

ENGINEERING SOLUTIONS FOR THE ELECTRO-POLISHING OF MULTI-CELL SUPERCONDUCTING ACCELERATOR STRUCTURES

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Abstract

Due to surface treatment with electro-polishing superconducting niobium resonators can potentially reach accelerating gradients well beyond 35 MV/m at a frequency of 1.3 GHz. The anticipated gradient for the 500GeV version of the TESLA collider is 23.4 MV/m. In view of the extendibility of the collider towards higher energies this technology is therefore of great importance for the TESLA project.

In this paper we discuss the engineering aspects of the planned electro-polishing facility at DESY. The facility will allow for the treatment of single cell cavities as well as the standard TESLA 9-cell structure, and also a so called superstructure that consists of 2x9 cells. The issues described cover the acid circulation including cooling requirements, the required current densities resulting in the specifications of the electrical circuit, removal of oxyhydrogen gas, rotating feed-through and the overall mechanical layout. Furthermore we report on recent tests of critical components.

1 INTRODUCTION

Electrolytical Polishing (EP) is an established treatment for the smoothening of metallic surfaces [1]. The surface is basically etched in an acid bath and in parallel an electric field is applied to the surface, which in turn causes a current flow. Because of the field enhancement sharp tips on the surface are removed preferentially. Electropolishing tends to flatten out roughnesses on a short wavelength scale, whereas long wavelength features remain [2]. For most metals one finds similar voltage-current curves (see Fig. 1) for the electropolishing process.

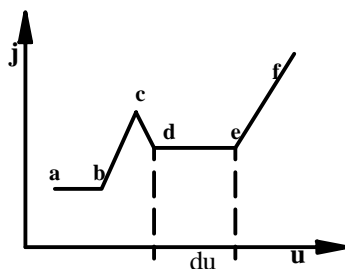


Figure 1: Typical Voltage Current Curve

The detailed shape of the curve depends on the surface area ratio of cathode and anode, but also on the initial surface roughness[3]. In the range (a-c) a relatively strong oxide layer is built up on the surface. At higher voltage (c-d) this layer is removed and the polishing process begins. In the range (d-e) the current is nearly independent of the applied voltage. The width of this plateau depends sensitively on the temperature of the electrolyte. For even higher voltages (e-f) gaseous oxygen is set free at the anode, i.e. the surface to be polished. The oxygen bubbles result in discontinuities on the surface. For best polishing results the process is kept in the plateau region (d-e). With Niobium (and also Tantalum) one observes oscillations of the current in this region while the voltage is kept fixed. The oscillation are probably caused by the cyclic build-up and removed of oxygen layers on the surface.

2 ELECTRIC CIRCUIT

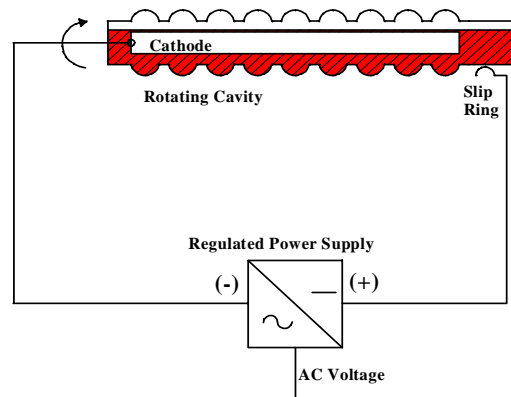


Figure 2: Electric Circuit

Electropolishing experiments at CERN[4] have shown that the voltage has to adjusted carefully with changing temperature of the electrolytic bath. The bath is heated due to electrical power deposition. For the chosen working point we expect current densities of 10 A/dm² and voltages of 25 V. The niobium cavity is polished in horizontal orientation and is filled with acid at a level of 65%. The system is layed out to allow for polishing of double 9-cell structures which have a total inner surface

of 150dm². The available power supply delivers a ripple filtered DC voltage of 40V and a current of 1500A at maximum. The voltage can be regulated and for the current it is possible to set an upper limit. The remaining 50Hz ripple from the grid is kept below 1%. Since the system will be run first with 9-cell structures the cathode is dimensioned for this case. We use aluminium with a purity of 99.5%. According to the electrochemical series aluminium is less noble than niobium which avoids the concentration of aluminium impurities on the niobium surface. For a maximum current in the 9-cell case of 750A we have chosen an aluminium pipe with an inner diameter of 22mm and a wall thickness of 4mm. The total length will be 1.5m which results in a resistance of 0.125 mOhm and a difference voltage of 100 mV over the length of the cathode. The niobium cavity has three electrical connections. The voltage decay over the cavity, due to the finite resistance of the niobium, is less than 60 mV. Since the cavity is rotating during the process, a slip ring contact is used. We use a commercial product of the company Nies which can transmit currents up to 1800A.

