PROTOTYPING OF A SINGLE-CELL HALF-REENTRANT SUPERCONDUCTING CAVITY*

M. Meidlinger†, J. Bierwagen, S. Bricker, C. Compton, T. Grimm,
W. Hartung, M. Johnson, J. Popielarski, L. Saxton, R. York,
National Superconducting Cyclotron Laboratory, East Lansing, Michigan, USA
E. Zaplatin, Forschungszentrum Jülich, Germany

Abstract

As superconducting niobium cavities achieve higher gradients, it is anticipated they will reach a performance limit as the peak surface magnetic field approaches the critical magnetic field. Low loss [1] and reentrant [2] cavity designs are being studied at CEBAF, Cornell, DESY, and KEK, with the goal of reaching higher gradients via lower surface magnetic field, at the expense of higher surface electric field. At present, cavities must undergo chemical etching and high-pressure water rinsing to achieve good performance. It is not clear whether this can be done effectively and reliably for multi-cell low loss or reentrant cavities using traditional techniques. A half-reentrant cavity shape has been developed with RF parameters similar to the low loss and reentrant cavities, but with the advantage that the surface preparation can be done easily with existing methods. Two 1.3 GHz prototype single-cell half-reentrant cavities have been fabricated; the non-reentrant wall angle is 8°, the beam tube radius is 29 mm, and the cell-to-cell coupling is 1.47%. The half-reentrant cavity design and status of the prototyping effort is presented.

INTRODUCTION

The concept and RF optimization of the half-reentrant cavity has been published in Ref. [3]. The goal of the half-reentrant cavity is to provide similar electromagnetic performance as both low loss and reentrant cavity designs (Table 1), but be able to be adequately cleaned with current technology, and therefore reliably reach high accelerating gradients.

Design Shape

The previously published half-reentrant shape was made more complex at the end of 2005, in that every ellipse was replaced by a series of arcs as seen in Figure 1. This gives the ability to adjust the surface electric and magnetic fields on a finer scale than previously possible. The iris radius was decreased to 29 mm to improve the electromagnetic performance and the non-reentrant wall angle was increased to 8° to allow for better fluid drainage. With a maximum surface magnetic field of 180 mT, the maximum theoretical accelerating gradient for a mid-cell is 50.7 MV/m.

Multipacting simulations were completed with MULTIP [4], a code developed at Cornell. Both one-point and two-point multipacting are predicted near the equator, however no hard multipacting barriers were found. Structural analysis of a half-reentrant nine-cell cavity has been done [5], and modal analysis indicates that stiffening rings significantly increase the rigidity of the cavity.

*Work supported by the National Science Foundation.
†meidlinm@nscl.msu.edu

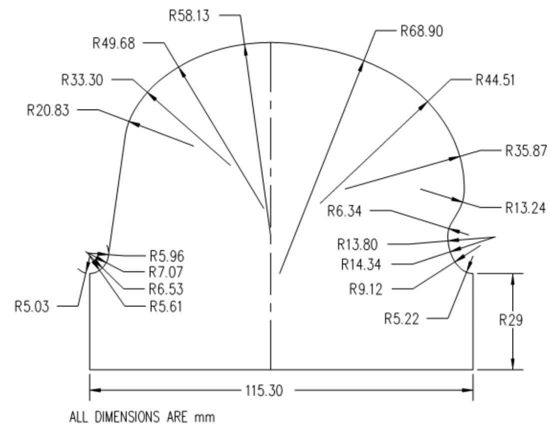

Figure 1: Mid-cell shape of fabricated half-reentrant cavity.

FABRICATION

Parts for three single-cell half-reentrant cavities have been fabricated, and two single-cell cavities have been completed and are ready to be processed and tested. The cavity cells were fabricated from 4 mm thick, high purity niobium (RRR=208) with a yield strength of 50-59 MPa and elongation of 44-48%, and a reentrant half-cell can be seen in Figure 3. The beam tubes were fabricated from 2 mm thick niobium (RRR=197) with a yield strength of 56-60 MPa and elongation of 45-58%. All niobium was supplied by Tokyo Denkai. The beam tubes were chosen to be 2 mm thick for cost savings after analysis predicted a maximum Stress Von Mises of 27 MPa in a very localized region

Figure 2: Deep drawing of non-reentrant half-cell with 75 tons.

Table 1: Parameters of the previously proposed half-reentrant inner cell, designed with ellipses, compared to the fabricated cell, designed with arcs as shown in Figure 1. Two other designs proposed for the ILC are shown as a comparison

		Half-Reentrant Ellipses [3]	Half-Reentrant Arcs (Fabricated)	Cornell Reentrant [6]	DESY/KEK Low Loss [1]
frequency	[MHz]	1300	1299	1300	1300
wall angle	[°]	6	8	-	0.165
E_{peak}/E_{acc}	[-]	2.38	2.41	2.28	2.36
B_{peak}/E_{acc}	$[\frac{mT}{MV/m}]$	3.60	3.55	3.54	3.61
R/Q	[Ω]	135	136	121	134
G	[Ω]	283	285	280	284
$(R/Q)\cdot G$	$[\Omega^2]$	38021	38796	41208	37970
k_{cc}	[%]	1.51	1.47	1.57	1.52
r_i	[cm]	2.97	2.90	3.00	3.00

near the reentrant iris. For the analysis, 1 bar pressure differential was used (vacuum inside the cavity, ambient pressure outside) with “fixed-free” boundary conditions and a beam tube thickness of 1.62 mm to account for thinning from machining and etching. These results indicate there may be plastic deformation in a localized region after the cavity is post-purified, which will reduce the yield strength by approximately a factor of two. The beam tubes were chosen to be 12.675 cm long, and with this length, simulations indicate a 0.025% reduction of Q at 1.5K due to losses in the stainless steel endcaps. The flanges are NbTi using 4-5/8” ConFlat® seals.

