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IMPROVEMENT OF CHEMICAL ETCHING CAPABILITIES (BCP) FOR SRF SPOKE RESONATORS AT IJCLAB

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Abstract

Buffered chemical polishing (BPC) is the reference surface polishing adopted for ESS and MYRRHA SRF spoke resonators at IJCLab. This chemical treatment, in addition to improving the RF performance, fits into the frequency adjustment strategy of the jacketed cavity during its preparation phase. In the framework of the collaboration with Fermilab for PIP-II project, IJCLab has developed a new setup to perform rotational BCP. The implementation of a rotation during chemical etching improves significantly the homogeneity and quality of surface polishing. In this paper, we present the numerical analysis based on a fluid dynamics model. The goal is to estimate the acid flow characteristics inside the cavity, determine the influence of several parameters as mass flow rate and rotation speed and propose the best configuration for the new experimental setup.

INTRODUCTION

Buffered chemical polishing is the chemical treatment performed at IJCLab on Spoke resonators equipped with their helium vessel (Fig. 1). A standard mixture of the three following acids is used: hydrofluoric HF, nitric HNO3 and ortho-phosphoric H3PO4, with 1:1:2 volume proportions. The heat generated during the chemical reaction is dissipated through both the acid maintained at 6°C and the cooling water inside the helium vessel.

Figure 1: Chemical treatment system equipped with a single Spoke resonator currently used at IJCLab.

The average material removal from the cavity surface by BCP is around 200µm in order to eliminate the damaged layer created during the manufacturing. Today, the cavity is static during the treatment. As a consequence, after half the time, the cavity is flipped in order to etch as homogeneously as possible the overall surface. The average removal rate measured on ESS and MYRRHA cavities by weighing is between 0.25 and 0.6 µm/min. The chemical treatments induce a frequency variation sufficiently well controlled, so that the RF frequency could be finely tuned. The BCP can be performed in vertical and horizontal positions for the ESS double Spoke cavities (Fig. 2) due to the presence of the high-pressure rinsing ports [1] (only in the horizontal direction for the MYRRHA single Spoke cavities [2]). These two BCP treatments do not etch the cavity walls in a same way and finally cause frequency changes which are different in magnitude and sign: around -0.6 KHz/µm in horizontal against +0.3 KHz/µm in vertical direction. Consequently, for each ESS cavity, a judicious combination of BCP operations is predefined to get the target frequency [3]. For MYRRHA cavity prototypes, the average frequency sensitivity is +1 KHz/µm.

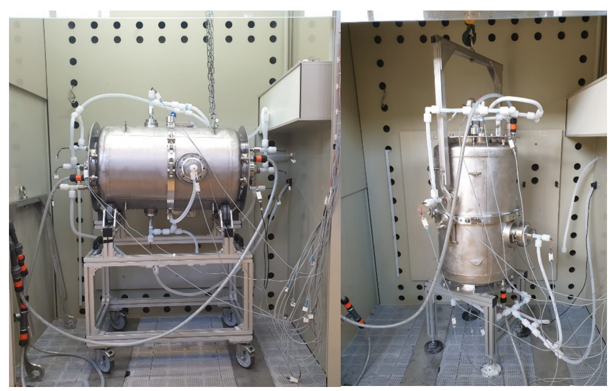

Figure 2: ESS cavity in horizontal and vertical position.

In the framework of the collaboration with Fermilab for PIP-II project, a new setup to perform rotational BCP was developed at IJCLab. Indeed, the implementation of a rotation during chemical etching improves significantly the homogeneity and quality of surface polishing. The idea is to integrate a rotation system along the axis of the beam tubes (called z axis) of the SSR2 cavity (Fig. 3) [4]. A gear mechanism makes the cavity rotate slowly back and forth with an amplitude of +/-180°. A continuous rotation is not possible so as to keep the ability to actively cool the helium vessel with chilled water. For this new experimental setup, a numerical simulation based on a fluid dynamics model was developed. The goal is to estimate the acid flow characteristics inside the cavity, determine the influence of several parameters as mass flow, rotation speed and filling factor to optimize the process in terms of temperature and material removal homogeneities.

