NIOBIUM CAVITY ELECTROPOLISHING MODELLING AND OPTIMISATION

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Abstract

It's widely accepted that electropolishing (EP) is the most suitable surface finishing process to achieve high performance bulk Nb accelerating cavities. At CERN and in preparation for the processing of the 704 MHz high-beta Superconducting Proton Linac (SPL) cavities a new vertical electropolishing facility has been assembled and a study is on-going for the modelling of electropolishing on cavities with COMSOL® software. In a first phase, the electrochemical parameters were taken into account for a fixed process temperature and flow rate, and are presented in this poster as well as the results obtained on a real SPL single cell cavity. The procedure to acquire the data used as input for the simulation is presented. The modelling procedure adopted to optimise the cathode geometry, aimed at a uniform current density distribution in the cavity cell for the minimum working potential and total current is explained. Some preliminary results on fluid dynamics is also briefly described.

INTRODUCTION

Electropolishing is at present widely used to process superconducting radio frequency (SRF) structures; however, most of the developments were made by trial and error, with basic electrochemical assumptions. Recently and with the increased computation power available, simulation software has been developed for a number of physics applications, namely for electrochemistry. The prospect of being able to fully simulate the EP on a SRF structure raises the probability of achieving the specified high gradients with less effort, time and material, and even to optimise the SRF structure performance.

The anodic electrochemical processing of niobium SRF accelerating structures is commonly performed with the Siemens bath formulation or within small range of composition variations [1]; the electrochemical cell is composed of the anode, which is the SRF structure and the cathode, which is typically made of copper or aluminium, the all in contact with the bath as referred previously. In optimum processing conditions, an even current density distribution on the inner wall of the SRF structure at the minimum working potential should be achieved. For this type of electrochemical cell, two types of current density distribution have to be taken into account: a primary current distribution (PCD), which is determined by the electrolyte resistivity and the cell geometry; and a secondary current distribution (SCD), which is determined by the electrode activation overpotential. To simplify, the first can be considered as constant within the working temperature range, while the SCD will be quite sensitive to local temperature and transport phenomena (convection and diffusion) variations.

DATA AQUISITION

The PCD is transposed to the simulation software providing the SRF structure geometry and the bath resistivity; the last was measured with a Radiometer conductivity sensor ($k = 1 cm^{-1}$). On the other hand, the SCD demands a series of laboratory measurements to obtain polarisation curves, with a three electrode configuration within controlled temperature and agitation parameters.

Laboratory Setup

The equipment used to acquire the polarisation curves is composed of: (1) a potentiostat Autolab PGSTAT30 controlled through a dedicated desktop computer software which allows applying a linear sweep potentiostatic voltammetry signal and record the feedback current signal from the electrochemical cell; (2) a three electrode electrochemical cell composed by a working electrode attached to an Autolab Rotating Disk Electrode (RDE) to master the transport phenomena, a counter electrode and a platinum pseudo reference electrode; (3) a thermostatic bath (Lauda ecoline RE212) for controlling the temperature of the bath solution. Some complementary polarisation curves were performed with an Ivium potentiostat IviumStat.XRe in order to make measurements above 10V (overpotential).

Samples

The working electrode is made of a niobium (anode) or copper (cathode) disc fixed to a RDE with a working surface area of 0.37 cm^2.

Results

The trials were performed between 8 °C and 25 °C at 0 and 100 rpm as they would correspond to the most probable working conditions inside an SRF structure (SPL based installation). Besides the correlation between temperature and mass transport, the acquired data allowed to put into evidence that, within the studied range of temperature and mass transport dynamics, the limiting current overpotential becomes constant at about 2V.

This finding is represented in figure 1 and is of utmost importance as it implies that if the electrochemical cell potential reaches the electropolishing conditions for the entire SRF structure, this condition will prevail

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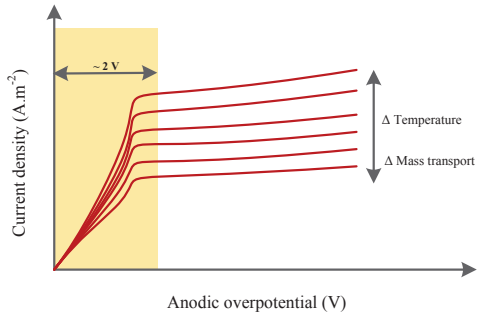

Figure 1: Schematic representation of trials made at different (Δ) temperatures and RDE speeds.