Figure 3: Reentrant half-cell with checking fixture.

Deep drawing was done with the regular two-step process with each half-cell pressed with 75 tons (Figure 2) followed by coining dies pressed with 17 tons. We did not notice any tearing of the initial copper test blanks, even with small inner diameter holes. The outer edge of the niobium was constrained with the proper torque on the hold down bolts. No intermediate anneals were performed. Vent holes were drilled in the reentrant region for both the female and male dies to allow lubrication to escape during stamping. The half-cells were trimmed and interlocking equator and iris joints were machined.

Electron-beam Welding

All e-beam welds were done at Sciaky Corporation in Chicago with a 50 kV welder. The beam tubes were rolled, stamped, and then e-beam welded length wise with a full penetration weld of the butt joint. The tubes were then e-beam welded to the NbTi flanges using a very focused beam to minimize alloying of titanium into the niobium beam tubes. The iris was tack welded to the beam tubes and then welded from the inside at an angle of 30° using a 10 inch gun-to-work distance, 38 mA, and 18 inches/minute. This was followed by a weld from the outside, perpendicular to the beam axis, using a 8 inch gun-to-work distance, 38 mA, and 18 inches/minute.

The full penetration equator weld (Figure 4) was performed from the outside through 2 mm thick niobium. The equator weld used an oscillation of 1 kHz, maximum spot diameter of 0.005 inches, and gun-to-work distance of 8 inches. Tack welds were completed with 18 mA at 18 inches/minute, followed by a seal pass with 38 mA at 18 inches/minute. The main e-beam weld was then done for cavity 1 with 48mA, 12 inches/minute. The weld did not

Figure 4: Full penetration e-beam weld of equator.

fully penetrate, so the cavity was rewelded with 55 mA, 12 inches/minute, following the rule of thumb to increase the current by 10%. Cavity 2 was e-beam welded one time with 51 mA, 12 inches/minute. While the weld for cavity 2 was sufficient, we plan to use 53 mA for the main equator weld for future cavities.

Coordinate Measurement

The half-reentrant cavity profile was measured at two different times during the fabrication process by a Zeiss Prismo 10 Vast HTG 2400 at Advanced Consulting and Engineering. The first coordinate measurement was done after the reentrant and non-reentrant half-cells were stamped, before any machining. A second coordinate measurement was performed after the iris weld, and the results can be seen in Figure 5. The equatorial plane of the machined equator step is used as the reference for the second coordinate measurement. Using this reference, the maximum deviation of the fabricated shape from the design shape is .033 inches and occurs near the iris at the location of the red circles. However, this equatorial reference plane is not absolute, as there will be machining errors in the machined weld prep. One can shift the reference to better align the coordinate measurement profile with the design shape. If this is done, the maximum deviation of the fabricated shape from the design shape, before the equator weld, is reduced to 0.014 inches and is within our goal of 0.020 inches. The effect of the iris weld on the cavity shape should be negligible, since it is not a full penetration weld. Indeed, the two coordinate measurements showed a small change in the cavity shape near the iris of less than 0.003 inches.

There is thinning from 4 mm to 3.71 mm as well as a sharp transition in the cavity profile at near the iris where the coining die was pressed. This could perhaps be avoided by increasing the radius of the coining die and thus providing a more continuous transition. One can also see the expected material thickening near the equator. A 0.020 inch allowance for weld shrinkage was designed into the equator prep, however actual weld shrinkage ranged from 0.024-0.040 inches.

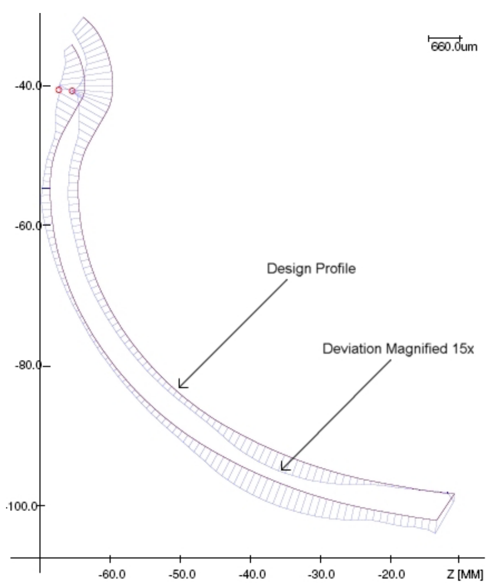

Figure 5: Coordinate measurement of reentrant half-cell after iris weld.

CONCLUSION

Two single-cell half-reentrant niobium cavities have been fabricated at Michigan State University. Coordinate measurements show the cavity shape to be within 0.016 inches of the design profile before the equator weld. Bench top measurements show a resonance frequency of 1293.03 MHz, 4.45 MHz higher than the simulated single-cell cavity frequency. Processing and testing will begin in the fall.

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