MINIMIZING HELIUM PRESSURE SENSITIVITY IN ELLIPTICAL SRF CAVITIES*

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Abstract

Superconducting cavities in CW operation with small beam loading can operate at high Q_L to significantly reduce power requirements. However, the resulting small bandwidth makes them vulnerable to microphonics from helium pressure fluctuations, which can detune the cavity and cause it to trip. In this paper, we present a mechanical optimization of elliptical cavities for minimization of df/dp, the sensitivity to helium pressure changes. Using the Cornell ERL main linac cavity as an example, an analytical model is developed to illustrate the factors that contribute to df/dp. Methods to reduce df/dp are presented. In addition, df/dp measurements made at the Cornell Horizontal Test Cryostat are presented and corrections to the model are made to account for the thickness of the welds in the helium vessel.

INTRODUCTION

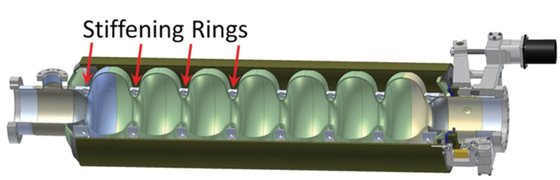

Figure 1: Early ERL main linac cavity-He vessel-tuner model used for ANSYS simulations.

The Cornell Energy Recovery Linac (ERL) main linac requirements call for 384 superconducting 7-cell cavities (shown in Fig. 1) operating CW at 16.2 MV/m, with 2×100 mA of beam current passing through them [1]. In energy recovery operation, the effective beam loading on the cavities is very small, which allows the cavities to operate with relatively small power requirements by keeping their loaded quality factors large (6.5×10^7). However, this decreases the bandwidth of the cavities, making them highly sensitive to detuning from microphonics, external vibrations that change the frequency of the cavity. The power required as a function of beam current and bandwidth is shown for the ERL main linac cavity parameters in Fig. 2. Perhaps the largest source of microphonics detuning is fluctuations in the pressure of the helium bath surrounding the cavity. The sensitivity of the cavity frequency to these fluctuations is given by df/dp. Finding ways to minimize df/dp could save millions of dollars in costs of

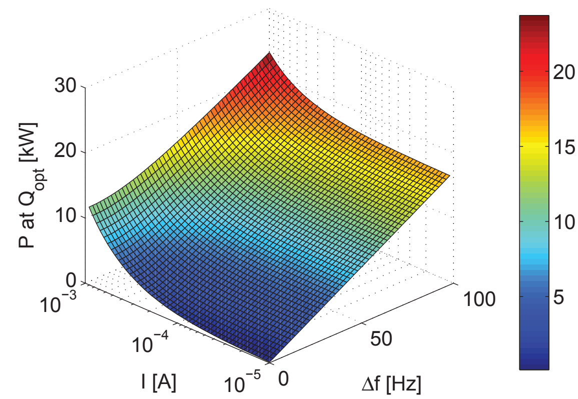

Figure 2: Required RF power to the cavity depends on the beam current and the cavity detuning.

power supplies and grid power for facilities that would use linacs with many elliptical SRF cavities in CW operation with high Q_L, including the Cornell ERL, as well as the KEK ERL and Project X.

ANALYTICAL MODEL AND SIMULATIONS

In order to find ways to minimize df/dp, it is helpful to have an analytical model breaking down the factors that contribute to it. First, one can isolate the contribution due to the length change of the cavity from the contribution due to cell shape changes in the cavity at fixed length [2].

$$\frac{df}{dp} = \frac{df_{shape}}{dp} + \frac{df_{length}}{dp} \tag{1}$$

Next, the length change factor can be deconstructed into variables that depend on the length of the cavity L and the axial force F experienced by the cavity.

$$\frac{df_{length}}{dp} = \frac{df}{dL}\frac{dL}{dp} = \frac{df}{dL}\frac{dL}{dF}\frac{dF}{dp} = \frac{df}{dL}\frac{1}{K_{total}}\frac{dF}{dp} \tag{2}$$

All of these factors can be found using an engineering simulation package like ANSYS [3] on a model of the cavity-He vessel-tuner assembly, as shown in Table 1.

Results from simulations on early models of the ERL 7-cell cavity are shown in Fig. 3. df/dp is given as a function of stiffening ring radial position, presented as a fraction of the iris-equator distance, $(r_{ring}-r_{iris})/(r_{equator}-r_{iris})$.

Several observations were made while performing these simulations that inform methods of reducing df/dp [4]:

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Table 1: Simulations used to find Parameters from df/dp Model.

Parameter	Boundary Conditions	Load	Result Calculated
df_{shape}/dp	Fix beam tubes	1 bar helium pressure	Δf
K	Fix one beam tube	1 kN axial force to other beam tube	Length change
df/dL	Fix one beam tube	1 μm shift of other beam tube	Δf
dF/dp	Fix beam tubes	1 bar helium pressure	Average restoring force

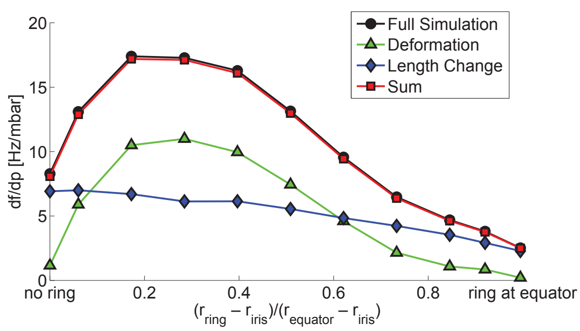

Figure 3: Results of df/dp simulations in ANSYS, showing how the shape and length change contributions change with radius and how combining calculations from the broken down model compares with the full simulation.

