OPTIMIZATION OF THE SRF CAVITY DESIGN FOR THE CEBAF 12 GEV UPGRADE*

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Abstract

Based on initial testing of the "HG" and "LL" 7-cell cavities in the prototype cryomodule *Renascence*, several opportunities for improved optimization were identified. The HOM damping configuration was refined so as to meet the requirements for damping key dipole modes while simultaneously dramatically reducing risk of HOM pickup probe heating and also creating beamline clearance for mounting the tuner to stainless steel helium vessel endplates (rather than NbTi/Ti transitions to a titanium helium vessel). Code modeling and bench measurements were performed. The new design maintains the 7-cell LL cells and incorporates a brazed transition between Nb and the SS helium vessel. The resulting configuration is now called the "C100" design. Cavity design details as well as vertical dewar and horizontal test bed performance are presented.

INTRODUCTION

Experience gained with the *Renascence* cryomodule validated some design choices and highlighted opportunities for improvement of the cavity design for the CEBAF 12 GeV Upgrade.[1] The HOM damping was found to be more than adequate for use in CEBAF. Several opportunities were identified to increase the thermal and mechanical robustness of the cavity design and its integration with the balance of the cryomodule.

Cavity rf specifications for 12 GeV CEBAF

- LL-cell shaped, 7-cell 1497 MHz cavities – thermally stable to 25 MV/m CW
- Q_{ext} FPC – 2.4–5.0 $\times 10^7$ (nominally 3.2×10^7) [2]
- Nulled transverse kick in FPC
- Dipole HOM shunt impedance $< 6.2 \times 10^8\ \Omega$

Cavity mechanical features

- No stiffening rings, to increase tunability
- New helium vessel design, to replace titanium with stainless steel for cost and joint reliability
- New tuner interface, mounts to stainless steel helium vessel endplates and allows use of proven scissor-jack tuner
- Nb HOM coupler probes confidently cooled

* This manuscript has been authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177.
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OPTIMIZATION OF THE HOM COUPLERS

Several modifications were made to the HOM couplers for the C100 cavities. The objectives were to

- Reduce vulnerability to rf heating,
- Provide adequate damping of the high shunt impedance dipole modes, and
- Create space on the ends of the cavities for mounting the tuner.

The HOM couplers located on the same end of the cavity as the waveguide coupler (A & B) were most susceptible to thermal runaway during early tests on Renascence. Since adequate damping was demonstrated to be available via the couplers at the other end of the cavity (C & D), the A & B HOM couplers were removed from the C100 cavity design.

Detailed bench measurements on a copper model were performed with various alternative arrangements for the C & D couplers. The coupler cans were displaced outward from the end cell by 6.4 mm to reduce exposure to the fundamental field. Improved coupling to the dipole modes was found to be available by rotating the hook in the manner indicated in Figure 1. Finally, the out-coupling probe of each can was rotated so as to create clear space for tuner mounting and to accommodate assembly of the cavity flange and rf feedthrough and cabling.

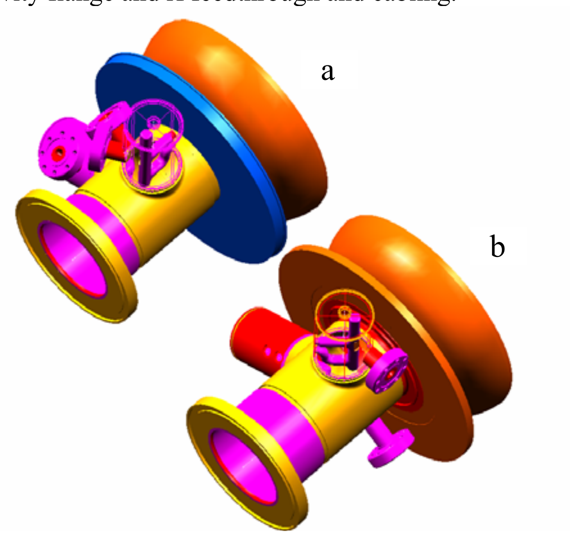

Figure 1. HOM coupler configuration for a) C100 and b) *Renascence*-style cavities.

This reorientation results in a decrease of the (small) rf dissipation on the superconducting niobium HOM coupling probe by a factor of 90. See Figure 2.