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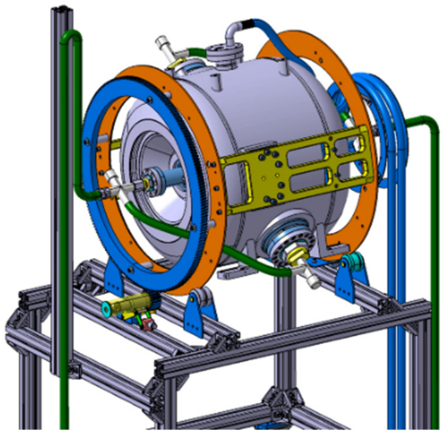

Figure 3: Overview of the rotational BCP tooling.

CFD SIMULATIONS

Simulation Parameters

All calculations were done using ANSYS Fluent. The full geometry of the fluid domain and the niobium walls are considered in the simulation. As practiced on the current treatments, a double inlet and outlet are defined: one located on a beam pipe (z axis) and the other on a side port (y axis) (Fig. 4). During the simulation, different variables such as the rotation speed and the input flow are studied. The fluid and solid properties used for the simulation are presented in the Table 1 [5]. We used a homogenous fluid to simulate the mixture which correspond to a density of 1,5. The k-epsilon model is used with a coupled pressure-velocity model. Moreover, the second order upwind is used for each parameter in order to improve the solution accuracy.

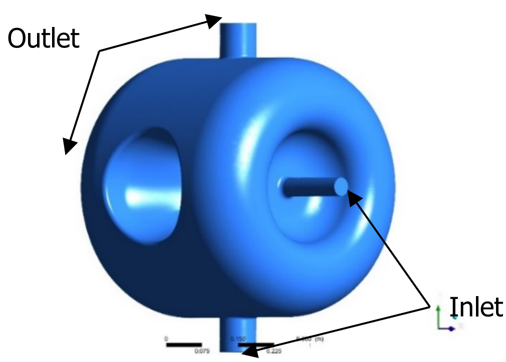

Figure 4: Fluid domain and solid domain used in the simulation.

Table 1: Fluid and Solid Input Properties

Properties	Fluid (acid)	Solid (Niobium)	Unit
Density	1530	8570	kg/m^3
Specific heat	2330	265	J/kg.K
Thermal conductivity	0.236	53.7	W/m.K
Viscosity	0.022	X	Kg/m.s

Thermal Analysis

The reaction between acid and niobium is an exothermic reaction. In order to control this reaction, it was important to perform a thermal analysis of the cavity to underline what is going on during the chemical treatment. We applied 1.2 kW/m² of reaction heat generation on all cavity inner surfaces [6]. We tried different cooling options like ambient air at 20°C or forced water flow at 15°C on the external cavity walls, the cavity remains fixed. For air cooling, the maximum temperature obtained is 47°C (320K) (Fig 5). Moreover, there are some huge differences within the cavity: some areas are well cooled because of the acid inlet flow temperature at 6°C and some others are on the contrary warmer because the acid is heating and is not renewed at all. Figure 6 shows the improved temperature distribution with a forced water flow. The introduction of a constant rotation of the cavity (0,1 rad/s for example) becomes very interesting in terms of temperature distribution (Fig. 7). The cavity wall temperature is nearly uniform, around 15°C. Rotating walls drag the fluid thanks to its high viscosity. This kinetic energy helps cooling down the cavity because the fluid is not stationary and the exothermic energy of the reaction is dissipated as the fluid is moving.

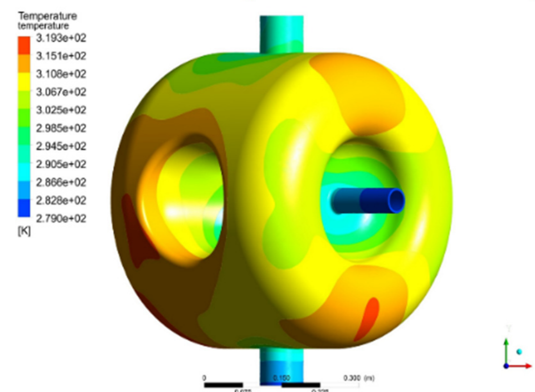

Figure 5: Flow rate of 5L/min without rotation, cavity cooled with air.

