

CATHODE GEOMETRY AND FLOW DYNAMICS IMPACT ON VERTICAL ELECTROPOLISHING OF SUPERCONDUCTING NIOBIUM CAVITIES

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Abstract

CERN has now a fully operating vertical electropolishing installation, which has been used for the processing of 704 MHz high-beta five-cell Superconducting Proton Linac (SPL) niobium cavities. This installation relies only on the electrolyte circulation (HF/H₂SO₄) for power dissipation, evacuation of gases and homogeneous finishing; thus, parameters like cathode geometry, electrolyte flow and temperature become even more crucial when compared with horizontal electropolishing installations. Based on computational simulations performed with Comsol Multiphysics® and on a methodology developed at CERN, it is possible to assess the impact of the different cathode geometries as well as of the flow on the etching rate distribution. The data obtained with two different cathode geometries are presented: electrolyte velocity distribution, etching rate distribution, average current density and minimum working potential. One geometry was defined through a purely electrochemical approach while the second was defined to minimise the difference between the maximum and the minimum electrolyte speed inside the cavity; in both cases, the influence of the electrolyte flow was taken into account.

Introduction

The most interesting electrochemical characteristic of the Siemens bath formulation is the absence of a transpassivation behaviour in the anodic branch of its polarisation curve, see figure 1. The main outcome is that for a very large range of anodic overpotential, the anodic dissolution yield is 100%; in other words there are no secondary reactions taking place other than the dissolution of niobium. Unlike many other electropolishing (EP) bath formulations, there is no formation of molecular oxygen at the surface and thus, pinholes and related surface defects are less prone to appear and surely not related to anodic oxygen evolution.

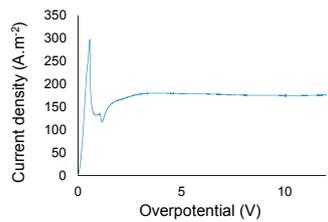


Figure 1: Anodic polarisation curve measured at 25 °C

Cathode geometry

Two cathode geometries were used so far to process SPL 5 cell cavities. The first geometry was designed taking into account only electrochemical parameters and it'll be referred as the electrochemical cathode (EC). The surface finishing achieved with this cathode was bright and smooth, but macrostructures were apparent and could be related both to the bath flow and gas bubbles in the circulating bath (see figure 2).



Figure 2: Macrostructures on cavity SPL #1

The SPL cavity geometry cannot be modified and it implies already significant bath velocity differences between the equator (wider section) and the iris (narrower section); the cathode geometry cannot improve the bath velocity distribution, but its impact can be minimised. Taking this principle into account, a second cathode geometry was defined: cylindrical hollow shape, the hollow cathode (HC); this approach is still able to provide sufficient cross section for the total applied current and minimises its impact on the bath velocity distribution across the SPL cavity. A feature was also added to the HC, a PFE 70 µm mesh membrane; it's intended to minimise the contact of hydrogen gas bubbles, which are produced at the cathode, with the cavity surface. Figure 3 presents the geometry of the two cathodes.

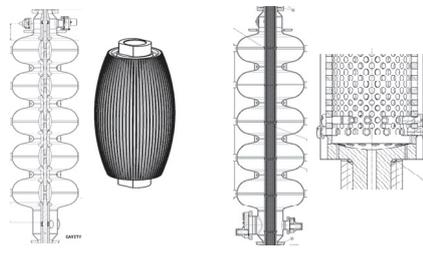


Figure 3: EC (left) and HC (right) geometries and respective active parts zoom up; both inserted in a SPL five cell cavity.

Bath flow

The HC geometry was defined and validated for production by comparing several fluid dynamic simulations done on the new HC and on the EC geometry. At lower flow rates, and independently of the cathode geometry, the bath speed distribution becomes more uniform. Here, the main constraint for further reducing the bath flow is that the bath temperature depends on its flow rate; the latter cannot be fixed independently of the electrolyte temperature constraints, namely a maximum of 15 °C and with a differential between the inlet and the outlet below 5 °C. Practical evidence showed that 10 lpm was, in average, the minimum flow allowed to respect the temperature constraints as defined above.

In figure 3 and 4 are direct comparisons between the EC and the HC geometries at 10 lpm. For both cathode geometries, it's possible to observe that the bath velocity in the z direction is very low near the equator and it increases sharply near the iris; however, this velocity gap is smaller for the HC than for the EC. In the radial direction bath speed representation, it's possible to identify several vortexes features, but with a less extent and intensity for the HC if compared with the EC. For both velocities representations it's possible to see that the HC gets closer to the EC velocities profiles as it goes from the bottom bath inlet (left) to the cavity top outlet (right).