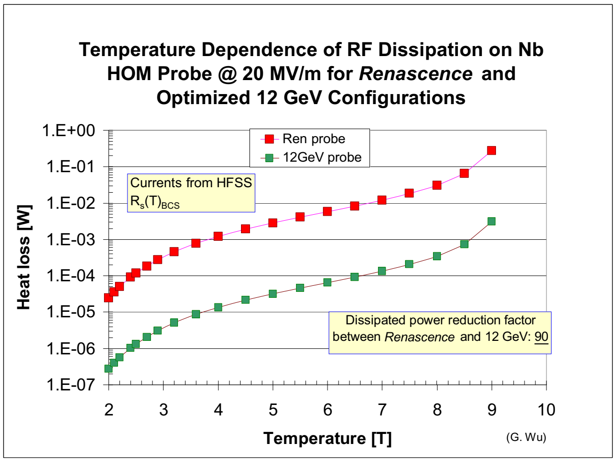

Figure 2. Calculated rf heating on the niobium probe of the *Renascence* and C100 cavity HOM coupler configurations with CW 20 MV/m cavity operation.

The damping of the dipole HOMs is less effective in the C100 cavity configuration, but still well within requirements. See Figure 3.

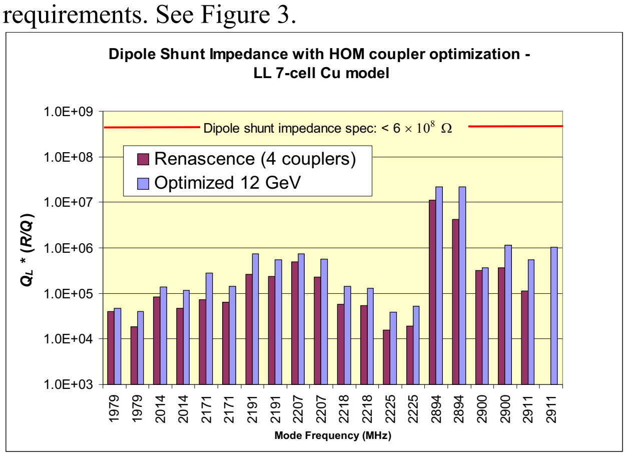

Figure 3. Copper model bench measurements of dipole shunt impedances obtained with the *Renascence* and C100 cavity HOM coupler configurations.

OPTIMIZATION OF THE WAVEGUIDE INPUT COUPLER

Two dimensional parameters are available to adjust the Q_{ext} of the waveguide Fundamental Power Coupler (FPC): the distance from the end cell and the length of the shorting stub of the waveguide. Maintaining the shorting plane a distance $\lambda/4$ from the beamline is needed to minimize transverse kicks to the beam.[3] Removal of the HOM cans and the change of the Q_{ext} specification for 12 GeV cavities to 3.2×10^{7} required revisiting the appropriate distance between the plane of the input waveguide and the outer iris of the first cavity cell.

A copper 7-cell cavity model and the HG006 Nb cavity were used to benchmark the use of HFSS to predict the Q_{ext} of the cavity designs. Then the appropriate C100 dimension was directly predicted. As a part of the trouble-shooting effort associated with the endgroup heating, the FPC endgroup with HOM couplers was removed by wire EDM and a new endgroup without HOM couplers was attached by electron beam welding. When the HFSS calculations properly predicted the Q_{ext} of this as-built assembly, we gained confidence in its use as a design tool. See Figure 4.

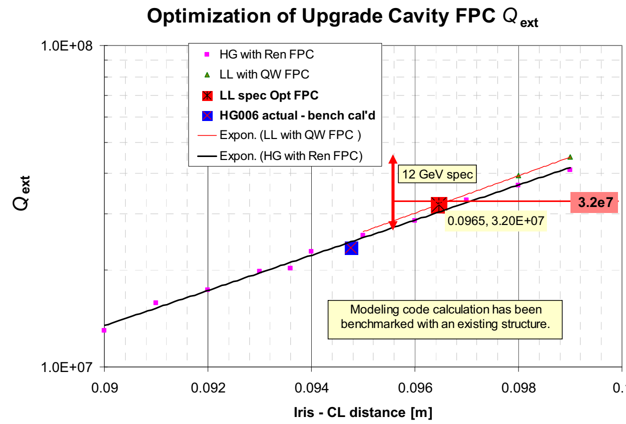

Figure 4. Variation of Q_{ext} with distance from endcell, simulation and bench measurements.

CAVITY FABRICATION AND TESTING

The C100 cavity design optimization and the fabrication and qualification of the first two niobium 7-cell C100 cavities took place in 2006. The cavities were fully fabricated at JLab.

