SRF LOW-BETA ELLIPTICAL RESONATOR TWO-RING STIFFENING

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Abstract

Elliptical SRF cavities are the basic accelerating structures for the high energy part of many accelerators. Since a series of external loads on the resonator walls predetermine the main working conditions of the SC cavities the detailed investigation of their mechanical properties should be conducted in parallel with the main RF design. The effects of very high electromagnetic fields that result in strong Lorentz forces and the pressure on cavity walls from the helium tank that also deforms the cavity shape, the tuning scheme resulting in the change of accelerating field profile and mechanical eigen resonances of cavities which are the main source of the microphonics must be taken into account during integrated design of the resonator and its liquid helium vessel.

SRF elliptical cavities for the medium energies (β=v/c is around 0.6) inherently have more flexible shape and their ultimate stiffening with a "standard" stiffening rings installed between resonator cells becomes problematic. The second set of the rings should enhance the overall cavity rigidity.

In the paper we report the basic investigations of the cavity two-set ring stiffening using FNAL 650 MHz β=0.61 as an example [1]. The single-cell investigation results were used as the reference to develop the ultimate scheme of the helium vessel structure to ensure the best resonator stability.

PRESSURE RESPONSE OF MID-CELL

The response of the cavity to a pressure differential is calculated with vacuum inside the resonator and ambient pressure outside. Differing from the pressure differential case the Lorentz forces at the dome region are directed outward the cavity volume (Fig. 1). So, the choice of the ring position is the trade-off between these two effects.

The procedure of a middle cell stiffening investigations using two-set rings was similar as used for the single-set rings [2]. The main goal was to find the stiffening condition to balance resonator frequency shifts caused by the change of the magnetic and electric stored energies. Hence, the strategy of cavity design should include the integrated simulations of RF and mechanical properties. The simulations are made with the cell-to-cell junction constrained by symmetry.

The second ring installation provides the cavity cell rigidity where LFD is nearly independent on the second ring position since it is defined mainly by the first ring set. Changing the second ring position results in the change in the wall deformations and as a result in df/dp value. There are two places for the second ring where the frequency shift df/dp reaches zero. The summary of simulations is presented on (Fig. 2).

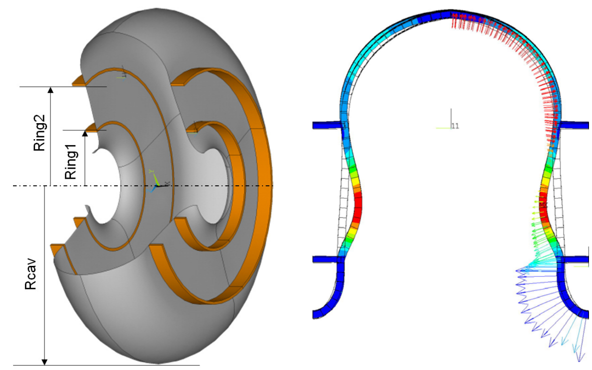

Figure 1: FNAL 650 MHz, β=0.61 mid-cell geometry and Lorentz force deformations with two-set stiffening rings.

The best ring-2 position is R_{ing2}/R_{cav}=0.75 with R_{ing1}/R_{cav}=0.35 that corresponds to the minimum of LFD (K_L=-0.27 Hz/(MV/m)^2) and df/dp=0.

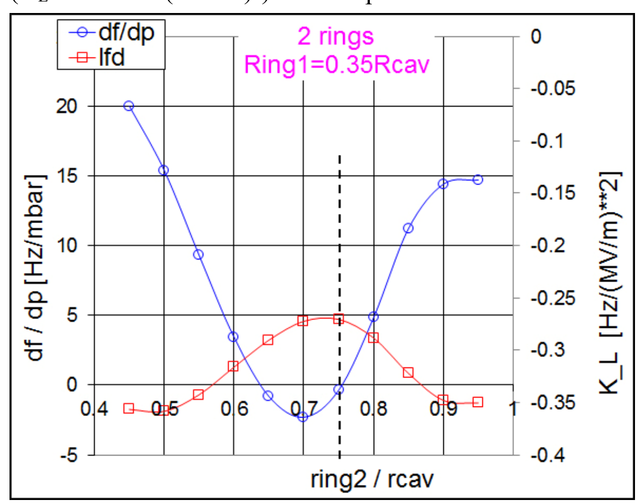

Figure 2: FNAL 650 MHz, β=0.61 mid-cell simulation summary.

