MINIMIZING MICROPHONICS DETUNING BY OPTIMIZATION OF STIFFENING RINGS*

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Abstract

Maintaining a constant gradient in a superconducting cavity requires much more power if the cavity is not driven on resonance. Significant cost savings in both power consumption and power supplies can be realized by minimizing the detuning of the cavity away from the drive frequency. One of the largest contributions to detuning is microphonics. In this paper, simulations of microphonics detuning by LHe bath pressure fluctuations in a Cornell ERL cavity are presented, and the effect of varying stiffening ring radius is investigated. The consequences of using optimal stiffening ring radii are explored as well, including bandwidth limitations in active detuning compensation due to mechanical resonances and requirements for the frequency tuner.

INTRODUCTION

Several proposed accelerator facilities such as the Cornell ERL, the KEK ERL, and Project X, plan to use SRF cavities in continuous wave (CW) operation with low effective beam loading. At small cavity bandwidths, even a few hertz difference between the cavity frequency and the drive frequency can require significantly more than the on-resonance drive power to maintain a constant gradient.

Studies [1] have shown that careful cryomodule design can successfully decouple ground vibration from cavities. This leaves fluctuations in the helium bath pressure as likely the main source of microphonics detuning for CW operation, when Lorentz force detuning is not relevant. The detuning Δf depends on the product of the helium pressure deviation Δp and the cavity pressure sensitivity df/dp. The pressure stability depends on the pumping system, where the peak, not average, pressure deviation is the important measure of its stability. The cavity sensitivity depends on the design of the cavity and its helium vessel frequency tuner assembly. Careful design through simulation can reduce this factor to a tolerable level.

This paper presents efforts to reduce the pressure sensitivity of the Cornell ERL main linac cavity, shown in Figure 1, through optimization of the stiffening ring radius. The analysis benefits from the work of Zaplatin et al. [2], Conway et al. [3], and Schappert et al. [4].

SIMULATIONS

A technique was developed to simulate the full 3D cavity including helium vessel and tuner. The engineering simulation package ANSYS [5] was used, which is capable of performing both high frequency electromagnetic eigenmode analyses and structural analyses on the same model. The ANSYS modules used were APDL and Workbench. APDL is the older module, capable of high frequency analysis, but with limited ability to interface with CAD geometries. Workbench is more user-friendly, is able to work with more geometry file types, and has more functionality when handling complicated geometries. Images from the two programs are shown in Figure 2.

To determine the pressure sensitivity, first the CAD file was imported into Workbench. A pressure load was applied to the appropriate areas and the cavity was fixed as it would be in normal operation by supports in the helium vessel. The resulting length change of the cavity was the output of the Workbench analysis. Then a simple quarter model of just the cavity and enddishes was input to APDL, and a conformally meshed vacuum volume was generated. To duplicate the deformation of the cavity found in Workbench, it was subjected to a displacement constraint using the length change found earlier, along with a pressure load on the relevant areas and a symmetry constraint on the quartered faces. An update was performed on the FEA model to reflect the resulting geometry change. A high frequency eigenmode analysis was performed both before and after the model was updated to determine the frequency shift. By performing the analysis in this way, the strengths of both Workbench and APDL were exploited.

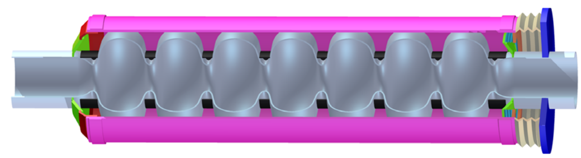

Figure 1: 3-quarter section view of a CAD model of the ERL main linac cavity cryomodule.

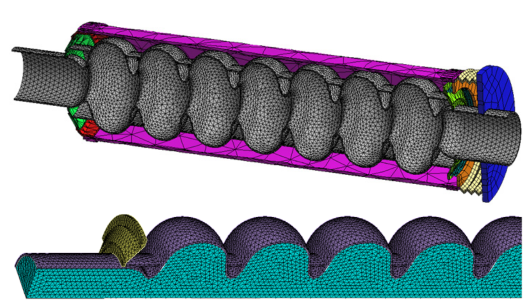

Figure 2: ANSYS Workbench model (top) and APDL model (bottom).

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To simplify the mesh and reduce computation time, the geometry was simplified. Notably, the Saclay I tuner was removed entirely from the model and replaced with a bellows-like part (the tan part in figure 1) with material properties selected to give it the 100 kN/mm stiffness that was measured for the Saclay I tuner [6]. The material properties used for Nb, NbTi, and Ti were obtained from [7].

DF/DP RESULTS

The simulation was repeated for different cavity material thicknesses and different tuner stiffnesses. The nominal values were 3 mm and 100 kN/mm. The results are shown in Figure 3.

