Optimisation of copper electroforming for manufacturing superconducting radiofrequency cavity substrates

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INTRODUCTION: In the framework of the Future Circular Collider (FCC) study, SRF (Superconducting Radio Frequency) cavities will be produced by applying niobium superconducting thin films onto copper substrate cavities [1,2]. A seamless process, which guarantees a high quality Cu substrate and very smooth surface finishing, would be an advantage.

In the present innovative approach, seamless model cavities are produced by copper electroforming on a sacrificial aluminium mandrel [3]. The bottleneck of the process is the heterogeneous distribution of the plated copper layer along the cavity and the resulting thinner section at the cavity iris. COMSOL® simulations exploiting the electrochemistry module were performed in order to optimise the copper thickness uniformity along the cavity.

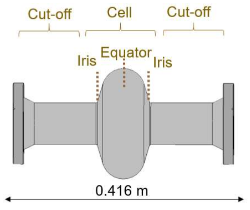

Figure 1. 1.3 GHz SRF cavity nomenclature.

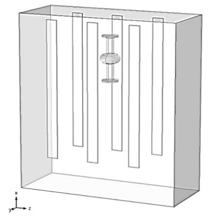

Figure 2 Geometry of the cavity and the electroplating bath.

COMPUTATIONAL METHODS: The current density distribution in the cavity was modelled with COMSOL Multiphysics® using the Secondary Current Distribution (SCD) physics module.

The electron transfer reactions that take place are:

Anode: $Cu \rightarrow Cu^{2+} + 2e^-$
Cathode: $Cu^{2+} + 2e^- \rightarrow Cu$

Within SCD, the local current density and the local potential derivative are described by the Ohm's law. The secondary current takes into account the effect of electrode kinetics and the bath resistance. The local current at the electrode surface follows the Butler-Volmer equation:

$$i_{loc,Cu} = i_{0,Cu}\left(exp\left(\frac{\alpha_a \cdot F \cdot \eta_{Cu}}{R \cdot T}\right) - exp\left(\frac{-\alpha_c \cdot F \cdot \eta_{Cu}}{R \cdot T}\right)\right)$$

Where $i_{loc,Cu}$ is the local current density, $i_{0,Cu}$ is the exchange current density, α_c and α_a are the reaction transfer coefficients, T is the temperature (298K). The kinetic parameters and electrolyte properties are given in Table 1.

$i_{0,Cu}$ (A/m^2)	0.1
α_c, α_a	0.5
$CuSO_4$ (M)	0.5
Conductivity σ (S/m)	15

Table 1. Kinetic parameters and electrolyte properties

The simulations were run with a moving mesh in order to simulate the boundary displacement resulting from the plating on the cathode and the consumption of the secondary anodes.

RESULTS:

Validation of simulation model

- The simulated thickness agrees with the experimental values.
- The maximum thickness is located at equator, the minimum at the iris.
- 300 hours to achieve a thickness of 2 mm at the iris.

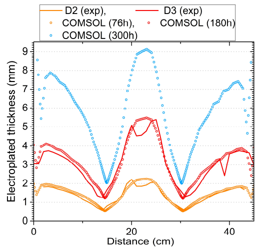

Figure 3. Thickness distribution along the cavity.

Design of secondary anodes and masking

- Solution for uniformity: secondary anodes positioned at the iris to promote plating, mask at the equator to reduce the deposition.

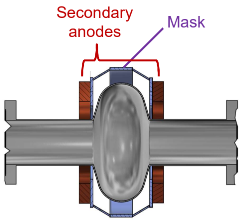

Figure 4. Proposed mask-anodes design.

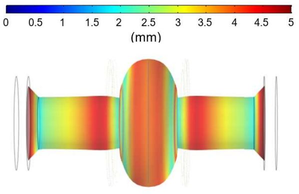

Figure 5. Deposited thickness after 175h plating.

Optimisation of anodic dissolution

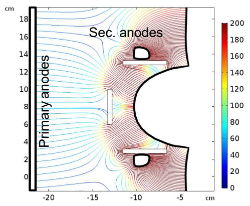

Figure 6. Current line distribution with both anodes at same voltage (1PS), 175 h.

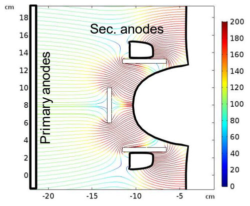

Figure 7. Current line distribution with 30% current on secondary power supply, 190 h.

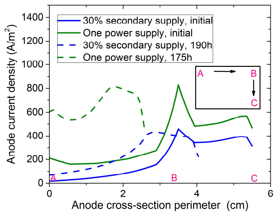

Figure 8. Sec. anodes current density.

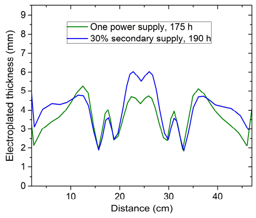

Figure 9. Plated thickness one vs. two PS.

- Severe anodic dissolution and high current density at the sec. anodes with one power supply (PS) and both anodes at same voltage.
- Split of 30% of total current on secondary supply on sec. anodes minimizes anode consumption and improves control of the process.

CONCLUSIONS: COMSOL modelling of the electroforming process of the cavity was made to define an optimised geometry of anode and masking that highly improves the copper layer thickness distribution along the cavity. The re-meshing of the anodes helped identifying the anode end life and to determine the secondary anode current density. Two power supplies were implemented to control independently the primary and secondary anodes. The current density at the secondary anodes was reduced to minimize anode consumption and the overall control of the process was improved.

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3. Lain Amador, L., 'Production of ultra-high vacuum chambers with integrated getter thin film coatings by electroforming'. PhD Thesis. 2019. CERN-THESIS-2019-160

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