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Fabrication and Performance of Superconducting RF Cavities for the Cornell ERL Injector *

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Abstract

Six 1300 MHz superconducting niobium 2-cell cavities are manufactured in-house for the prototype of the Cornell ERL injector to boost the energy of a high current, low emittance beam produced by a DC gun. Designed for high current beam acceleration, these cavities have new characteristics as compared to previously developed low-current cavities such as those for TTF. Precision manufacture is emphasized for a better straightness of the cavity axis so as to avoid unwanted emittance dilution. We present the manufacturing, processing and vertical test performance of these cavities. We also present the impact of new cavity characteristics to the cavity performance as learnt from vertical tests.

INTRODUCTION

A 5 GeV ERL based X-ray light source is the goal of the ERL project at Cornell University. The project is currently in the phase of prototyping its injector, which consists of a DC photo-emission gun, a normal conducting copper buncher cavity, and a booster cryomodule hosting five 2-cell superconducting RF (SRF) cavities [1] [2].

A schematic layout of the five-cavity string is shown in Fig. 1. The injector SRF cavities accelerate a 100 mA CW

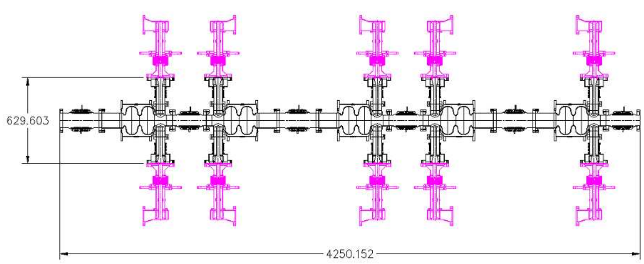

Figure 1: Layout of the 5-cavity string of the Cornell ERL prototype injector.

beam from 500 keV to 5 MeV. Each cavity provides a 1 MV voltage, corresponding to an accelerating gradient of 5 MV/m in CW operation. Injector cavities will also be operated at 15 MV/m at a reduced beam current of 30 mA. Each cavity has two symmetric RF input couplers. This arrangement cancels kicks due to coupler fields for better emittance preservation. Each coupler delivers a 50 kW CW power to the beam. Beam-line tile absorbers are fitted between cavities for damping HOM's.

CONSIDERATIONS IN ELECTRO-MAGNETIC AND ENGINEERING DESIGN

Designed for high current beam acceleration, the 1300 MHz 2-cell cavity geometry is optimized to allow propagation of HOM's into beam-line HOM absorbers [3]. Efficient HOM propagation is facilitated by a transition from the 78 mm iris to a 106 mm beam tube diameter. In contrast to other 1300 MHz cavities designed for operation in the pulsed mode where Lorentz force detuning is important, the 2-cell ERL injector cavities have omitted stiffening ribs in their mechanical design.

CAVITY FABRICATION

An important goal for the cavity fabrication is to achieve critical dimensions at a high precision. The mechanical axes of all welded components must stay at a tight tolerance within the cavity axis as defined by end flanges of the two beam tubes. This improves the straightness of the cavity electrical axes and reduces unwanted emittance dilution. Strict QA/QC procedures were implemented for each individual component and sub-assembly. Cups are fabricated with RRR 300 niobium sheets (Wah Chang) by standard deep-drawing and coining method. The RF input coupler ports are fabricated with a CNC milling machine. This allows a high precision in the symmetry between the twin RF input couplers, important for avoiding coupler kicks to bunches. We have chosen RRR 200 niobium (Tokyo Denkai) for the coupler block since the field in this region is still rather high. Reactor grade thin-walled niobium tubes (rolled and welded in-house as well as seamless tubes purchased from OTIC) are used for beam tubes. This reduces the static heat leak into the 2K liquid helium. All cavity flanges have the Conflat design, the size of which ranges from 1-1/3 to 6 inch. The knifedge is machined after a 316LN stainless steel ring is furnace brazed onto a niobium tube. Each cavity has 6 brazed flanges plus one more on the liquid helium vessel. The helium vessel dishes are fabricated from titanium and electron beam welded to the niobium cavity. The helium vessel (flanges, tank and bellow) is also made from titanium and is entirely manufactured with electron beam welding. Fig. 2 shows a picture of the 2-cell cavity before and after the helium vessel is welded.

