Computational Modelling of Fluid Dynamics in Electropolishing of Radiofrequency Accelerating Cavities

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Abstract

The work hereafter investigates into the use of COMSOL Multiphysics® to simulate the electropolishing process performed on radiofrequency accelerating cavities in order to improve their inner metal surface finishing. The physics studied in COMSOL Multiphysics® is the fluid dynamics of the process, and the use of exported velocity data is made to transpose into current density to determine the effectiveness of the existing electropolishing process currently undertaken

Introduction

Superconducting radiofrequency (RF) cavities are accelerating cavities that enable the propelling of charged particles to high energy in particle accelerators. Electropolishing is the electrochemical process that RF cavities undergo in order to improve their inner metal surface finishing. This is performed prior to their installation into the accelerators, to enhance their accelerating properties. Using COMSOL Multiphysics® it is possible to model the electropolishing process of the cavities and study the fluid dynamics of the setup.

Theory

Levich equation:

$$i_l = 0.62nFAD_0^{\frac{2}{3}} v^{\frac{-1}{6}} C_0^{*} \omega^{\frac{1}{2}}$$

Hydrodynamic relationships [1]:

$$\omega = 0.545 \times \frac{V_r}{r} \qquad \omega = 0.023 \times \frac{V_y^{\,2}}{v}$$

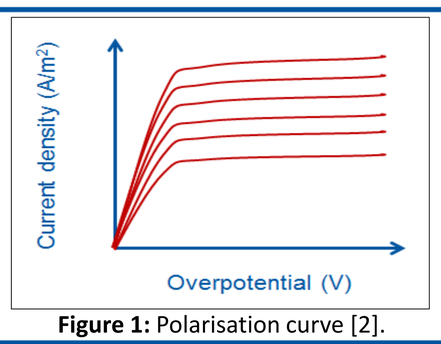

Figure 1: Polarisation curve [2].

Computational Modelling

Fig.2 shows the modelled pentacell electropolishing. By employing the CFD module in COMSOL Multiphysics®, in addition to Wall Distance, and obtaining velocity data for the flow at specified distances from the cavity wall, it was possible to express the data in terms of current density via the Levich equation. Fig.4 shows the wall distances studied.

Fig.3 shows the pentacell in the electropolishing workshop undergoing measurement of the thickness of the inner pentacell wall before and after electropolishing took place.

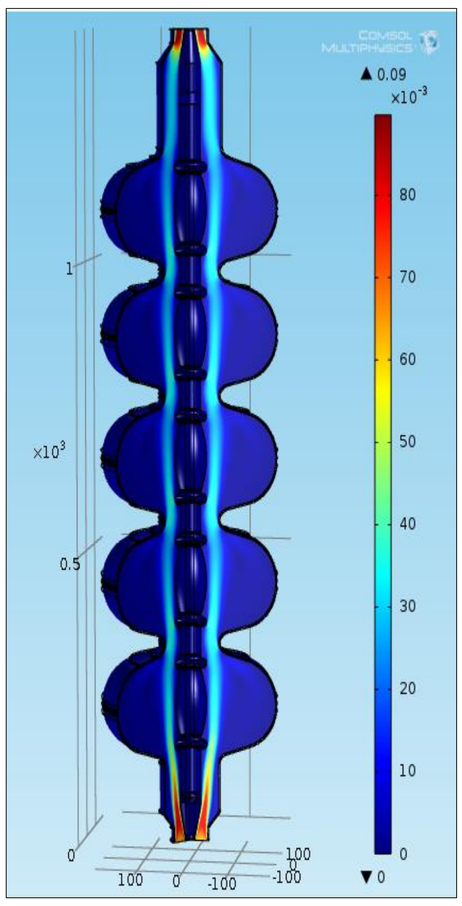

Figure 2: Five cell cavity model.

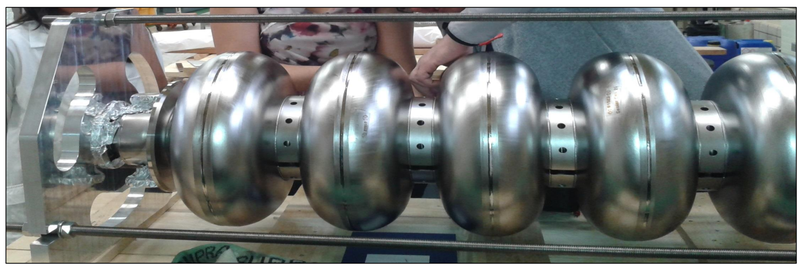

Figure 3: Pentacell in the Electropolishing Workshop.

