ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMA035

LOW- AND HIGH-BETA SRF ELLIPTICAL CAVITY STIFFENING

E. Zaplatin, Forschungszentrum Juelich, Germany,
A. Kanareykin, Euclid TechLabs, Ohio, U.S.A,
V. Yakovlev, FNAL, Geneva, IL, U.S.A

Abstract

Elliptical SRF cavities are the main accelerating structures in many accelerators worldwide. Different types of external loads on the resonator walls predetermine the main working conditions of the SC cavities. The most important of them are 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. Also mechanical eigen resonances of cavities are the main source of the microphonics. To withstand any kind of external loads on the resonator walls different schemes of the cavity stiffening were applied.

In the paper we report the basic investigations of the cavity stiffening using FNAL 650 MHz beta=0.92 and 0.61 as an example. 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 first step of a superconducting elliptical cavity RF design is made as a trade-off in the optimization of the cell shape between the region of high electric field and the region of high magnetic field. In practice, the cavity performance may be limited not only by the RF characteristics, but also by detuning due to the Lorentz force, bath pressure fluctuations, or microphonics. Lorentz force detuning (LFD) is of concern primarily for pulsed accelerators such as the proposed Proton Improvement Plan-II (PIP-II) at Fermilab [1]. Hence, the strategy of cavity design should include the integrated simulations of RF and mechanical properties.

For the high energy sections of SC accelerators the well-studied multiple-cell elliptic cavities are optimal. An initial investigation should be provided on middle-cell geometries. Usually the simulations are made with the cell-to-cell junction constrained by symmetry. The goal for these calculations was to understand the behaviour and trends under different stiffening options.

The response of the cavity to a pressure differential is calculated with vacuum inside the resonator and ambient pressure outside. The pressure differential changes the cavity shape and shifts the RF frequency of the accelerating mode. Inward deformation near the iris (the region of high electric field) increases the capacitance and hence reduces the frequency. Inward deformation near the equator (high magnetic field region) reduces the inductance and hence increases the frequency. Thus the effects tend to cancel one another. Although the equator region is generally more rigid than the iris region, the volume change near the equator is larger due to the larger radius.

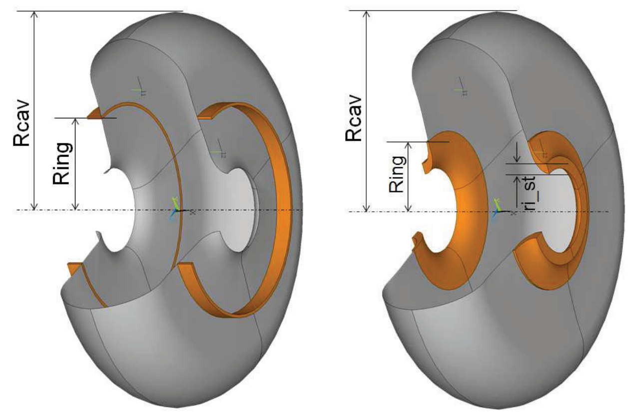

Figure 1: Elliptical mid-cell geometry (β= 0.61) with ring and iris stiffening options.

A stiffening ring position and a shape of the iris thickness can be used to change the frequency shift (Fig. 1) [2]. On the other hand the ring position also affects the Lorentz force detuning [3]. But differing from the pressure differential case the Lorentz forces at the dome region are directed outward the cavity volume. That's why the choice of the ring position is the trade-off between these two effects since their optimizations result in the different ring positions. For the pulsed accelerators like TeSLA the ring was placed to minimize primary the Lorentz force detuning (Fig. 2).