The cavities receive the current standard BCP/600°C degas bake/tuning/BCP/HPR processing treatments. The cavities were tested individually in the JLab vertical test area (VTA) and assembled together and tested with tuners and waveguide coupling in the Horizontal Test Bed (HTB), in which the thermal boundary conditions replicate those of a full cryomodule. This HTB test was completed in January 2007 and demonstrated all of the performance characteristics required for the 12 GeV Upgrade.

Figure 5 depicts the C100 cavity configuration with “scissor-jack” tuner in place. This tuner leaves all active components outside the cryostat.

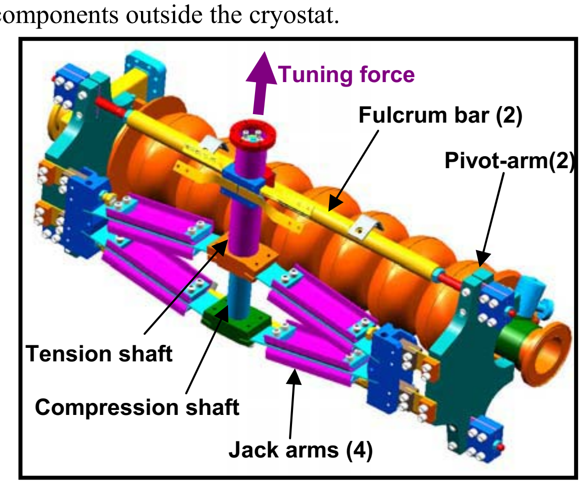

Figure 5. C100 cavity with tuner attached.

Helium vessel design changes

Previous helium vessels constructed around niobium cavities have been fabricated from titanium. As both a cost-saving improvement and a potential reliability enhancement, the C100 cavity design incorporates a change to a stainless steel helium vessel.

Use of titanium requires an intermediate material transition between the niobium cavity and the titanium shell. This has previously been accomplished via NbTi, which can be electron beam welded to niobium and TIG welded to titanium. A second type of transition has been needed between the titanium vessel and the stainless steel process helium distribution piping. Explosively bonded transition joints have typically been used in these locations.

For the C100 cavities, a brazed transition was fabricated between the inboard niobium beampipe sections and the stainless steel endplates of the helium vessel. See Figure 6. Design analyses and component testing have demonstrated the strength of the mechanical design. Use of a pair of stainless steel bellows decouples tuner motion from distribution piping and absorbs any differential contraction between niobium cavity and stainless steel vessel.

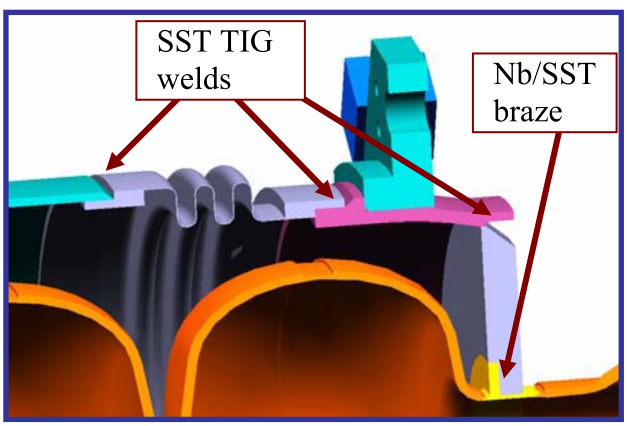

Figure 6. Material transitions for the C100 cavity and helium vessel.

C100 Cavity Performance

The cavity performance in VTA and HTB tests were quite consistent. Following the HTB test, the cavities were returned to the VTA for follow-up testing to provide cross-calibration information between the two facilities. Temperature regulation for Q measurements in the Cryomodule Test Facility (CMTF), where the HTB tests was accomplished, is not as accurate as in VTA tests, so test conditions may vary somewhat. The agreement between the test results was quite good. See Figure 7.

The 2 K dynamic heat budget for each cavity in the 12 GeV Upgrade is 30 Watts. We note that if the Q droop can be improved, these cavities could potentially be operable to 25 MV/m CW in CEBAF.