Vortexes are fluid dynamic features that can be identified by a sharp change in the velocity direction (+/-), as in figure 4.

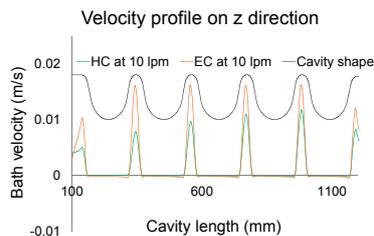


Figure 3: Velocity profile on the axial direction (z) for both HC and EC geometries at 10 lpm.

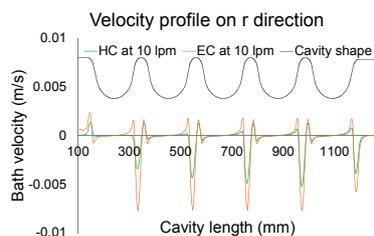


Figure 4: Velocity profile on the radial direction (r) for both HC and EC geometries at 10 lpm.

Electrochemical behaviour

The minimum working potential for the EC cathode is 8 V, while the HC cathode needs only 7 V.

Using the methodology described in [4], the impact of the bath flow on the current density distribution, both for EC and HC geometries, was estimated.

The improvement in the uniformity of the polishing rate distribution from EC to HC geometry is quite important near the iris, reducing of roughly to half the polishing rate peak at this location; elsewhere, the polishing rate is quite similar between the two geometries, but still with an advantage towards HC in terms of homogeneity.

Faraday's laws of electrolysis was used to convert the estimated current density into polishing rate values

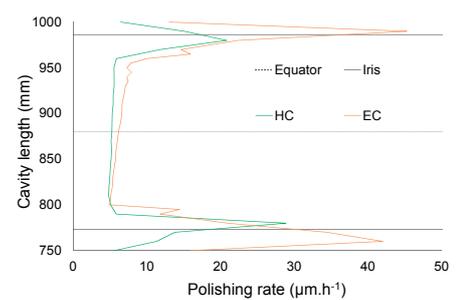


Figure 5: Polishing rate estimation at an average temperature of 10 °C and a bath flow of 10 lpm.

Data from SPL #2 Electropolishing

The first evidence from the operation with this new geometry was the fast clogging of the cathode, the 70 µm mesh FEP membrane, but also the 4 mm diameter holes on the copper structure.

The SPL #2 cavity had nine runs; the first two runs went smoothly with a constant total current around 130 A (76 A.m⁻² at 8V), but the following runs saw a decreasing of this value down to 90 A (52 A.m⁻² at 8V) as well as an increasing instability on the total current records and this even after replacing the bath by a new one. The average working temperature was 9.9 °C and the bath flow 9 lpm.

The achieved surface finishing improved until the 6th run (see figure 6). The main macrostructures still visible were the ones already present before the EP, such as the mechanically polished areas, the deformation lines or tool marks; the absence of grooves and pinholes is quite evident namely on the mechanically polished areas.

The 7th and 8th run were performed without an intermediate stop, and the outcome was the fall of clogging products, from the cathode and membrane, onto the cavity wall. This incident had a negative impact on the surface finishing, with the formation of stains with a rougher surface and the surface appearance became slightly less shiny.



Figure 6: SPL #2 inner surface after the 6th run. Top is the equator and bottom the iris with a noticeable mechanically polished area.

Conclusions

The three main modifications introduced on the vertical EP of SPL #2 cavity had a positive impact on the surface finishing. The use of a hollow cathode together with the reduction of the flow rate contributed to an even bath velocity distribution and consequently a more homogeneous, although smaller, EP rate; the introduction of a membrane together with the two other previous modifications, allowed the elimination or at least a significant reduction of grooves and pinholes.

On the other hand, the decrease of the bath flow and consequently bath velocity, increased the bath diffusion layer thickness which decreases the EP efficiency to eliminate macrostructures; also, the clogging of the cathode holes and membrane had a negative impact on the EP velocity and on the surface finishing, namely after two consecutive runs and where the accumulation of copper hydroxides became too important and ended by falling into the cavity surface. An alternative material for the cathode is already in study and this within the ones commonly used for this application.

The surface finishing achieved on SPL #2, on the CERN vertical EP installation, with the new cathode geometry and new operation parameters was only limited by the initial poor surface condition. There was no evidence of formation of defects related to the EP process like pinholes or grooves. Related radio frequency measurements showed a consequent improvement from SPL #1 to SPL #2 [7].

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