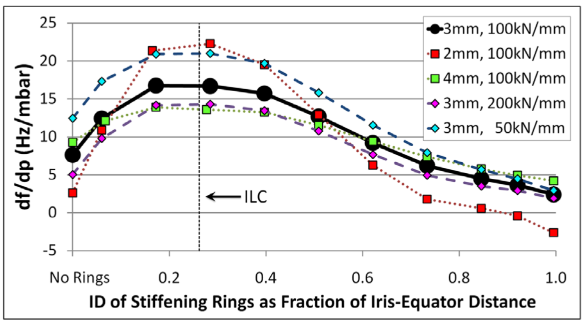

Figure 3: df/dp in the Cornell ERL 7-cell cavity as a function of stiffening ring radius, wall thickness, and tuner stiffness.

The results show that very large rings or none at all achieve the smallest df/dp values. Interestingly, the ILC cavity, which is very similar in shape to the ERL cavity, is designed with stiffening rings in a location with close to the highest df/dp possible. This is a result of it being optimized for pulsed operation with the objective of minimizing the Lorentz force detuning coefficient. In helium pressure detuning, deformation of the iris produces a negative contribution to df/dp which compensates for the positive contributions of the equator deformation and length change. For Lorentz force detuning, both the iris and equator deformations produce a negative frequency shift.

The results in Figure 3 also show that having a very stiff tuner significantly reduces df/dp at small ring diameters, but becomes less influential as the cavity stiffness approaches that of the tuner. Using thinner material is advantageous at low and high ring diameters, but thicker material is better for diameters closer to the ILC cavity rings. For 2 mm material, df/dp actually becomes negative for high enough radii and would in fact be zero for a certain radius.

The ERL cavity will use 3 mm material and the Saclay I Tuner. If one were to ignore all other issues and consider only microphonics detuning, the optimal choice would be to place stiffening rings at the equator. However, there are several other issues associated with changing the stiffening ring radius.

OTHER CONSIDERATIONS

Tuning Force

Using a cavity with stiffening rings at the equator is not feasible. The cold cavity tuner is required to elastically deform the cavity by enough distance to change its frequency by several hundred kHz. Using ANSYS, the force required from the tuner to achieve this range was calculated, and the variation with stiffening ring radius can be seen in Figure 4. The calculations show that with rings at or close to the equator, it would require an enormous force to tune the cavity. The images to the right of the plot show the location of the deformation, where the blue part of the cavity is fixed and the increasingly red areas are more displaced. For stiffening rings at the equator, the only visible deformation is in the enddishes and first irises. Tuning in this manner would spoil the field flatness of the cavity and therefore would be undesirable.

Plastic Deformation During Handling

An unstiffened cavity presents the opposite challenge—it is very easy to deform. Consider the deflection of a cavity resting on its enddishes. The maximum stress and maximum deflection in the cavity under these conditions, again generated using ANSYS, are plotted in Figure 5. Only a small safety margin exists between the maximum stress in the unstiffened cavity and the yield strength of ~60 MPa for Nb. In this analysis, the bottoms of both enddishes were constrained from movement transversely, but only one was constrained longituinally.

Mechanical Resonances

It is important to maximize the frequencies of the mechanical resonant modes of the cavity. The piezo controller which provides feedback compensation of microphonics has a bandwidth limited to about 1/10th of the lowest frequency mechanical mode. From the ANSYS results in Figure 6, it is clear that increasing the radius of the stiffening rings increases the possible bandwidth of the piezos. Furthermore, for very small stiffening rings, the frequencies of the lowest two modes lie dangerously close to 60 Hz. Depending on the Q of these modes, they could be driven by external vibrations at the frequency of the electrical grid.

Fabrication

Performance issues aside, it would be faster and less expensive to manufacture cavities without stiffening rings. If an unstiffened cavity can meet the ERL design goals, it would be preferable.

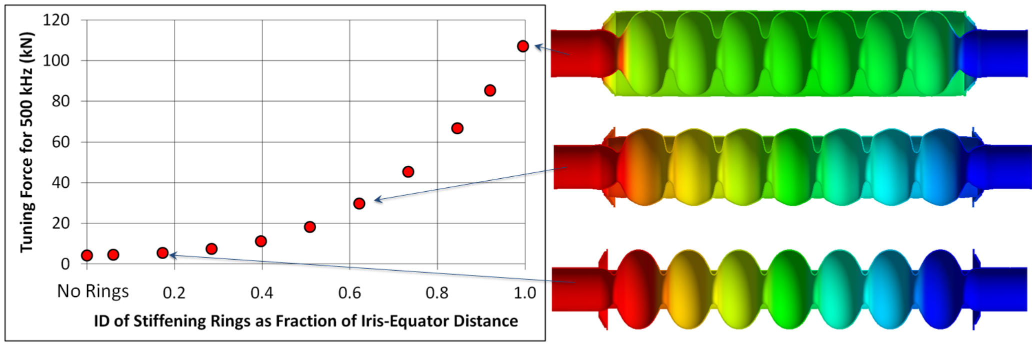

Figure 4: Required force to tune ERL 7-cell by 500 kHz as a function of stiffening ring radius. The images to the right show the location of deformation for three different cases.