MULTI-CELL CAVITY STIFFENING

The simulation model of FNAL PIP-II multi-cell elliptical cavities (650 MHz, β = 0.61, Fig. 3) consists of 5-cell cavity surrounded by the cylindrical helium vessel. A whole helium vessel (HV) except HV end dishes will be made from titanium (Ti). One side of the helium vessel end flanges (right on Fig. 3) is firmly attached to the cavity beam pipes through Nb-Ti end dishes. On the tuning side of the HV (left on Fig. 3) there is a slot in the Nb-Ti end dishes imitating the connection of the tuner. Such slot is bridged by the bellow for vacuum sealing. Bellows are included in the helium vessel to accommodate the motion produced by the tuner. The

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stiffening rings are installed between cavity cells and connect end cells with vessel end flanges. Both beam pipe ends are supposed to be completely free. The helium vessel is completely fixed at the supporting ring at the external surface of HV. The place of the HV end flange where the tuner is supposed to be connected is also fixed since the tuner stiffness is not taken into account in simulations. The cavity and cryostat are under vacuum and the helium vessel is at 1 bar, the pressure differential is exerted on the cavity walls and on the inside surfaces of the helium vessel, including end flanges.

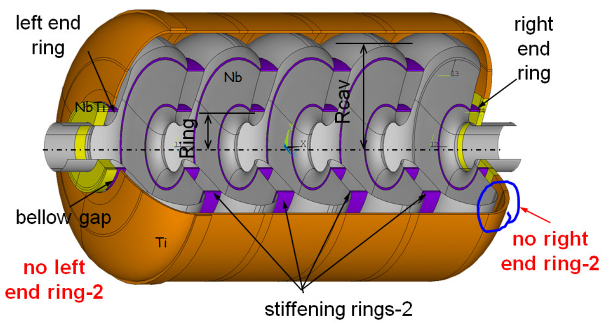

Figure 3: FNAL 5-cell elliptical cavity simulation model with two-set rings in provisional helium vessel.

An additional issue for the cavity mechanical design is the tuning option development. The simulation model (Fig. 3) is related to the case when the lever tuner is supposed to be installed at one side of the helium vessel at the beam pipe region with the tuning force applied close to the cavity iris. This allows providing nearly 100% tuning force transfer on the cavity.

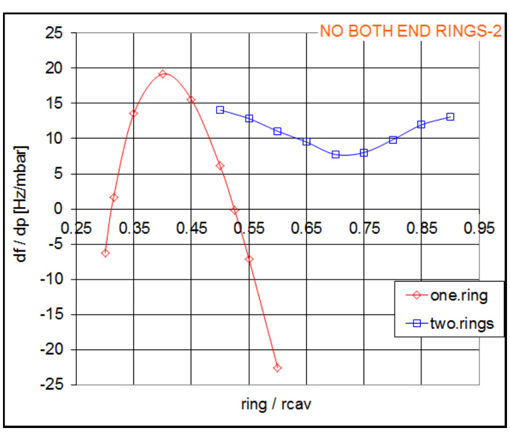

Figure 4: 5-cell cavity with helium vessel simulation results of df/dp (both end stiffening ring-2 missing).

Using all stiffening rings connecting cells with outer helium vessel walls together with HV constrains results in a rather rigid structure. These secure perfect conditions for df/dp minimization without affecting a field profile. On the other hand it creates problems for the resonator tuning using a lever tuner installed on one side of the structure since high structure rigidity results in the higher tuning force and also in the strong accelerating field profile distortion even with only 1 mm tuner shift. It is caused by only one end cell deformation. Exclusion of the end ring-2's (like on Fig. 3) results in sufficient reduction of the required tuning force keeping the same tuning sensitivity. An accelerating field profile is still strongly affected.