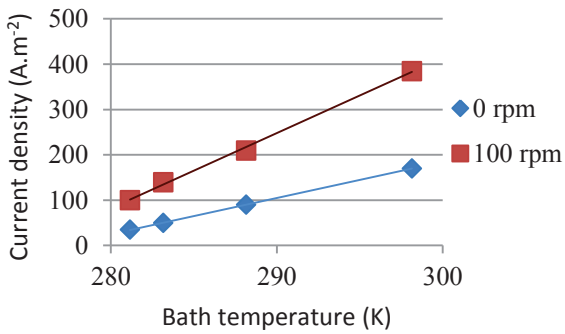

Figure 2: Limiting current (electropolishing current) as a function of bath temperature and mass transport.

independently of mass transport (agitation) or temperature as long as these are as well within the proper range to achieve electropolishing (extremes values of temperature and mass transport will not allow to achieve an electropolished surface). However the rate of removal of material will differ as illustrated in figure 2.

CURRENT DISTRIBUTION MODELLING

The detailed electrochemical measured quantities were used as input for the simulation for a fixed process temperature and flow rate in the real SRF structure. The optimisation of the current density distribution and of the power input were based on two criteria : obtain a ratio between the highest and the lowest current density across the SRF structure, $j_d = j_{max} / j_{min}$, to be as close as possible to unity; and, keep the minimum input power for the most even current distribution.

Cathode eometry

The starting point for the cathode was the simplest geometry, a rod. The rod radius shall be in accordance with to the total applied current and the cathode surface should be as big as possible in order to hinder any possible extra resistance due to uneven cathode/anode surface ratio. This cathode geometry has two dimensions that can be adjusted, the length (orange arrow in figure 3) and the radius (green arrow in figure 3).

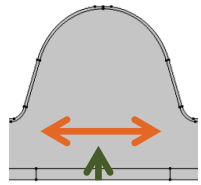

Figure 3: SPL beta 1 rod cathode.

The first optimisation was performed by modifying the cathode length. Figure 4 shows the effect of modifying the cathode length; as can be seen, there is little variation (The change in j_d is less than 0.5%) between near 0 and 150 mm. After this, the difference appears to increase dramatically. As such, a cathode shorter than 150mm will be used for further optimisation.

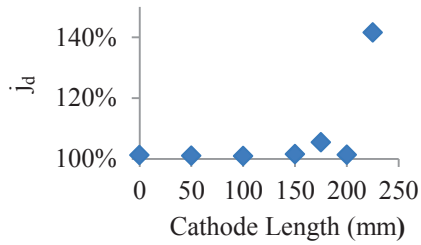

Figure 4: Cathode length optimisation.

Using this length cathode model, the main cathode radius was adjusted. As can be seen in figure 5 the cathode radius has a significant impact only below about 5 mm. Following this, the impact is minimal, with an improvement of approximately 2%. However it is an advantage to have the two electrodes closer and therefore to reduce the total power input; here the upper limit of the radius is given by the SRF cut-off radius (entrance of the structure).

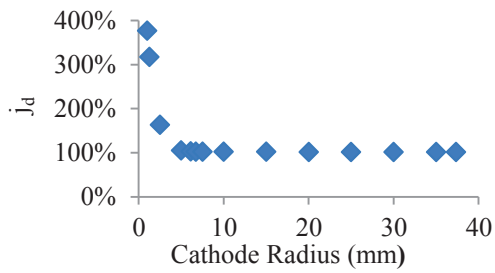

Figure 5: Cathode radius optimisation.

A fine tuning of the geometry was performed in order to avoid excessive high current densities at the cathode and keeping the anodic current density as even as before, while adapting to manufacturing possibilities. As a consequence an arc shaped cathode and insulated protrusions were added at the extremities of the cathode as shown in figure 6. This is also the present cathode geometry for SPL beta = 1 SRF structures.

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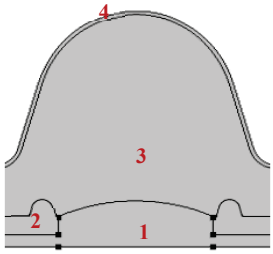

Figure 6: Final cathode geometry for SPL beta1 cell (radial axisymmetric cut): 1) cathode active surface; 2) insulated cathode surface; 3) electrolyte; 4) anode (SRF structure).