- df/dp is strongly dependent on the radius of the stiffening rings
- Very small and very large ring radii give the smallest overall df/dp
- At these ring radii, the length change contribution dominates df/dp
- The overall stiffness K depends strongly on stiffness of endwall and tuner
- dF/dp can be greatly reduced by using a tuner that sits on the end of the cavity in conjunction with a bellows in the helium vessel that has a small radius, as shown in Fig. 4
- Rings with radius $\geq \sim 0.7$ of the iris-equator distance cannot be used since the cavity cannot be tuned
- Other considerations are discussed in [4]

Each of these observations influenced the final design of the cavity-He vessel-tuner assembly of the first prototype

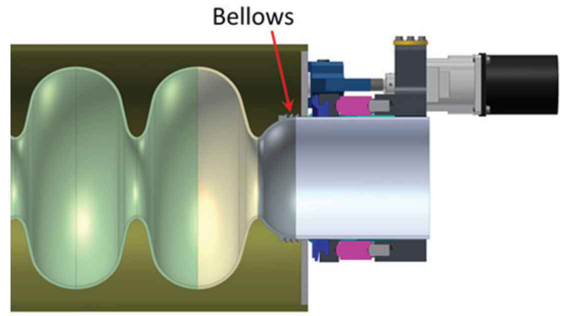

Figure 4: Reducing the radius of the tuner bellows reduces dF/dp.

cavity. Compared to the early model used in the simulations, the production cavity has endwalls with enhanced stiffness, a bellows with a reduced radius, and no stiffening rings, as shown in Fig. 5.

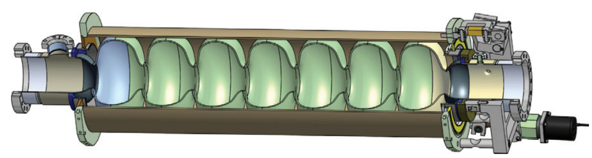

Figure 5: Production cavity-He vessel-tuner model used for the prototype in the HTC.

MEASUREMENTS AND COMPARISON TO SIMULATION

Measurements of df/dp were carried out on the first prototype ERL main linac cavity in the Horizontal Test Cryostat [5]. The results are shown in Fig. 6 as a function of accumulated steps over the full range of the frequency tuner.

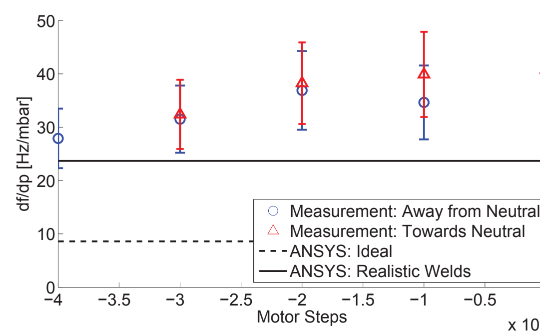

Figure 6: df/dp as a function of tuner motor steps in the HTC.

The measurements were significantly higher than the initial prediction. Additional details were added to the models used in the simulations to try to make the simulated cavity closer to the real cavity as produced. One simplification that had been made in the original model was to bond all parts that were welded together over the full contact region

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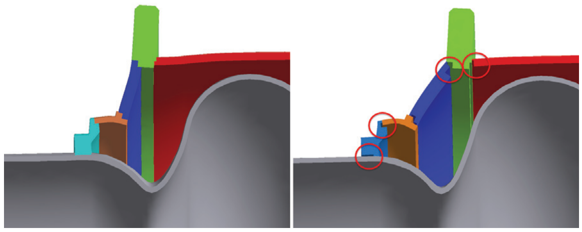

Figure 7: Original model for production cavity, deformed by helium pressure (left). Also shown is a model in which the welds are modelled more realistically (right). The updated model gives df/dp values that are much closer to the measurements.

instead of just the weld zone. To remove this simplification, gaps were created in the contact region in all areas except those that would actually be reached by the weld, as shown in Fig. 7. Using a model with thin welds brought the simulation results much closer to the observed df/dp values, as can be seen in Fig. 6. Taking into account potential variation in the thickness of the welds and other material parameters, the agreement is quite good.

CONCLUSIONS AND OUTLOOK

Finding ways to minimize df/dp could save millions of dollars in costs of power supplies and grid power for facilities that use linacs with many elliptical SRF cavities in CW operation with small beam loading, including the Cornell ERL, as well as the KEK ERL and Project X. Through simulations and analytical modelling, methods have been developed to significantly reduce df/dp. These methods were used in the design of a prototype cavity for the Cornell ERL main linac. Adding details to the simulation model has shown that full penetration welds on the helium vessel are important to achieving small df/dp. This new understanding has resulted in changes to welding methods that will be implemented for the current production run of ERL cavities.

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