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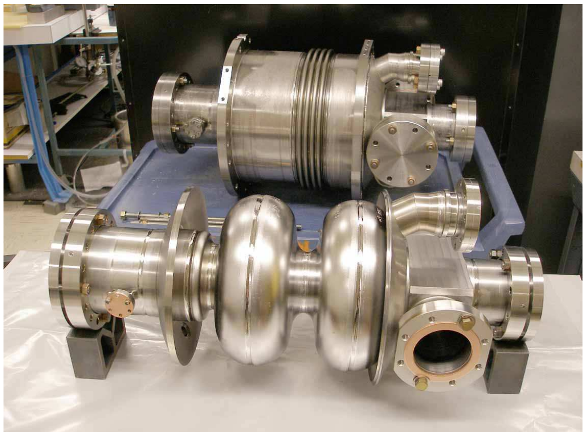
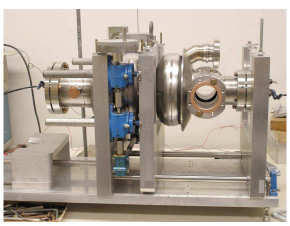
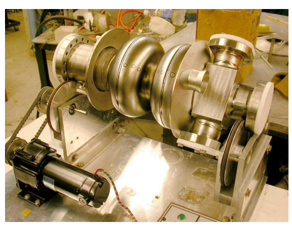


Figure 2: 2-cell cavity before and after welding the helium vessel.

Post-fabrication tuning is done with a mechanical apparatus as shown in Fig. 3(a). The prototype cavity as built had a frequency error of more than 4 MHz. It was tuned by removing material from the inner surface of the inductive region of the cells with a tumbling apparatus (Fig. 3(b)).



(a) With tuning apparatus



(b) With tumbling apparatus

Figure 3: Tuning of a 2-cell cavity by stretching/squeezing the cell length with a tuning apparatus (a) or by removing material from the inductive region of the cell with a tumbling apparatus (b).

For the 5 cavity production, we implemented an active frequency compensation method, which is based on the actual shapes of half-cells as welded in sub-assemblies. The total frequency error is compensated by trimming the dumb-bell equators to a suitable dimension. The active frequency compensation method allows one to selectively match half-cells for a better mechanical (and hence electrical) symmetry. It also results in a resonant frequency of the as-built cavity very close to the design target (average error being -150 kHz).

Fig. 4 gives the result of the straightness of the cavity mechanical axis as measured by CMM. The central coordinate of cavity segments is measured progressively from one end flange to the other end and projected onto a plane perpendicular to the axis defined by centers of end flanges.

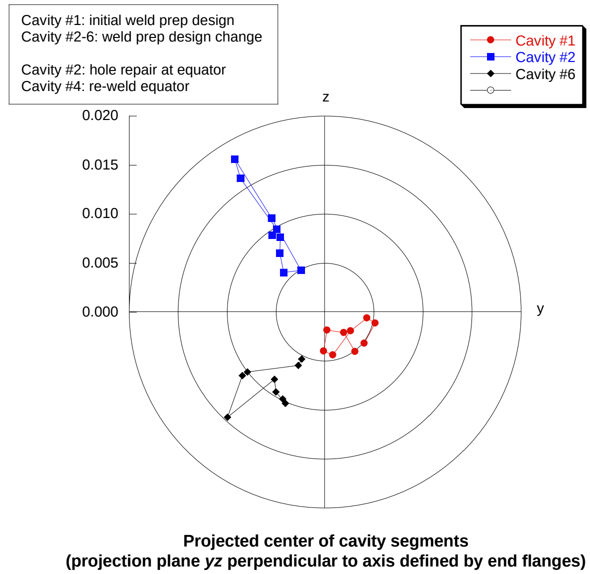


Figure 4: Result of the cavity axis straightness measurements.

CAVITY PROCESSING

The inner surface of a completed cavity is etched for 120 μm with BCP1:1:2 as shown in Fig. 5(a) at a temperature below 15 °C (water cooling cavity). Because of the vertical orientation during etching, the cavity needs to be flipped to eliminate asymmetric removal across cells. Brazed joints and knifedges at the Conflat flanges are protected by Teflon plugs shielding them from being attacked by the acid.

After chemical etching, the cavity is rinsed with a closed-loop DI water system for over night, followed by a 4-hour session of high-pressure water ringing in our clean room as shown in Fig. 5(b).

(a) Chemical etching

(b) High-pressure rinsing

Figure 5: 2-cell cavity processing: (a) Chemical etching with BCP1:1:2; (b) High-pressure water rinsing.