Power Input

The minimum applied potential necessary to achieve the most even current density distribution across the SRF structure was calculated for each cathode geometry. In figure 7 is shown the current density distribution achieved for the SPL beta = 1 mono cell with the cathode as presented in figure 6. This simulation was made from data acquired at 0 rpm and 15 °C and for which the corresponding limiting current is 87 $A.m^{-2}$. It is thus possible to determine that all the cavity is within the electropolishing regime starting from 11V of applied potential; and a total inward current of 36 A.

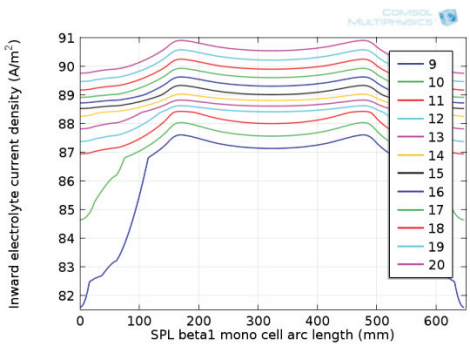

Figure 7: Current density distribution across SPL beta = 1 mono cell SRF structure. Each line corresponds to the applied potential in volts as shown in the legend.

FLUIDS DYNAMICS MODELLING

The work described so far allowed to define the minimum potential needed to get a SRF structure within the limiting current range and the total inward current, but it still lacks the correlation between the limiting current and the transport phenomena (fluid dynamics). This work is still on going, nevertheless some single physics fluid dynamics simulations were performed and the results showed already some features that could be correlated with the experimental results on the real SRF structure. In figure 8 it's possible to see the bath speed distribution inside the cavity and identify a volume of bath near the upper half cell where the bath speed is higher than for the remaining cell surface. Indeed, it was possible to observe that the upper half-cell presented a better finishing, during the early stages of EP, if compared with the lower half-cell.

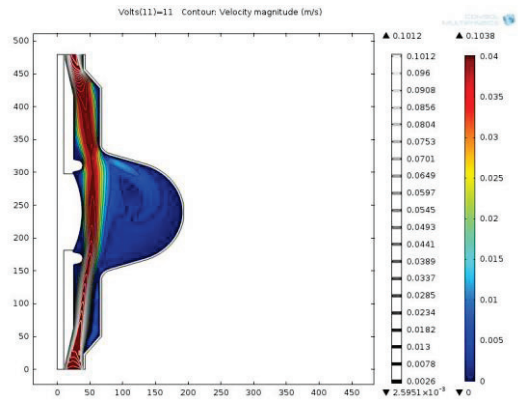

Figure 8: Bath speed distribution inside the SPL beta1 mono cell for a nominal flow of 1.2 m^3/h. The scale is in $m.s^{-1}$.

FIRST PRACTICAL RESULTS

The results obtained with real SRF structures (ASH Nb cavity beta0.65 and SPL beta = 1 mono cell) are in agreement with the results from the simulation, namely the minimum working potential and the total inward current. For the SPL structure, there is a good correlation between the total real inward current recorded at 1.2 m^3/h and the laboratory data recorded at 0 rpm; see table 1.

Table 1: Total Inward Current Data from Simulation and SPL Beta 1 Mono Cell Electropolishing

Temperature	Total current inward / A	
	from simulation	Real cavity
10 °C	21	18
15 °C	37	36
25 °C	70	57

The resulting surface is bright and smooth which is proof that the SRF structures are within the limiting current range and therefore within the good electropolishing parameters. Some macrostructures are apparent, as shown in figure 9, some are from the shaping of the SRF structure, but others are probably related to gas bubbles evolving at the surface of the SRF structure [2].

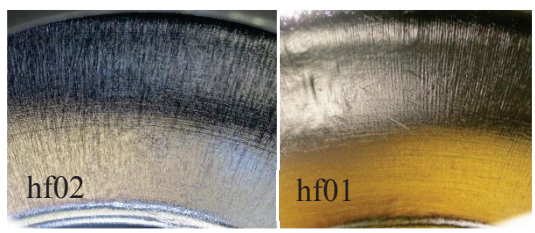

Figure 9: hf02) half-cell 02; hf01) half-cell01.

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