An optimal position of the ring-2 set (without end rings of the second ring set) is R_{ing2}/R_{cav} =0.7 (Fig. 4) with minimal value of df/dp=7.5 Hz/mbar. This makes nearly symmetrical stiffening scheme with the symmetrical field profile that has a drop in the central cell for about 10% under 1 bar external pressure. To keep a field profile symmetrical with minimal distortions caused by cavity deformations from external helium pressure one has to keep the whole structure stiffening scheme symmetrical. At the same time the whole structure should be constrained in the way that the tuning force applied at one cavity end also resulted in rather homogeneous resonator deformations along the length of the structure.

The simulation results of the structure tuning without both end rings of the second ring set (nearly symmetrical stiffening scheme except of the helium vessel end cups asymmetric design) are presented on Fig. 5. A field profile along the cavity axes has drops at the end cells of about 18% with 8% enhancement in the central cell. The tuning force is rather low (3 kN/mm at $R_{ing2}=R_{cav}$*0.7) with the same tuning sensitivity of about –(210-240) kHz/mm in the range up of to 1.2 mm tuner shift.

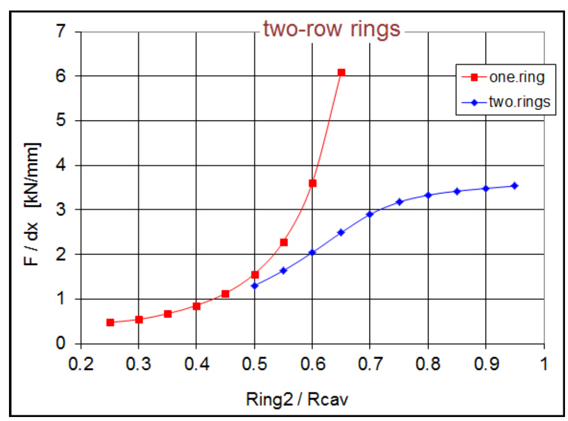

Figure 5: Simulation results of tuning forces (both end stiffening ring-2 missing).

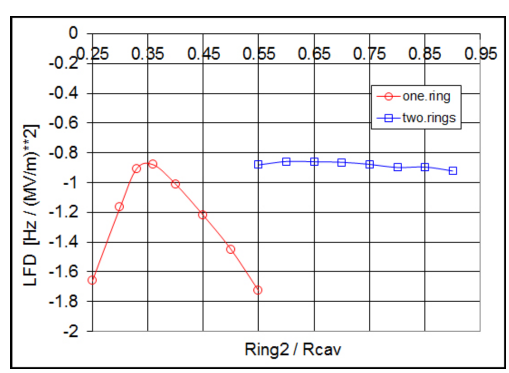

Figure 6: Simulation results of Lorentz force detuning using one- or two-set stiffening rings.

The main cavity deformations from the Lorentz force pressure occur at the plane section and iris of the cell

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geometry and hence the main part of the frequency shift resulted by electrical field region deformations. That's why an installation of the second set of the stiffening rings results in overall high cavity stability with LFD is independent on the rings-2 position (Fig. 6).

The mechanical eigen modes of the structure is a serious source of microphonics. External vibrations can excite mechanical resonance of cavities in a cryomodule. The structural modal analyses were conducted for the dressed elliptical cavity (Fig. 3).

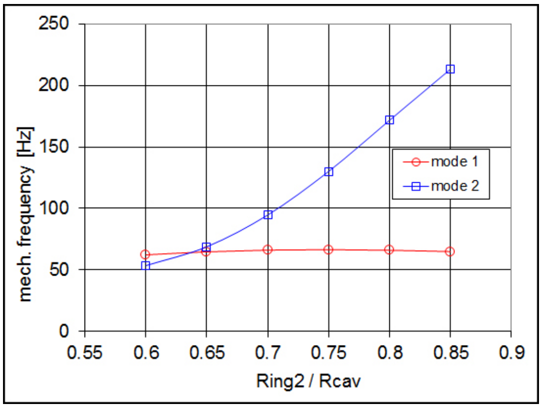

Figure 7: 5-cell cavity with helium vessel results of eigen mechanical modes.

A frequency of the most dangerous in terms of the microphonics level longitudinal mode (mode 1, Fig. 7) nearly doesn't depend on the second-row ring positions. Mode 2 is a transversal mode and strongly depends on ring-2 positions since the larger ring-2 radius results in higher cavity rigidity in the transversal direction.

