FABRICATION AND MEASUREMENTS OF 500 MHz SUPERCONDUCTING DOUBLE SPOKE CAVITY*

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Abstract

A 500 MHz β_0=1 double spoke cavity has been designed and optimized for a high velocity application such as a compact electron accelerator at the Center for Accelerator Science at Old Dominion University [1] and the fabrication was recently completed at Jefferson Lab. The geometry specific to the double spoke cavity required a variety of tooling and fixtures. Also a number of asymmetric weld joints were expected to make it difficult to maintain minimal geometric deviation from the design. This paper will report the fabrication procedure, resulting tolerance from the design, initial test results and the lessons learned from the first β_0=1 double spoke cavity fabrication.

ELECTROMAGNETIC DESIGN

A superconducting double spoke cavity was optimized to minimize the peak surface fields while maximizing the shunt impedance. It was designed to operate at 4.2K to lower the operating cost. Table 1 shows the radio frequency (RF) and geometric properties of the cavity design.

Table 1: Properties of β0=1 Double Spoke Cavity [1]

Parameter	Value	Units
Frequency	500	MHz
Cavity diameter	416	mm
Cavity length	805	mm
Aperture diameter	50	mm
R/Q	675	Ω
QR_s	174	Ω
E_p/E_{acc}	3.7	-
B_p/E_{acc}	7.6	mT/(MV/m)
B_p/E_p	2.05	mT/(MV/m)

†Reference length=$3\beta_0\lambda/2$

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FABRICATION

The double spoke cavity was divided into symmetric sections in order to reduce the number of forming dies and weld joints. A total of four forming dies were made: spoke half, end cap, 50 mm ID beam pipe, and 40 mm ID ancillary port. The outer cylindrical conductor half was rolled in multiple steps instead of using forming dies. The radius was verified by a template. Figure 1 shows the formed spoke half and end cap.

Figure 1: Formed spoke half and end cap.

The spoke halves were trimmed and welded along with a beam pipe to form a spoke subassembly. Then, the spoke base, where it joins the outer cylindrical conductor, was trimmed. Figure 2 is the complete spoke subassembly being measured on the coordinate measuring machine (CMM). A total of 152 points were measured, the best fit model was constructed, and compared with the cavity model. Figure 2 also shows the results.

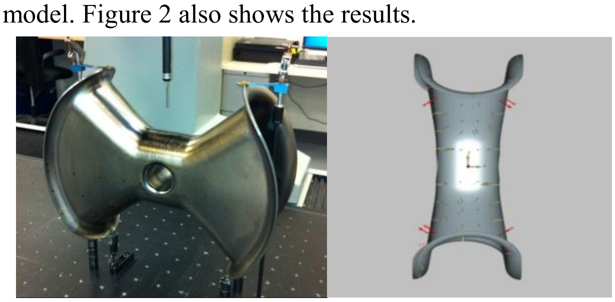

Figure 2: Welded spoke and CMM results showing deviations from the cavity model.

The forming die of the spoke half was within .13 mm (.005 inch) of the design profile. However, the spoke assembly showed a spring back with a maximum deviation of 2.8 mm (.111 inch). The deviation was symmetric about the central plane.

The openings for the spoke base in the cylindrical conductor halves were machined while the cylinder was held in a fixture. The machined profile is perpendicular to the surface, which makes the cut cross section uniform 1/8 inch throughout. This provides a uniform butt weld joint with a constant electron beam parameter during welding. Figure 3 shows the weld fit-up of the spoke

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subassembly to the outer conductor and the finished subassembly. The fixtures were used to hold the two outer conductor haves round. However, after the welds were complete and the fixtures were removed, the outer conductor did not maintain roundness.

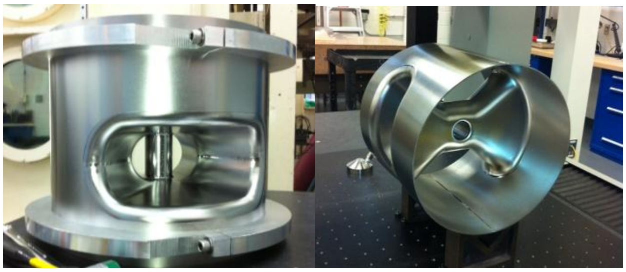

Figure 3: Weld fit-up and completed spoke-outer conductor subassembly

The two identical spoke-outer conductor subassemblies were fixtured in order to recover roundness for welding. The spokes were oriented 90 degrees from each other. Figure 4 shows the middle seam weld set up in the e-beam welding machine.

Figure 4: Cavity main body middle seam welding.

The two end cap subassemblies were made in parallel. Before the final welding, the main body and the end caps were tightly clamped and bead pulling was performed to determine the proper amount of trimming. It was decided to trim to bring the frequency to the design target rather than achieving the field flatness between the three cells. The joints between the main body and the two end caps were the final weld seams. Figure 5 is the completed cavity set up for the final bead pull.

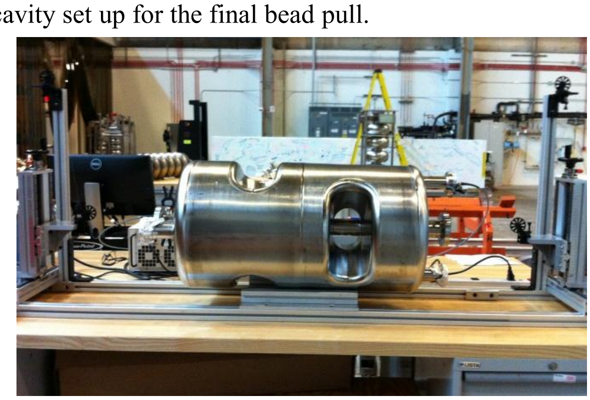

Figure 5: Complete cavity for bead pull set up.

