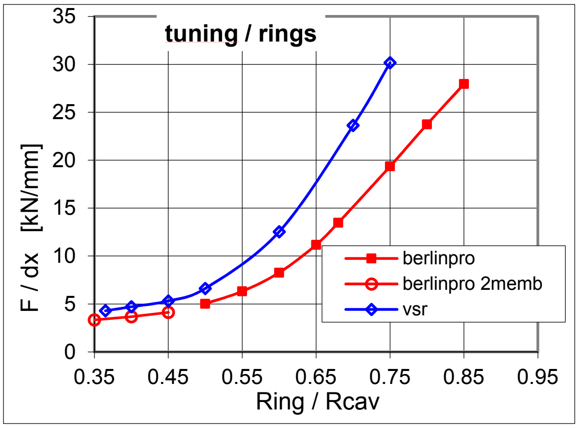

Figure 8: Simulation results of tuning forces with middle rings position variation.

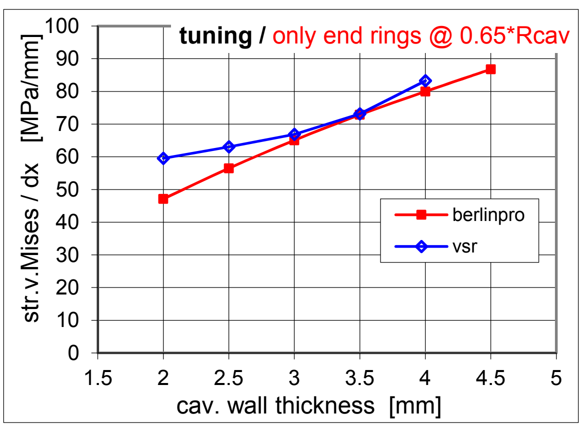

Figure 9: Simulation results maximal stresses with wall thickness variation.

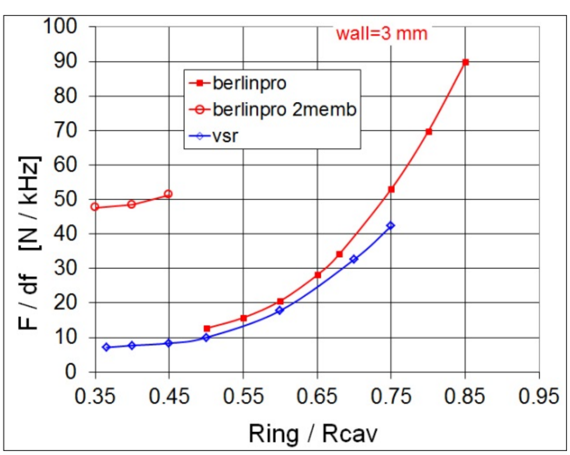

Figure 10: Simulation results of tuning forces with middle rings position variation.

Simulation results of tuning sensitivity and tuning forces with cavity wall thickness variation and only end stiffening rings are shown on Figs. 8-10. An accelerating field profile is not affected by tuning or by the pressure differential for both resonators. The mechanical stresses are well below the room temperature plastic deformation limit.

However, the minimization of the pressure and Lorentz force sensitivities does not ensure alone the low level of microphonics. Cornell built the half of their resonators in the test cryomodule omitting the stiffening rings relying on low values of df/dp and LFD. All those non-stiffened resonators experienced high level of microphonics [6].

The mechanical eigen modes of the structure are another serious source of microphonics. External vibrations can excite mechanical resonance of cavities in a cryomodule. To minimize the level of microphonics it is important to maximize the frequencies of the mechanical resonant modes of the cavity. The detailed investigations of the mechanical resonant cavity vibrations were provided using different simulation models starting with the simplest of the naked resonator and variation of the cavity structural constraints.

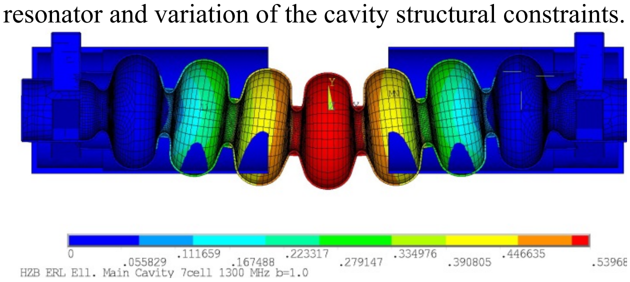

Figure 11: The lowest mechanical transversal mode 1 (84.49 Hz) of bERLinPro 7-cell elliptical cavity in helium vessel with low position (Ring/Rcav=0.4) of inner stiffening rings.

