SRF CAVITY ETCHING DEVELOPMENTS FOR FRIB CAVITY PROCESSING*

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Abstract

Updates to the FRIB beta=0.53 half wave resonator (HWR) design have provided an opportunity to test new buffered chemical polish (BCP) flow control techniques. New processing fixtures have been fabricated and used to process the FRIB beta=0.53 HWR. This paper will present details of the fixture mechanical design iterations, the resulting BCP flow simulations, a qualitative evaluation of the agreement between simulations and measured results, and developments in process validation techniques.

INTRODUCTION

Buffered chemical polish (BCP) processing techniques continue to progress with the FRIB β=0.53 half wave resonator (HWR) cavity. With the updated cavity design we were able to use new fixturing concepts and take a variety of measurements to better understand the processing parameters. The new β=0.53 HWR cavity has an internal volume of 76 L, and an internal surface area of 1.4 m^2.

The objectives for the design of the new chemistry fixtures were to reduce fixture complexity, reduce fixture installation time, and increase the etch uniformity.

FIXTURE DESIGN

Twelve different configurations were analyzed to determine the best concept for achieving uniform etch removal. Seven of the configurations were a derivative of the directional quill injection system used on the previous β=0.53 HWR cavity [1]. The other five configurations consisted of a single directional quill. Ultimately the single directional quill was chosen. The analysis of the single directional quill, and the four injection quill design, can be seen in Figure 1.

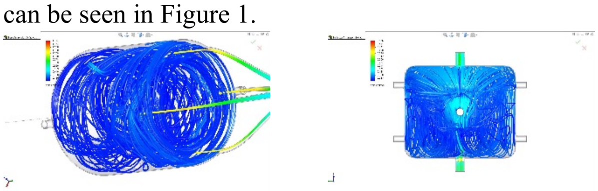

Figure 1: Left, analysis of four quill injection system. Right, analysis of single quill injection system.

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The single quill configuration shown in Figure 2 was chosen because it appeared to deliver equivalent mixing of the BCP compared to the four quill configuration, while reducing the complexity of the BCP delivery plumbing. The quality of the BCP mixing is determined qualitatively by choosing the fixture concept which produces the least velocity variation across the superconducting surface of the cavity.

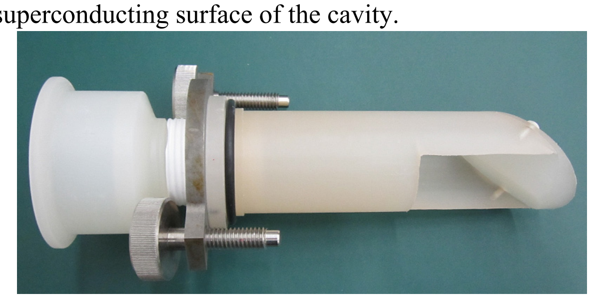

Figure 2: Single injection quill used for FRIB β=0.53 HWR cavity BCP processing.

One of the stated goals of this fixture iteration was to reduce installation time. This was done in two ways. First, the force needed to make the o-ring seal on each flange was carefully examined and revised. Second, we attempted to eliminate the need for tools during the fixture installation.

Past chemistry flanges were designed with a hole pattern to match the mating flange on the cavity. For example, one of the 2.75” ConFlat flanges of the prototype β=0.53 HWR cavity had six ¼” clearance holes (See Figure 3). Once the fasteners are were tightened there was nearly 12,000 lbs of force on the flange, though it is not known what portion of that force was transmitted to the o-ring.

O-ring Analysis

The Parker Hannifin o-ring handbook [2] indicates that only 20-30% compression is necessary to make a static o-ring seal. Given the o-ring hardness, thickness, and desired percent compression, the Parker Hannifin o-ring handbook indicates that 10-20 lbs of force per linear inch of o-ring is required to make a reliable seal. This means that only 300 lbs of force is needed for this seal.

A stainless steel backing plate was added to each flange to ensure that the tension from the fasteners was evenly distributed to the o-ring and, the number of fasteners was reduce from six to two. Because a well lubricated 1/4” fastener requires only 7.5 in*lbs of torque to produce 150 lbs of tension (half of the required 300 lbs), thumb screws were used in place of hex head cap screws. This eliminated the need for hand tools, and reduced the total BCP processing flange installation time from ~30 minutes to ~5 minutes.

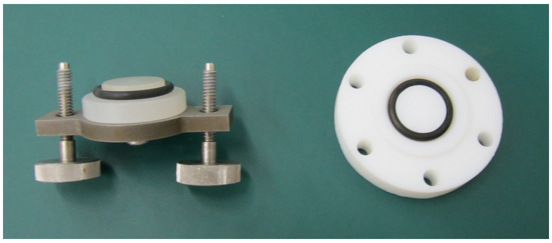

Figure 3: Left, new BCP blank flange design. Right, old BCP blank flange design.