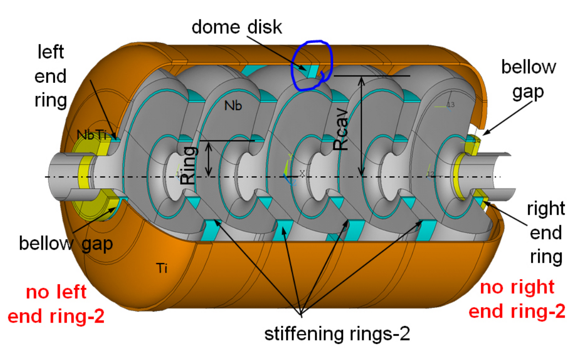

Figure 8: 5-cell cavity with helium vessel model for two-side tuning simulations.

Since any asymmetry of the resonator constraints results in the strong change of the accelerating field profile, the model with both sides tuning (Fig. 8) was investigated. To simulate a two-side tuning the slot at the right helium vessel cut securing the lower tune force was made. For cavity tuning calculations the forces were applied on the both left and right beam pipe flanges. To provide the direct comparison with one-side tuning case the beam pipe flanges were shifted by 0.5 mm at left and right sides. These results in the symmetrical resonator deformations mainly of the cavity end cells along axes with about 5% lower fields in the mid-cells. Also two-side tuning requires two times lower cavity deformations for the same frequency shift. This automatically secures a lower field profile change.

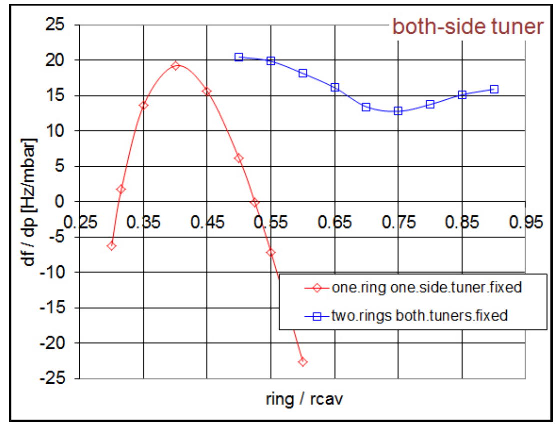

Figure 9: 5-cell cavity with helium vessel results of eigen mechanical modes.

Symmetrical constraints of the left/right tuner strongly reduce additionally right end cell iris deformations and increase the resonance frequency shift caused by liquid helium external pressure df/dp (Fig. 9). At the same time it reduces LFD of the cavity (Fig. 10).

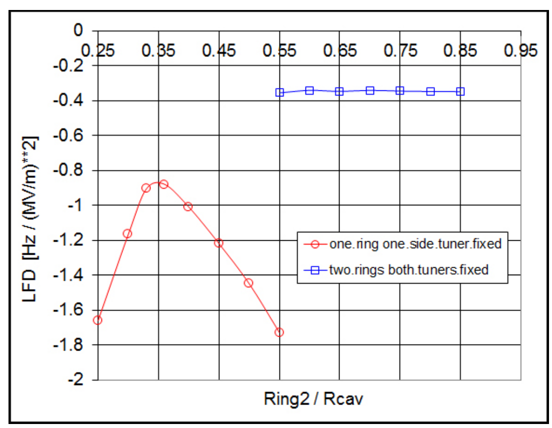

Figure 10: 5-cell cavity with helium vessel results of eigen mechanical modes.

To increase the frequencies of the mechanical eigen modes, a radial disk connecting the cavity mid-cell dome with the helium vessel external wall (Fig. 8) is used. An installation of such disk doesn't affect df/dp or LFD optimization. Such disk splits the longitudinal mode 1 from the case without disk in two similar modes increasing their frequencies up to higher than 200 Hz.

REFERENCES

[1] Proton Improvement Plan II, S. D. Holmes (editor).

[2] E. Zaplatin, *et al.*, "Low- and High-Beta SRF Elliptical Cavity Stiffening", in *Proc. IPAC'15*, Richmond, USA, May 2015, p. 2838.

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