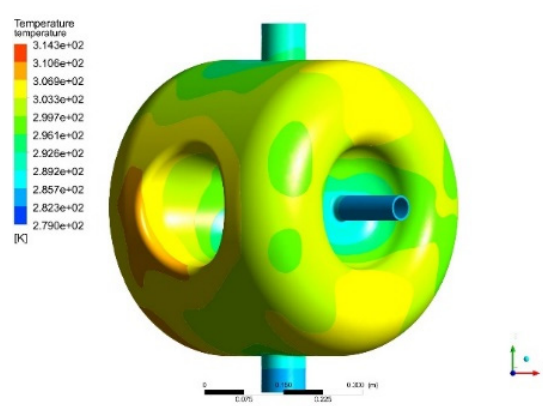

Figure 6: Flow rate of 5L/min without rotation, cavity cooled with forced water flow.

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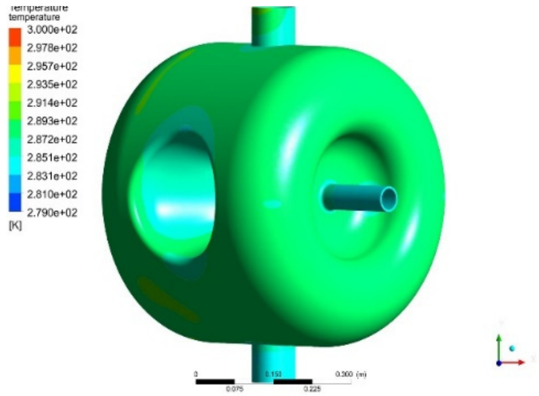

Figure 7: Flow rate of 5L/min and rotation at 0,1 rad/s, cavity cooled with forced water flow.

Etching Rate Analysis

For the study of etching rate, we used Equation 1 giving the etching rate versus the turbulent kinetic energy (TKE) described in [6] and obtained experimentally:

$$Etch\ rate = 3.1585 \times TKE^{0.186}\ \mu\text{m/min} \qquad (1)$$

Indeed, since the velocity of a fluid is equal to 0 next to a wall, the turbulent kinetic energy has been chosen to quantify the etching rate of the walls. Without rotation, the etching rate on the SSR2 cavity is estimated by simulation around 0.25 µm/min (Fig 8). This value is close to the one measured on the MYRRHA single Spoke resonator, which varies from 0.23 to 0.33 µm/min in the same flow rate conditions. To quantify the homogeneity of material removal, we defined different regions in the geometry to compute some local etching rates. We also compared different cases by modifying the flow rate and rotation velocity. Thus, we used the standard deviation to quantify and identify the optimum operating parameters.

We can clearly notice that even a slow rotation of the cavity is a good improvement: less discrepancy between the minimum and maximum values, less standard deviation and higher average of etching rate. Compared to a static treatment, the rotation improves the homogeneity and the efficiency of the surface polishing as we can see on the cavity walls (Fig. 9 and Fig. 10) and also on the Spoke bars (Fig. 11 and Fig. 12).

A higher rotating velocity as well as a higher flow rate could produce an increasing of the standard deviation of the etching rate. An optimum was found around 5L/min for the flow rate and a rotating velocity of 0.1 rad/s. Another rotating axis can be used for the BCP, the Y axis defined by the side ports. The simulation gives very similar results in terms of etching rate.