3 ACID CIRCUIT

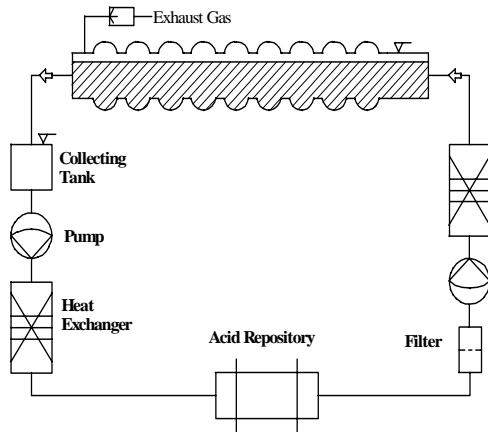


Figure 3: Acid Circuit

The acid is a mixture of sulphuric acid (95-97%) and hydrofluoric acid (46%) with a ratio of 9:1 according to the VLSI quality standard. For estimating the heat deposition we assume total conversion of the electrical power in heat. For the chosen working point this results in a total power of $15V \cdot 750A = 11.25kW$.

3.1 Acid heat exchanger

We assume that 35°C is the maximum acceptable acid temperature. Limitation of the temperature is necessary to reduce out-gassing of HF and to keep the working point stable. For the heat exchanger we assume a temperature difference of $\Delta T=13^\circ C$. In order to take out 11.25kW of heat we need a volume flux of 20l/min. From this number we determined the dimensions of a heat exchanger made from the material PVDF, company Calorplast. The heat

exchanger works in the so called cross flow principle and allows for a cooling power of 12kW. With a cooling water temperature of 15°C we can achieve a temperature reduction of the acid from 35°C to 22.5°C.



Figure 4: Acid Heat Exchanger

3.2 Acid Supply to the cavity

A constant temperature distribution in the cavity is essential for an equal removal of the Niobium in the individual cells. To achieve that we supply "fresh" acid to the individual cells through holes in the cathode. The flux distribution in the acid is also of importance for the current density in the diffusion layer close to the niobium surface. In practice the current density is proportional to the acid flux. Consequently the etching rate on the niobium is also affected by the acid flow [4]. The connection between time (t), thickness of the etched Niobium layer (d) and electrical current density is given by:

$$d[\mu m] = 0,811 \cdot j[mA/cm^2] \cdot t[h] \quad (1)$$

An experimental setup with a 9-cell cavity made from plastics was built to investigate the flux distribution in the fluid. It has been observed that it is advantageous to inject the acid downwards in the individual cells. This helps also to obtain a better mixing of "fresh" and "older" acid in the cavity. The acid is drained on both sides of the cavity into 1 inch pipes.

3.3 Gas Production

According to the German law the produced Hydrogen has to be diluted, for example with Nitrogen, below a concentration of 4%. It was not possible to do this inside the cavity since the required mass flow of Nitrogen (8000 l/h [5]) was too big and would have disturbed the electropolishing process. Therefore we dilute the Hydrogen gas outside of the cavity. In order to improve the safety of the system we installed additional gas sensors.

4 MECHANICAL DESIGN

The mechanical design has to fulfill the following requirements:

- The cathode and the cavity should be the only metallic parts that are in contact with the acid. All other parts have to be manufactured from acid resistant plastics. It is very important to avoid the contact of other metals to the acid.
- The acid circuit has to be leak tight. This requirement is especially critical for the rotating seals.
- When the cavity is emptied the amount of remaining acid should be minimal.
- It should be possible to rotate the cavity remotely around the longitudinal axis and to bring it in upright position. A support structure that rotates with the cavity is needed to minimize mechanical deformations.
- In case the remote control fails it must be possible to empty the cavity manually, i.e. using a mechanical device.

4.1 Technical Implementation

We use a double sealed rotational feed-through for each flange. Such seals were used successfully during the CERN single cell experiments. The material of the seals is a fluor rubber (FKM). The stainless steel spring of the seal will be encapsulated in Teflon. The rotational speed of the apparatus can be varied in the range 1-9 rounds per

minute. The rotating electrical connections require a torque of 30Nm. The mechanical support is layed out for the electropolishing of a double 9-cell superstructure (see Fig.5). The time for drainage of the acid via turning the complete cavity to upright orientation is about 1 to 2 minutes. All connections, i.e. gas, electrolyte and electrical have to be flexible enough to allow for the 90 degree turn.