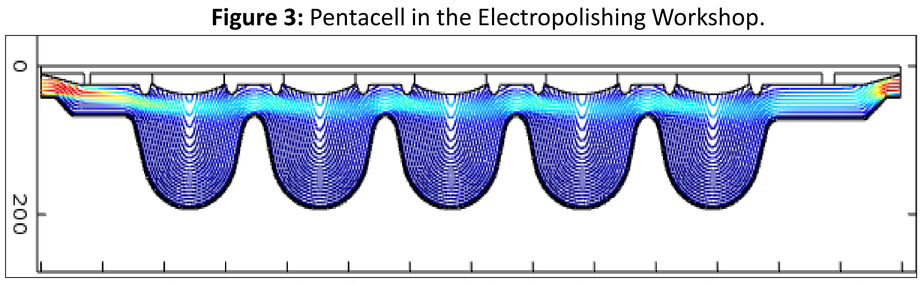

Figure 4: 2D Flow Plot with uniform user-defined Wall Distances from inner surface.

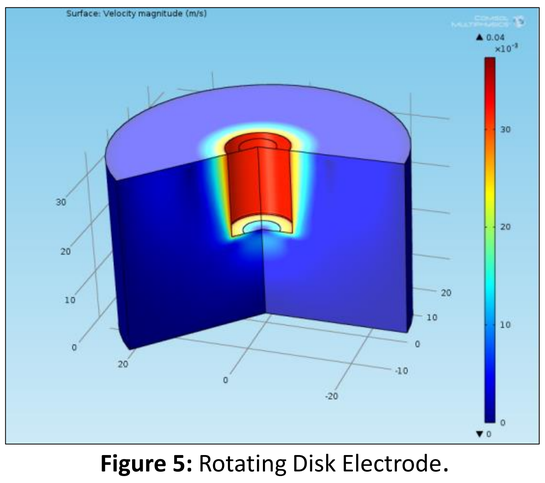

Figure 5: Rotating Disk Electrode.

In order to determine the validity of applying the Levich equation, which has been formulated for a RDE geometry, the fluid dynamics of the RDE was simulated, as shown in Fig.5.

Results

Using an initial relationship for current density and electrode angular velocity obtained via laboratory runs with an RDE setup, a current density distribution was created for the pentacell, giving an average current density of ~53 A/m².

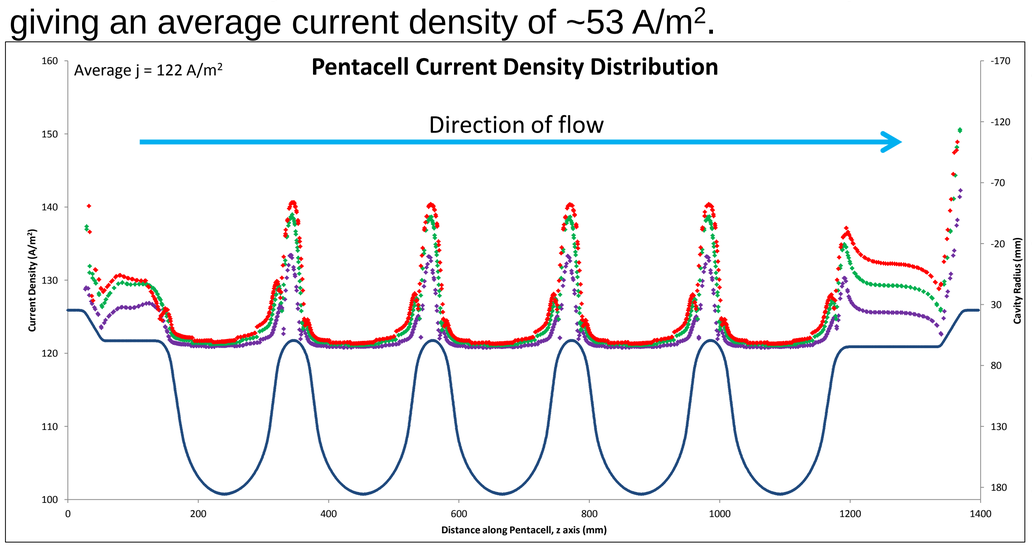

Figure 6: Transposed Current Density Distribution

Fig.7 shows a plot of the relationship between current density and electrode angular velocity, along with the new formulated relationship based on the findings from RDE simulations at three rpms, where the angular velocity now incorporates the RDE bath speed.