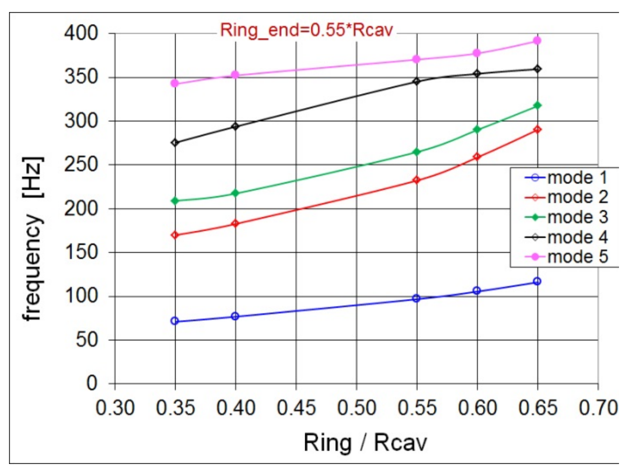

Figure 12: bERLinPro 7-cell elliptical cavity in helium vessel mechanical eigen modes with middle rings position variation.

For bERLinPro resonator ANSYS calculations show that an increase in the radius of the inner stiffening rings only slightly affects a frequency of the first transversal resonant mode (Figs. 11-12) since the whole structure design leaves the cavity flexible for this type of vibration. For very

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small radii of stiffening rings, the frequencies of the lowest mode lie dangerously close to 60 Hz. The second mode frequency (longitudinal) is strongly dependent on the ring positions.

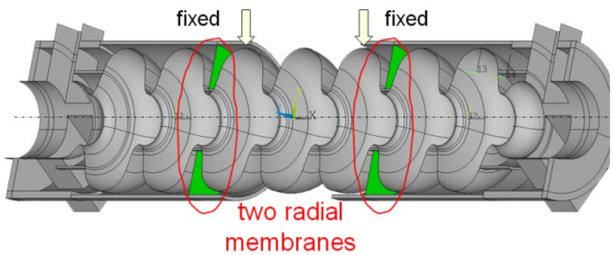

Figure 13: bERLinPro 7-cell cavity in helium vessel with two radial membranes (only end stiffening rings).

Since the first mode is of the transversal type (Fig. 11) an effective way to enhance its frequency is to fix the middle cell equator, like it is shown in [3]. It will result in the complete elimination of this mode type. On the other hand, fixing the cavity at the middle cell equator creates problems for the resonator tuning. Such structural constraints nearly eliminate the one half of the cavity from the tuning displacement that results in the strong accelerating field profile distortion since the tuning is caused by only half cavity deformation.

Table 1: bERLinPro Cavity Mechanical Frequencies

	no membranes rings	two membranes no rings
mode	Freq / Hz	Freq / Hz
1	84.49	199.03
2	202.43	212.25
3	224.91	342.12
4	319.58	349.04
5	354.44	389.96

To increase the frequencies of the mechanical eigen modes, a radial membranes (disks) connecting the cavity iris with the helium vessel external wall (Fig. 13) can be used. An installation of such membranes doesn't affect either df/dp or LFD optimizations. The mechanical frequencies of the first five modes (for the half of the structure geometry) are in Table 1. Two radial membranes provide effective first mode frequency shift changing vibration type and can replace all stiffening rings (including end rings).

During the resonator tuning the membranes are being bent (Fig. 14) and leave a freedom for the deformation of all cavity cells. This in turn minimizes the field profile distortion (keeping it within one to two percent). Simulation results correspond to the membrane thickness of 3 mm. Smaller thickness could result in lower field profile change. Additionally, two radial membranes reduce the deformations of cavity without inner rings caused by gravity by ten times (down to 0.005 mm).

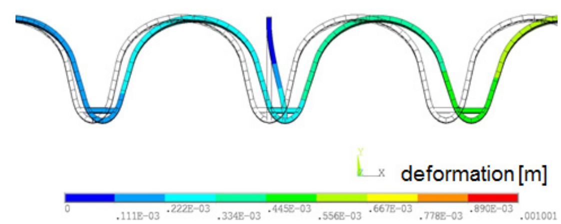

Figure 14: Cavity tuning deformations with transversal radial membrane.

However, the installation of the membranes could complicate the helium vessel design and manufacturing so that this approach is currently not included in the bELinPro and BESSY VSR baseline cavity design.

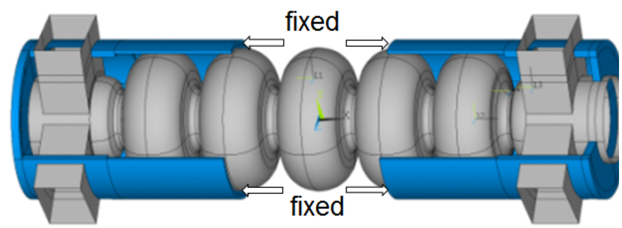

Figure 15: BESSY VSR 5-cell cavity in helium vessel without stiffening rings.

BESSY VSR 5-cell cavity possesses the inherently high structure rigidity even in the case without stiffening rings (Fig. 15), which leads to the frequencies of the lowest mode are being rather high (Table 2).

Table 2: BESSY VSR Cavity Mechanical Frequencies

	rings	end rings	no rings
mode	Freq / Hz	Freq / Hz	Freq / Hz
1	207.19	189.18	120.91
2	371.53	345.34	275.14
3	430.67	399.59	290.98
4	572.62	550.92	428.93
5	618.76	582.32	541.07

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ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB021

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