5 CONTROLS

The whole system is designed according to the stringent German safety standards with different interlock circuits. The electropolishing process is controlled by an programmable logic controller unit which is also connected to a PC for convenient control of the parameters and data acquisition. Important process parameters like temperatures, current, voltage, quality of the acid and flux of the acid are continuously monitored and archived[6].

6 CONCLUSION & OUTLOOK

The described system is presently under construction. It will be installed in an appendix to the presently used facility for the chemical treatment of TESLA cavities on the DESY site. The design of all components is finished and their manufacturing has been started. The software is under development. We expect the first 9-cell cavity to be treated in the system early 2002. The detailed process parameters are probably subject to a step by step

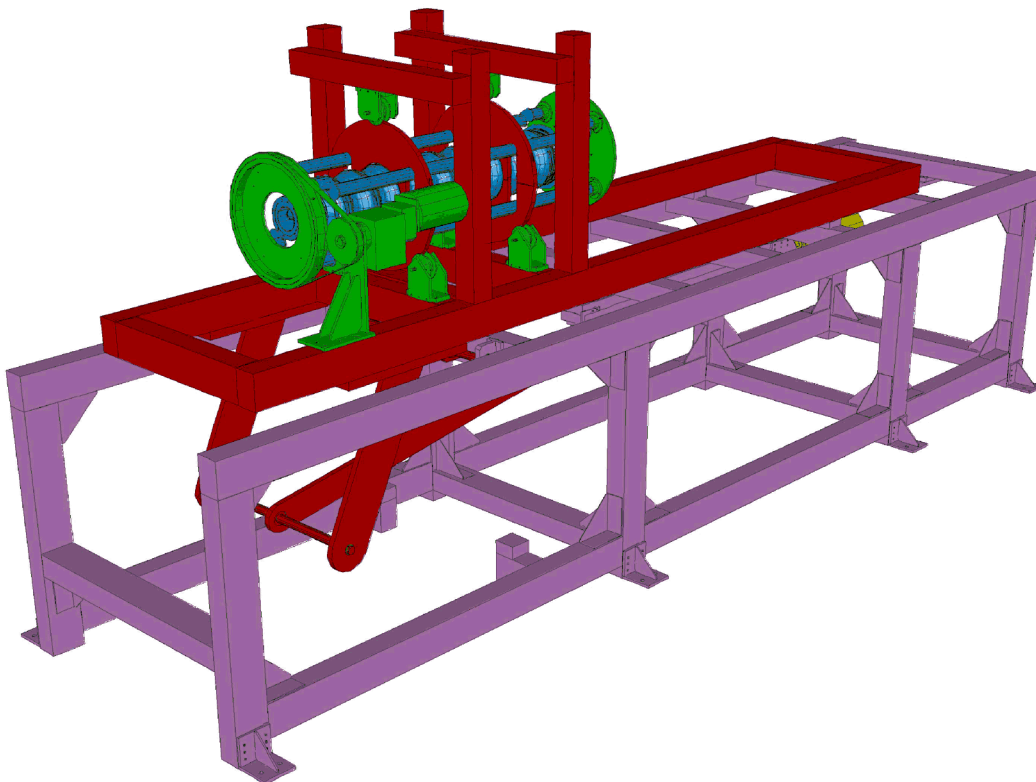


Figure 5: CAD Model of the EP Bench

optimization procedure with feedback from the RF tests of the cavities. Furthermore we are working on an improved shape of the cathode that will keep the current density better constant along the cavity. For the present design the varying distance from cathode to cavity surface (equator, iris) causes non-constant current density. In order to simplify basic investigations of the electropolishing process we also set up an apparatus for the treatment of single-cell cavities. In particular we are planning to investigate the ageing of the acid mixture, gas production and specific process parameters (see Fig. 6). We are also in discussion with industrial companies on the question how the electropolishing treatment could be done efficiently for a mass production of cavities.

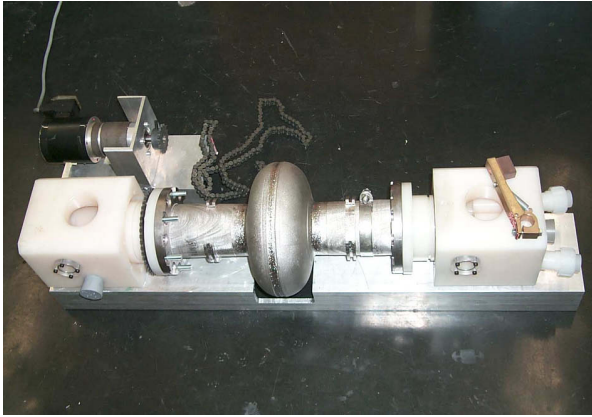


Figure 6: Single-Cell Treatment

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