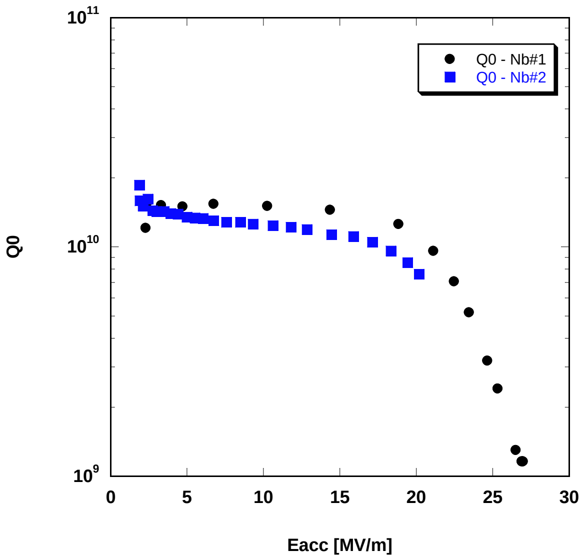


Figure 6: Summary of the vertical test performance.

CAVITY PERFORMANCE

The $Q(E_{acc})$ performance of the cavities is summarized in Fig. 6. A Q_0 of $> 10^{10}$ is achieved from 5 to 15 MV/m, the designed range of the operating gradient. The rapid decrease in Q_0 above 18 MV/m is typical of a cavity etched with BCP and not low-temperature (100-120 °C) baked. Some field emission also contributes to the Q_0 decrease.

A processing phenomenon, starting from 3.5 MV/m up to 8 MV/m, was reproducibly observed when the field was raised for the first time. Guided by the suspicion of multipacting, renewed simulation studies were carried out with the code MULTIPAC [4] with a new model which includes, in addition to cavity cells, the enlarged beam tube. It turns out that a multipactor exists near the bend in the enlarged beam tube (see Fig. 7). An experiment clearly confirmed the existence of the multipactor: detection of electrons by a biased probe and correlated temperature changes by thermometers at the outer wall of multipacting region.

Nevertheless, it is possible to process through the multipacting barriers. And the field amplitude and phase are stable after processing. Preliminary data show that the processing effect can be preserved as long as the cavity remains below 4 K; but the multipactor re-appears if the cavity is cycled to the room, or an intermediate, temperature.

The detuning sensitivity due to a change in the helium bath pressure is measured to be -597 $Hz/Torr$. The Lorentz force detuning coefficient is measured to be 3-4 $Hz/(MV/m)^2$.

CONCLUSION

Six 2-cell niobium cavities are fabricated for the Cornell ERL prototype injector. Conflat flanges with a brazed 316LN stainless-steel/niobium joint work reliably in superfluid liquid helium. The Q exceeds 10^{10} for the designed

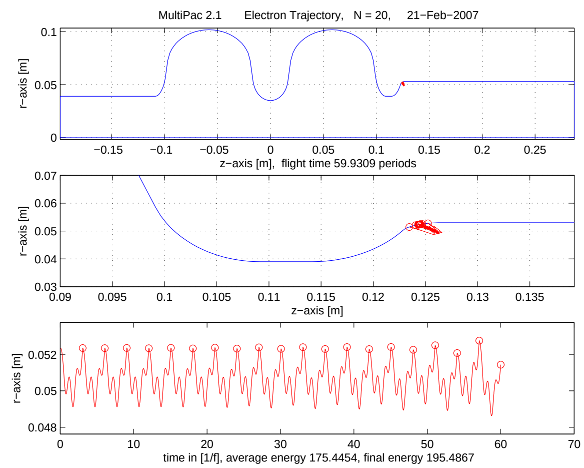


Figure 7: Multipactor in the 2-cell cavity. E_{acc}=6.5 MV/m. Upper: cavity model with beam tubes and location of the multipactor; Middle: magnified multipactor location and electron trajectories; Lower: time interval between impacts and the impacting energy.

operating gradient range of 5-15 MV/m.The multipactor at the bend of the enlarged beam tube can be processed through and seems to be not harmful to the field stability after processing. It re-appears when the processed niobium surface is re-contaminated by species in the vacuum. The bath pressure and Lorentz force detuning coefficients are both significantly larger as compared to that of a TTF cavity which has stiffening ribs. Multipactor re-appearing and sensitive bath pressure detuning will both affect the operation of the cavity when used for beam acceleration. We expect a full assessment of their impacts during the upcoming horizontal tests.

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