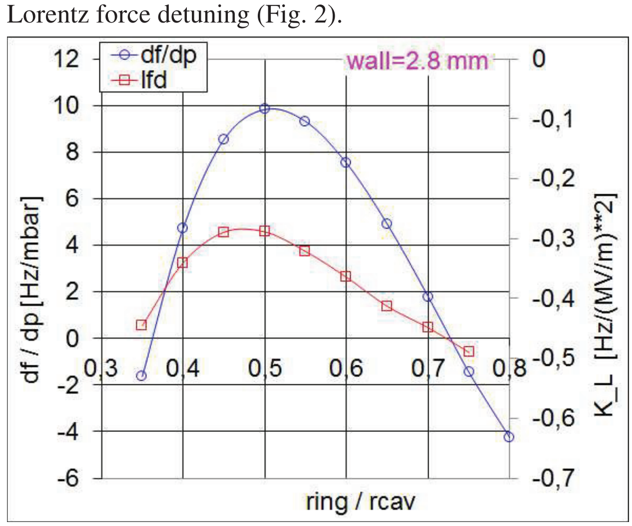

Figure 2: TeSLA mid-cell mechanical properties.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMA035

In PIP-II a resonant frequency of 650 MHz is used for the low- and high-beta elliptical resonators (0.61 and 0.92). The large dimensions of the cavity cells for such frequency result in large cell slope surface that is strongly affected by an external pressure. Still the relative volume change that results in the relative change of stored electrical and magnetic field energies is compared with a TeSLA cavity parameters (Figs. 3-4).

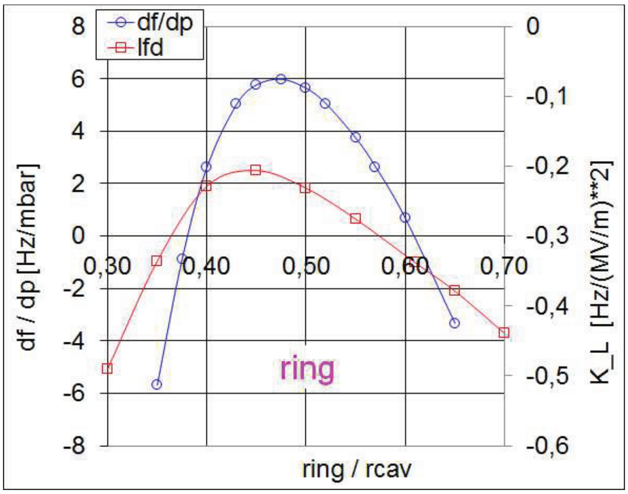

Figure 3: FNAL elliptical mid-cell (β= 0.92) stiffening optimization with ring.

There are two possible places for the ring position where the frequency shift df/dp reaches zero. And for the big cavity cell of 650 MHz the lowest ring position (ring/rcav = 0.33-0.38) coincides with a minimum of the Lorentz force detuning. The behaviours of the frequency shift on the cavity wall deformations caused by the external loads and by Lorentz forces for both betas are rather similar.

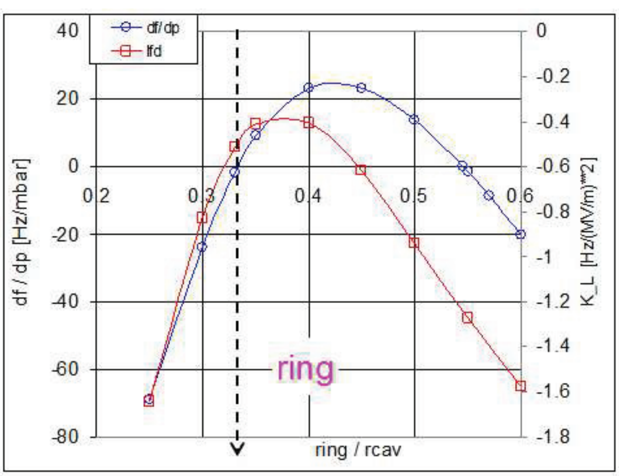

Figure 4: FNAL elliptical mid-cell (β= 0.61) stiffening optimization with ring.

Increasing of the cavity iris wall thickness (Fig. 1) makes this region more rigid, which primary works for the Lorentz force detuning minimization. Such stiffening option also results in the flat LFD optimum that gives a freedom for the df/dp optimum choice (Fig. 5).

