Results and Discussion

The existing electropolishing installation at CERN is a vertical setup, where cavities are assembled upright whilst the electrolyte is circulating upwards inside them [1].


The fluid dynamics of the process, however, has not been addressed in the previous work. Being able to study the electrolyte flow, and further, quantify its velocity at specific points inside the cavity would enable optimisation of the electropolishing process; such as the chosen electrolyte inlet flow or the cathode geometry and this to achieve a more uniform material removal at the cavity surface. Of particular pertinence is the desire to ascertain a correlation between the electrolyte velocity and current density. In order to achieve it, a known electrolyte geometry has been used to supply the necessary data; the RDE. Under limiting current conditions, the main advantage of the RDE is that the convective-diffusion equation (see Eq. 1) can be solved and its solution is known as the Levich equation (see Eq. 2). This equation gives a direct relationship between electrode angular velocity and current.

\[ j = 27.606 \frac{V_C}{\sqrt{\omega}} + 51.328 \sqrt{\omega} \]  
\[ j = \frac{k \rho n F}{S} \]  

Methodology

The method described hereafter assumes that the entire surface to be processed is under limiting current. It can be resumed to two main steps: perform fluid dynamics simulation and conversion of electrolyte velocity data from simulation into current density.

The fluid dynamics simulation was made through COMSOL Multiphysics®. The used geometry included the cathode defined by the optimisation of primary and secondary current distribution simulation on a five cell cavity and the cavity itself (see Fig. 1). From the fluid dynamics simulation, it was possible to acquire data that defined a boundary layer through the cavity length. This boundary was defined by the distance to the cavity wall at which the electrolyte velocity was 1% of the maximum velocity.

The conversion of electrolyte velocity, collected through the fluid dynamics simulation, into current density was made by coupling the solution of the hydrodynamic equations and that of the convective-diffusion equation for the RDE.

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The conversion of electrolyte velocity, collected through the fluid dynamics simulation, into current density was made by coupling the solution of the hydrodynamic equations and that of the convective-diffusion equation for the RDE. The first will provide a relation between radial (see Eq. 3) or normal velocity (see Eq. 4) with the angular velocity; this is of utmost importance, as it provides the means to make a bridge between RDE and cavity geometries; the second, as already mentioned, will provide the relation between angular velocity and current density as defined in Fig. 2.

In order to ascertain whether the conversion is an accurate representation for that which occurs during electropolishing, the values calculated for current density were compared with those found in reality. Finding the real current density distribution on the five cell cavity was achieved through measuring the thickness of the cavity wall before electropolishing and after, and by converting the change in thickness into current density through the Faraday law of electrolysis.

The wall thickness was measured by ultrasonic means, with an accuracy of 1% with respect to the wall thickness, roughly ± 30 µm. This control allows for the amount of niobium taken on the surface to be controlled.

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Conclusions

The accuracy of experimental data acquired based on wall thickness control is not enough to validate the fitting with the simulated values. Nevertheless, the values are close enough to evaluate the optimisation of the electropolishing process in terms of inlet flow and cathode shape.

The methodology applied to convert RDE data to elliptical shaped radio frequency structures gives satisfactory results.

References