Computational Modelling of Fluid Dynamics in Electropolishing of Radiofrequency Accelerating Cavities

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Abstract

This research investigates fluid dynamics simulated in computational models for the electropolishing of superconducting niobium radiofrequency (RF) cavities for particle accelerators at CERN. RF cavities undergo electropolishing; an electrochemical process performed to enhance inner cavity surface smoothness, reducing the possibility of field emission from inner cavity surface peaks. The latter would result in undesirable heating up of the cavity, and further, deceleration of the travelling particle. Thus, electropolishing is an extremely important procedure for cavities to undergo prior to installation into accelerators.

Previous work on the subject has involved efforts to optimize the cathode geometry of the electrochemical setup in an attempt to achieve uniform electropolishing along the anode cavity inner wall, however, this work has solely taken into account secondary current distribution where temperature and bath speed in the cavity were assumed constant. The fluid dynamics of the procedure therefore have not been thoroughly addressed.

The use of COMSOL Multiphysics® software was made in order to model the cavity electropolishing. The physics packages utilized in COMSOL Multiphysics® were laminar fluid flow, secondary current distribution, and the wall distance geometry package. Being able to study the electrolyte fluid flow, and further, quantify the fluid velocity at specific points inside the cavity with the wall distance package would enable optimization of the electropolishing setup; such as alteration of the chosen electrolyte inlet flow or the cathode geometry. Of particular pertinence is the desire to ascertain a correlation of the fluid velocities within the cavity to current density values, as this is a measure of electropolishing. In order to achieve this, a different system has further been investigated as a COMSOL Multiphysics® model; the Rotating Disk Electrode (RDE). The RDE is a hydrodynamic working electrode; its main advantage being that a direct relationship between laminar flow and current density has been formulated for it via the Levich equation.

In conclusion, this research found that computational modelling of the fluid dynamics is an effective method of acquiring data for the fluid flow throughout the system. Furthermore, it was found that changing the inlet flow rate from 30 l/min to 5 l/min for a pentacell RF cavity

increases the uniformity of electropolishing. A wall distance of 5 mm was determined as a threshold for significant change in velocity patterns. The transposition from RDE geometry to RF cavity was shown to deviate substantially whilst comparing results for low rpm simulations, however, averaged results were similar when comparing higher rpm data. The transposition was therefore not ruled out as a possibility for providing current density distributions from velocity data of fluid dynamics cavity models. A need for modelling of velocity-optimized cathode geometries is required in the future, as well as the study of the validity of the transposition of geometry from RDE to a simpler, more similar structure.