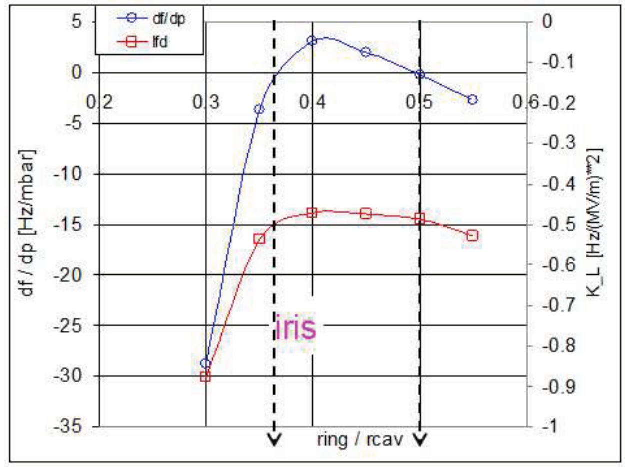

Figure 5: FNAL elliptical mid-cell (β= 0.61) iris stiffening optimization.

MULTI-CELL CAVITY STIFFENING

A more realistic analysis is that of multiple-cell elliptical cavities, formed from several coupled cells including beam tubes, end cells and a helium vessel (HV) [4]. The simple provisional simulation model of FNAL PIP-II multi-cell elliptical cavities (650 MHz, β = 0.91 and 0.61, Fig. 6) consists of 5-cell cavity surrounded by the cylindrical helium vessel. Helium vessel end flanges are connected to the cavity beam pipes. There is a slot in the HV left end flange imitating the connection of the tuner. The stiffening rings are installed between cavity cells and connect end cells with vessel end flanges. The tuner end ring is supposed to be completely fixed taking not into accout the tuner stiffeness. The cavity and cryostat are under vacuum and the helium vessel is at 1 bar, the pressure differential is exerted not only on the cavity walls, but also on the inside surfaces of the helium vessel, including end flanges.

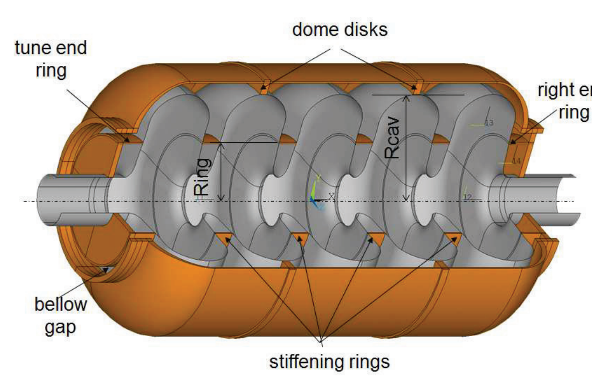

Figure 6: FNAL 5-cell elliptical cavity (β= 0.61) simulation model with provisional helium vessel.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMA035

The mechanical eigen modes of the structure is a serious source of microphonics. External vibrations can excite mechanical resonance of cavities in a cryomodule (Fig. 7).

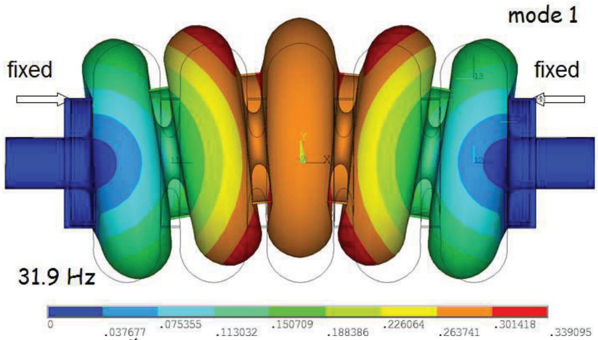

Figure 7: 1st mechanical eigenmode of FNAL 5-cell elliptical cavity (β= 0.61).

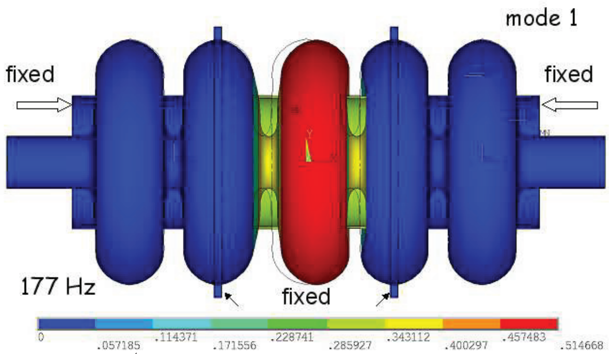

Figure 8: 1st mechanical eigenmode of FNAL 5-cell elliptical cavity (β= 0.61) with dome disks.