EVALUATION OF SIMULATION

Ultrasonic thickness measurements (USTM) were taken on the new HWR cavity before and after each bulk etch step. The bulk etch removal for this cavity was taken in steps of 45 µm, 55 µm, and 30 µm respectively. The ultrasonic thickness measurements show strong correlation between the predicted flow path and the resulting etch patterns. Notice the high etch region which begins below the cavity beam port and broadens as the BCP impinges on the cavity surface. The black triangles in Figure 4 highlight this behavior. The new fixtures provided a more uniform etch in most locations on the cavity. One exception to this uniformity is the area near the radio frequency (RF) antenna ports indicated by the arrow in figure 4. The weld bead around this port allowed a gas bubble to form, reducing the local etch rate.

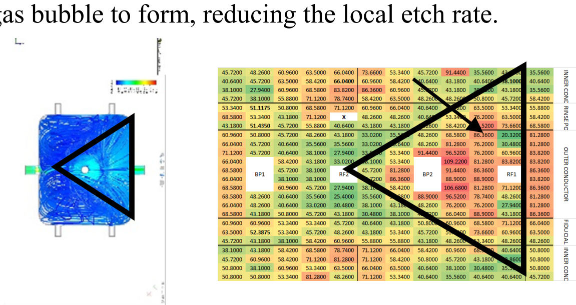

Figure 4: Left, Predicted flow pattern. Right, resulting etch removal measured by USTM.

PROCESS VALIDATION

Three different techniques were used to measure the amount of etching done to the cavity's RF surface. Those techniques were, ultrasonic thickness measurements, mass change analysis, and heat production analysis.

Ultrasonic Thickness Measurements

This method requires the user to take ultrasonic thickness measurements at numerous locations on the outside of the cavity before etching, and then repeat those measurements after etching. The thickness of material removed can then be calculated at each measurement location. This method is useful for determining locations of high etch removal, but it is also time consuming. If the removal has been calculated for the majority of the cavity's surface area all data points can be averaged to yield an accurate overall etch removal.

Mass Change Analysis

Unlike USTM's, this method does not provide information about removal rates in specific locations on the cavity. It is a useful way to quickly determine the overall etch removal. This method requires a mass measurement be taken before and after etching. Equation 1 below is used to calculate the average material removal from the cavity.

$$Removal = \frac{m_i - m_f}{\rho_{Nb} \times S.A.} \quad (1)$$

Where m is mass, ρ_{Nb} is the density of niobium, and S.A. is the surface area of the cavity.

Application of this method can be challenging because it requires a very accurate measurement of mass to yield accurate etch removal measurements.

Heat Production Analysis

Because the reaction between BCP and Niobium is very exothermic [3] a measurement of heat produced during the etching process can be used to determine the amount of niobium removed from the cavity's internal surface. The change in temperature of the flowing BCP is used to determine the amount of heat produced during the cavity etch. Equation 2 (below) is used to calculate the amount of heat which is put into the BCP.

$$Q(t) = \dot{V}(t) \times \rho_{BCP} \times c_{p,BCP} \times \Delta T(t) \quad (2)$$

Where $\dot{V}$ is the volumetric flow rate of the BCP, ρ_{BCP} is the density of the BCP, $c_{p,BCP}$ is the heat capacity of the BCP, and $\Delta T(t)$ is the temperature as a function of time. Now that the heat production known equation 3 (below) can be used to determine the amount of niobium removed from the cavity surface.

$$Removal = \frac{\int_{t_0}^{t_f} Q(t)dt}{M(Nb) \times \rho_{Nb} \times h_{RXN} \times S.A.} \quad (3)$$

Where M(Nb) is the molar mass of niobium, and h_{RXN} is the heat of the reaction.

One advantage of this method is that it can be applied during the etching process to determine when the cavity has received the desired amount of etching, and the resulting measurement is not affected by localized etch patterns.

Measurement Method Comparison

As mentioned earlier, this cavity was etched in three steps of 45, 55, and 30 micrometers respectively. Each measurement technique was used at every stage of the

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etching process. The result of each measurement technique are summarized in Figure 5 below.

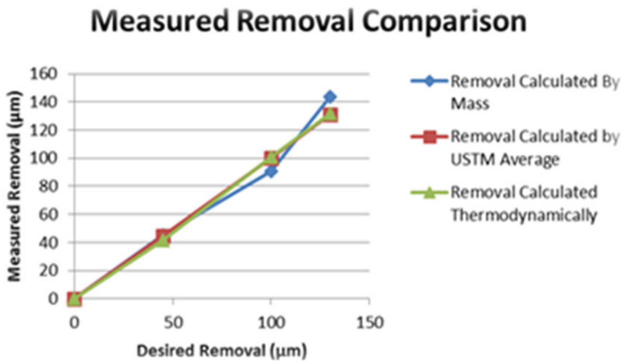

Figure 5: Comparison of measurement techniques for each stage of β=0.53 cavity bulk etch.

USTM is the most accurate technique at this time. The results of heat production analysis are in close agreement with the USTM method, as seen in Fig. 5. Measurements taken for the mass change analysis were done with a scale which had a resolution of .2 lbs., this can lead to measurement error of 7.5 μm.

CONCLUSION

Fluid flow simulations have proven to be effective in qualitatively predicting localized etch rates. Understanding predicted flow patterns will lead to accurate modeling of etch removal across the cavity's internal surface. After the removal patterns are understood the use of USTM's is no longer necessary. Instead mass change analysis or heat production analysis can be used to quickly and accurately verify etch removal.

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