Fig.6 shows the current density distribution along the pentacell, calculated using velocity data exported from COMSOL Multiphysics® at different wall distances.

It employs the newfound relationship incorporating bath speed from Fig.7, and the average current density value closely matches that found in the workshop (labelled in Fig.8). Fig.8 shows the current density profile generated from the ultrasound thickness measurement data of the pentacell before and after electropolishing in the workshop.

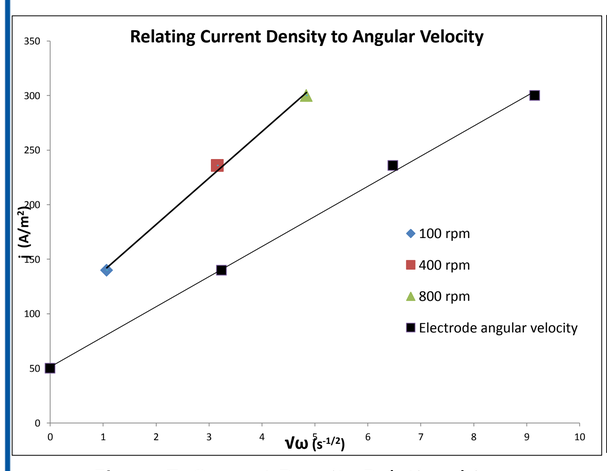

Figure 7: Current Density Relationships.

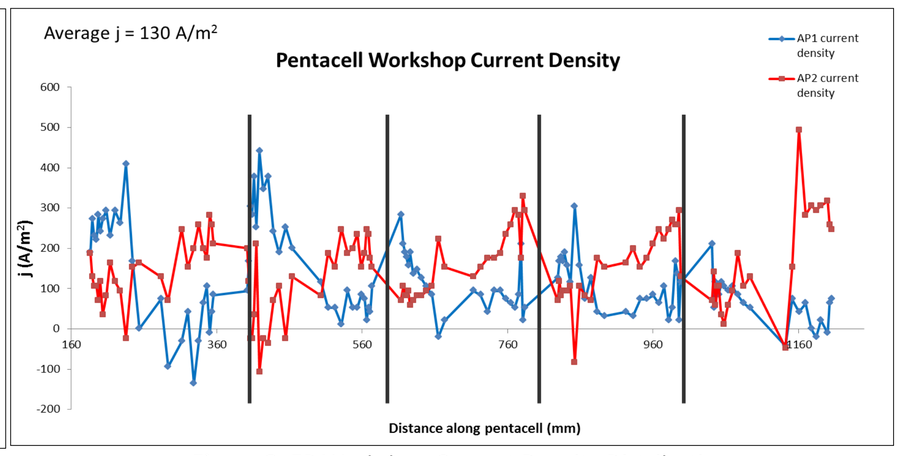

Figure 8: EP Workshop Current Density Distributions.

Conclusions

COMSOL Multiphysics® was found to be a vital tool in shedding light on what occurs during electropolishing of RF cavities at CERN.

Using the initial relationship that accounts solely for electrode rotation, the pentacell average current density was found to be ~ 53 A/m². Through the modelling of the RDE, it was possible to re-establish a relationship between current density and angular velocity that further incorporates fluid dynamics (bath speed of the system). With the bath speed relation, the average value is ~ 122 A/m², which is very close to 130 A/m² as found in the workshop.

References

1. A. Bard and L. Faulkner. *Electrochemical Methods: Fundamentals and Applications.* New York: John Wiley and Sons, 2001, pp.332-340.
2. L. Ferreira *et al*. *SRF2013 Conference: Niobium cavity electropolishing modelling and optimisation.* European Organisation for Nuclear Research (CERN), 2013.

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