The transverse stiffening disks connecting resonator dome regions with the outer helium vessel walls (Fig. 8) can be used to increase the resonator rigidity. In a real HV design the disks can be replaced by 3-4 radial spokes to simplify their manufacturing.

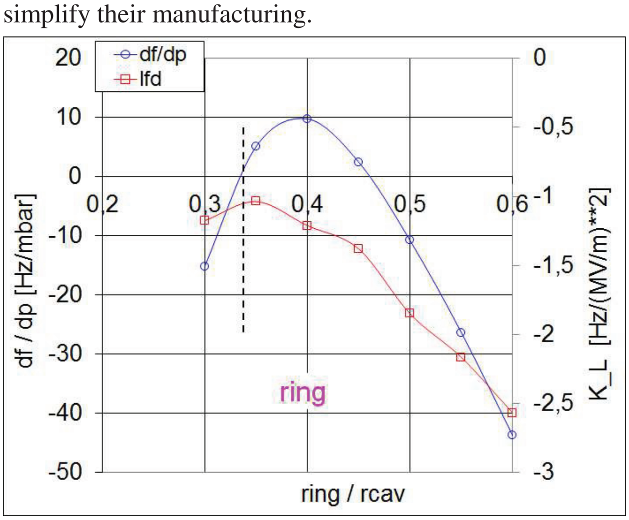

Figure 9: FNAL elliptical 5-cell cavity (β = 0.61) stiffening optimization with ring.

The simulation model with two transversal stiffening disks (Fig. 6) was used to investigate the cavity stiffening conditions for resonance high frequency shift minimization. The right end ring connecting end cell with HV flange is not used.

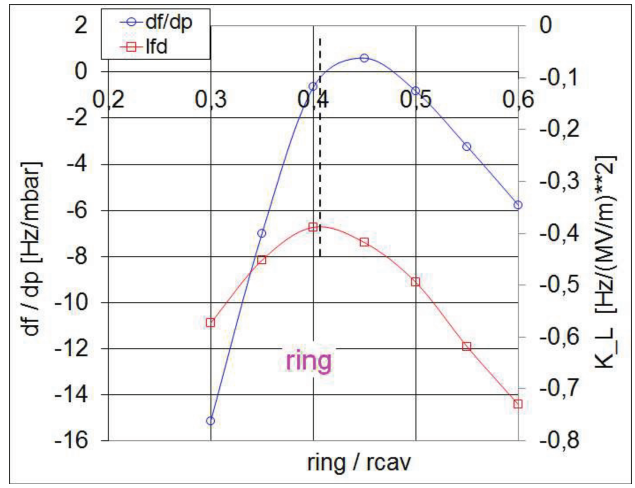

Figure 10: FNAL elliptical 5-cell cavity (β= 0.92) stiffening optimization with ring.

Such model configurations result in the best constrain conditions with low ring position (ring/rcav = 0.33 for β=0.61 and ring/rcav = 0.41 for β=0.92) to satisfy df/dp=0 and minimal Lorentz force detuning. The same results are for the iris stiffening option with the more flat LFD optimum.

REFERENCES

[1] Proton Improvement Plan II, S. D. Holmes (editor).
[2] E. Zaplatin, et all, “Structural Analysis for a Half-Reentrant Superconducting Cavity”, EPAC2006, Edinburgh, UK, 2006.
[3] E. Zaplatin, et all, “Lorentz Force Detuning Analysis for Low-Loss, Reentrant and Half-Reentrant Superconducting RF Cavities”, LINAC2006, Knoxville, USA, 2006.
[4] E. Zaplatin, et all, “Project X Elliptical Cavity Structural Analyses”, PAC’11, New York, USA, 2011.