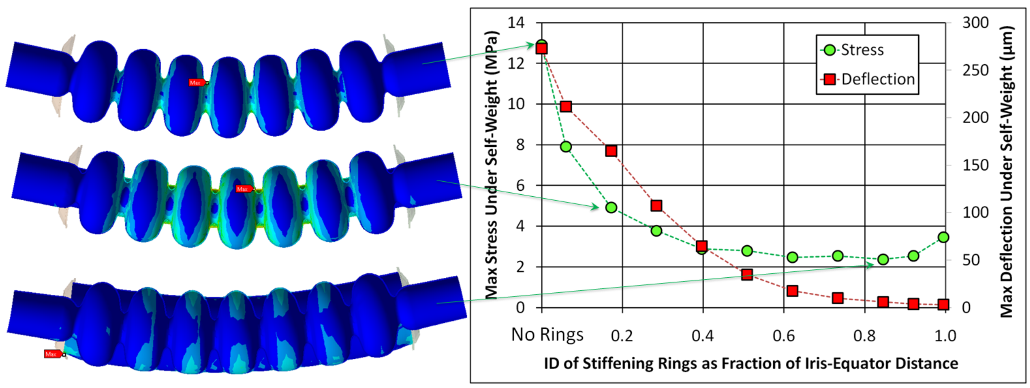

Figure 5: Maximum stress and deflection in the ERL 7-cell cavity as a function of stiffening ring radius when the cavity is resting on its enddishes and deflects under its own weight.

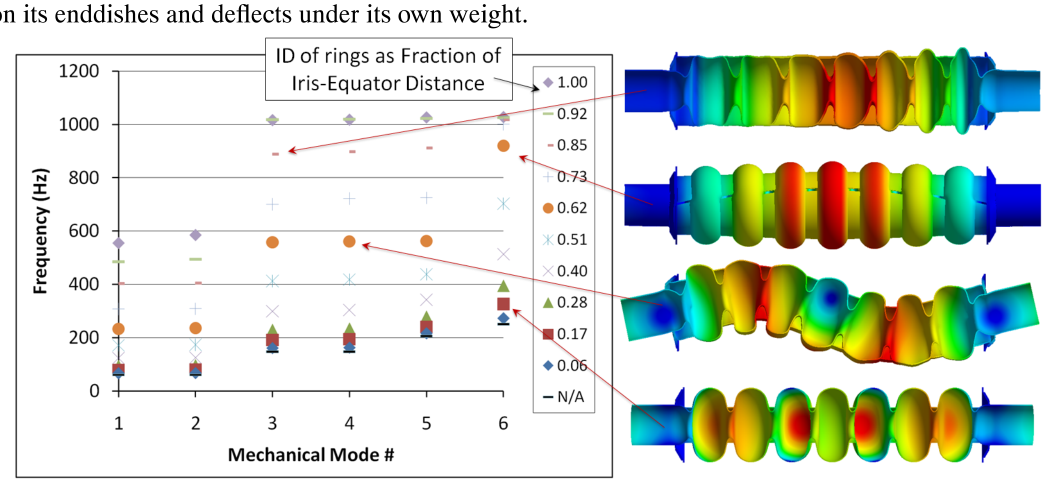

Figure 6: Frequencies of the six lowest mechanical resonant modes of the ERL 7-cell cavity as a function of iris-equator distance.

CONCLUSIONS

Placing stiffening rings near the equator gives the lowest df/dp, but the cavity would be very difficult to tune. Due to tuner constraints, the ERL group has limited the stiffening rings to below about 60% of the iris-equator distance. Given this limitation, Figure 3 shows that there are two choices that would have approximately the same minimized df/dp values. After considering the analysis presented here, the ERL group made the decision to fabricate two cavities, representing these two choices. Each will have significant challenges:

- *No stiffening rings*. It will be difficult to avoid plastic deformations while handling this cavity and the piezo bandwidth will be limited
- *Stiffening rings at ~60% of the iris-equator distance*. This cavity will require a strong tuner and more manufacturing steps

Both cavities will be tested horizontally in a test cryomodule to compare microphonics detuning and handling requirements. A final choice will be made based on this experience.

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