Lesson Learned from Fabrication

The geometry of the double spoke cavity is not axially symmetric. The welding deforms the cavity significantly. This is especially true for a butt weld through the full material thickness.

In order to minimize the distortion during the fabrication process fixtures were used every step and joints were tack welded prior to the full penetration weld. However, when the fixtures were removed the distortion was apparent.

The magnitude of the distortion is related to the size of the cavity as well. Reducing the fabrication tolerance means increasing the fabrication cost. The balance between the fabrication tolerance and the cavity performance will be studied.

CAVITY PROCESSING

The processing before the test includes the following steps.

- Bulk 150 micron buffered chemical polish (BCP) surface removal.
- Heat treatment at 600 deg C for 10 hours.
- Light BCP of 10 micron.
- Ultrasonic degreasing and high pressure rinse (HPR).
- Cavity assembly in the clean room
- Bake at 120 deg C for 48 hours.

The following processing steps are particular to the spoke cavity.

BCP

The BCP tool at JLab is a vertical set up. To assure uniform material removal throughout the cavity inner surface, the cavity was flipped once. The removal rate was monitored with an ultrasonic thickness gauge mounted in the middle of the cavity. It was expected that the removal rate on different surfaces would be different and this was confirmed at the final thickness measurement. Figure 6 shows the removed thickness at the various locations.

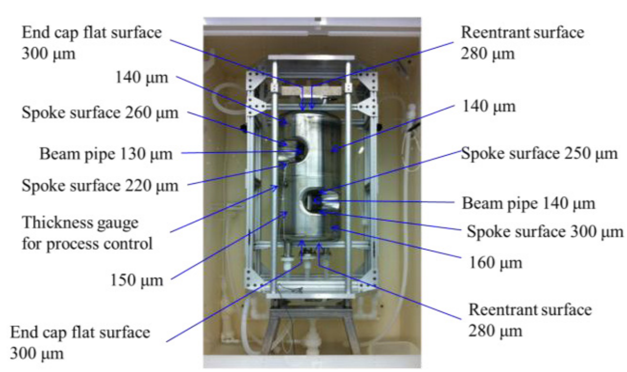

Figure 6: BCP set-up and thickness measurement results.

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The surfaces perpendicular to the acid flow experienced a lot more removal than the vertical surfaces such as the outer conductor and beam pipe.

Horizontal BCP set up with a rotating cavity may remove the material more uniformly.

HPR

The HPR tool at JLab is also a vertical setup with the wand travelling vertically through the beam pipe while the mounting table is rotated. The nozzle sprays the pressurized (pump pressure 1300 psi) ultra clean DI water. The large spoke base inhibits cleaning all surfaces. Therefore, a manual rinse step was added just before the cavity was placed in the automated HPR cabinet. During the manual rinse, the cavity was placed horizontally on the table and the wand with forward and backward nozzle was inserted through the ancillary ports. The clean DI water is from the same DI water system used at the automated HPR cabinet. The high power test at 4.3 K showed little field emission and proved the effectiveness of this manual rinse.

CAVITY TEST RESULTS

The cavity was placed in a vertical dewar and the helium was cooled down to 4.3K while the cavity vacuum pressure was monitored. During the cooling process we noticed a leak. Since we actively kept evacuating the cavity the pressure became stable and we were able to test the cavity at 4.3K and 2.3K [2]. Figure 7 shows the high power RF measurement results.

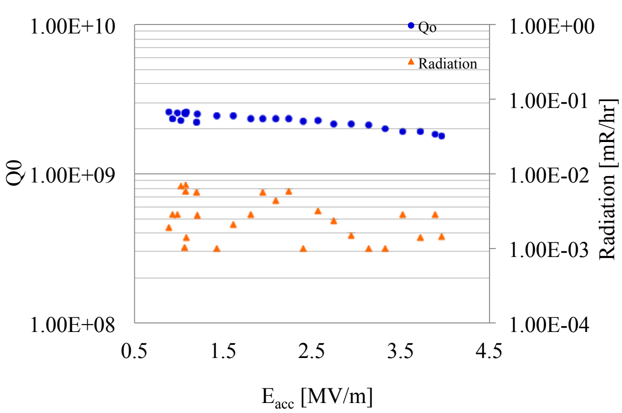

Figure 7: High power test results at 4.3K.

The multipacting was observed at the very beginning. The oscilloscope trace showed a very obvious multipacting with the transmitted power oscillating with a flat level. The multipacting was easily processed and it did not occur when the measurement was repeated.

Thanks to the development of a multipacting simulation tool such as Track3P [3], multipacting simulation for full 3D structures has been possible and the test of the double spoke cavity seems to validate the results of the code [4].

At about a gradient of 4 MV/m oscillating slow decay of transmitted power was observed and it persisted. The measured unloaded quality factor is 2.5 $\times 10^9$.

ON GOING EFFORTS AND PLAN

The cold leak source was identified to be at the field probe flange connection to the cavity port. It has been replaced and the cavity is being prepared for additional testing. The investigation is planned to find a cause of slow decay (30-40 ms) of the transmitted power. After fixing the cold leak, the cavity will be tested at both 4.2K and 2K. This will allow more accurate residual surface resistance measurements. It is also planned to measure the entire cavity 3D profile with the CMM and to see how the geometrical deviation affects the RF property of the cavity. The results will provide valuable insight how tolerant the spoke cavity is against the fabrication errors and what level of fixturing effort is required during the fabrication.

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