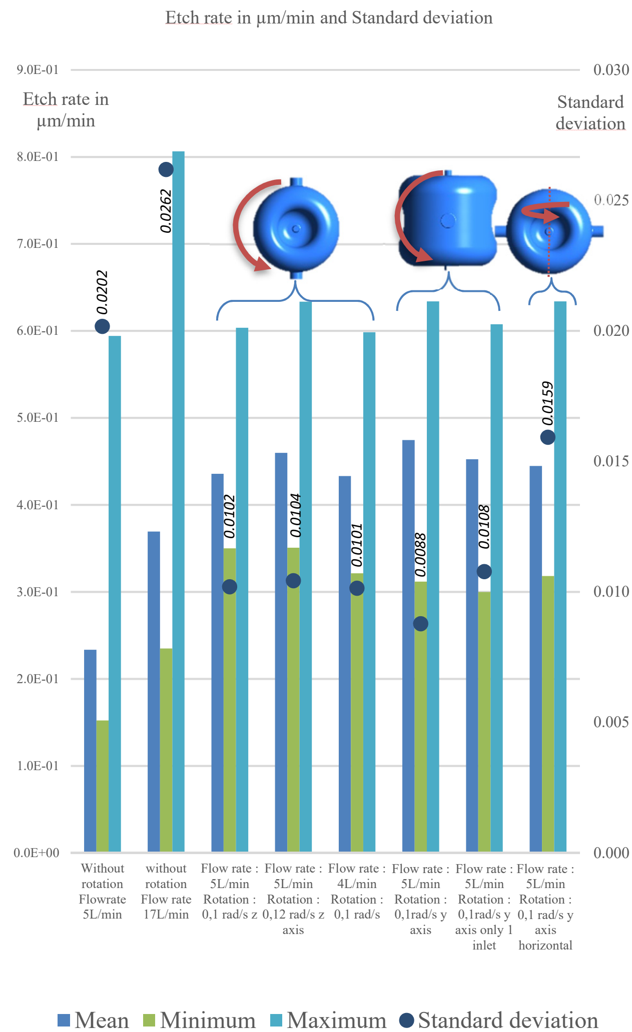

Figure 8: Histogram of etch rate and Standard deviation.

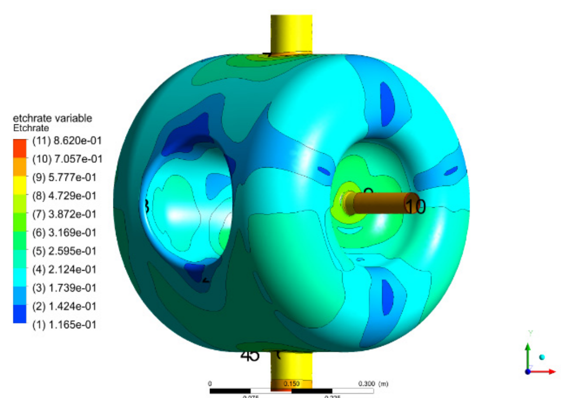

Figure 9: Etch rate in µm/min, Flow rate of 5L/min without rotations.

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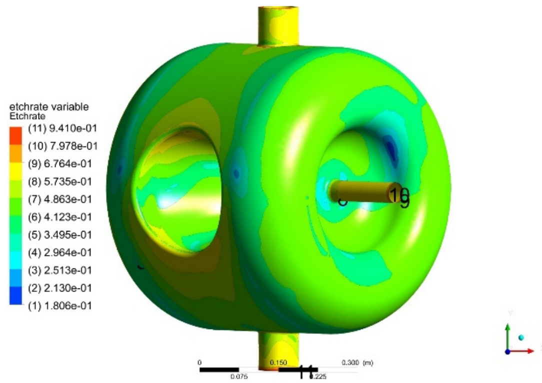

Figure 10: Etch rate in µm/min, Flow rate of 5L/min and rotation at 0,1 rad/s.

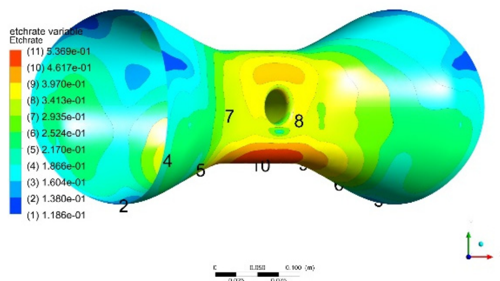

Figure 11: Etch rate of spoke cavity in µm/min, Flow rate of 5L/min without rotations.

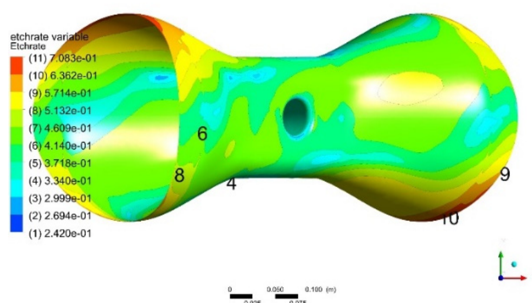

Figure 12: Etch rate of spoke cavity in µm/min Flow rate of 5L/min at 0,1 rad/s.

CONCLUSION

In conclusion, the etching rate of a cavity depends on the rotating speed and the mass flow inlet. To improve homogeneity of etching, it is important to have a good balance between both of them. From our simulation, a flow rate of around 5 L/min for both inlets which is around 0,125 kg/s and a rotating speed of around 1 rad/s correspond to an optimal configuration. Moreover, these parameters values are easily to achieve with the new rotating BCP setup. Finally, too much flow rate or higher rotational speed will increase the etching rate discrepancies between the different regions of the cavity. To go further, we would like to try new CFD calculations (transient and multiphase analyses) with different cavity filling factors and also estimate the overall RF frequency shifts from the calculated local etching rates.

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