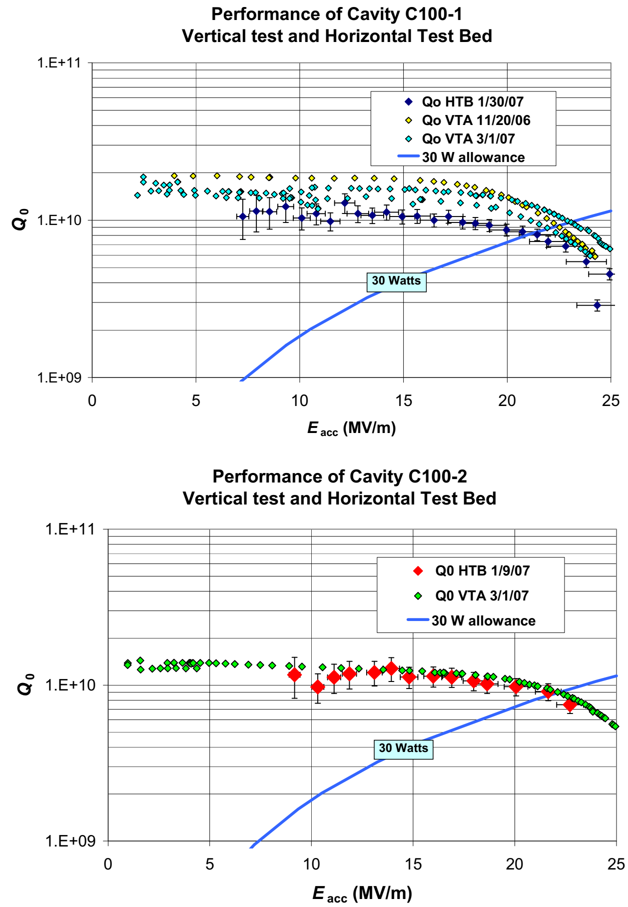

Figure 7. Performance of cavities C100-1 and C100-2 in vertical tests and the HTB test

Other C100 Cavity Properties:

The elimination of the stiffening rings from the LL-shaped cells yields a factor of eight increase in pressure sensitivity of cavity frequency and an increase of the Lorentz-force detuning coefficient by a factor of 4.3, which yields a tune shift of 1.7 kHz at 20 MV/m, 37 times the resonance bandwidth at the design Q_{ext}.

- Pressure sensitivity: 420 Hz/torr
- Static Lorentz-force detuning coefficient: - 4.3 Hz/(MV/m)^2

During the HTB test the damping effectiveness of the new HOM coupler arrangement was verified. Figure 8 shows the dipole shunt impedances for the two cavities, showing all modes adequately damped.

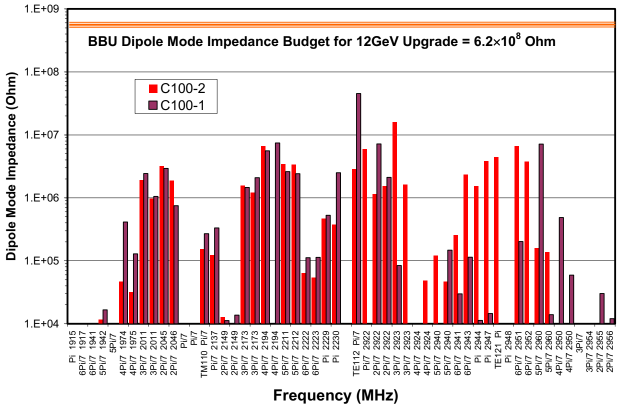

Figure 8. Dipole shunt impedances for the C100 cavities, based on MAFIA calculations and measured loaded Q's.

SUMMARY

Building on two prior generations of 7-cell cavity designs, we have optimized and qualified the cavity design for the CEBAF 12 GeV Upgrade. The LL cell shape has been integrated with an optimized HOM coupler arrangement, an optimized input waveguide coupler, a proven and serviceable tuner, and a reduced cost helium vessel design.

ACKNOWLEDGMENTS

The rapid fabrication of the C100 cavities was ably accomplished by B. Manus, S. Manning, and G. Slack. All the members of the cavity processing and cryomodule assembly groups can take credit for the successful demonstration tests of this cavity design. M. Drury managed the HTB testing.

REFERENCES

[1] C. E. Reece et al., "Performance of the CEBAF Prototype Cryomodule *Renascence,"* contribution WEP49 to this Workshop.

[2] J. Delayen, "RF Parameters for the 12 GeV Upgrade Cryomodule," Jefferson Lab Internal Technote: JLAB-TN-05-044

[3] G. Wu et al., "Waveguide coupler kick to beam bunch and current dependency on SRF Cavities," contribution WEP85 to this Workshop.