ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS118

LASA ACTIVITIES ON SURFACE TREATMENT OF LOW-BETA ELLIPTICAL CAVITIES

M. Bertucci†, A. Bignami[1], A. Bosotti, M. Chiodini[2], A. D'Ambros, P. Michelato, L. Monaco, R. Paparella, L. Sagliano[1], D. Sertore, INFN/LASA, Segrate (MI), Italy
D. Rizzetto, M. Rizzi, Ettore Zanon S.p.A., Schio (VI), Italy
C. Pagani, Università degli Studi di Milano and INFN LASA, Segrate, Italy
[1]now at ESS, Lund, Sweden
[2]now at CERN, Geneve, Switzerland

Abstract

This paper describes the efforts made by LASA on the development of surface treatments for low-beta elliptical cavities, for the current series production of ESS and the foreseen series production of PIP-II. The traditional techniques of buffered chemical polishing and electropolishing are here discussed taking into account the industrial environment, the practical issues due to the size and geometry of such cavities and according to the required qualification values for quality factor and accelerating gradient.

INTRODUCTION

In the past years, INFN-LASA has been involved in the series production of superconducting Nb cavities for several projects, such as the European XFEL in which the surface treatments of Tesla Shaped 1.3 GHz cavities (bulk Electropolishing - EP), and also the third harmonic 3.9 GHz cavities (bulk Buffered Chemical Polishing - BCP), has been developed and optimized at the industrial qualified vendor Ettore Zanon SpA. The LASA current and future activity is focused on cavities for proton acceleration: the series production of 36 β=0.67 704 MHz cavities for ESS, currently ongoing, and the forthcoming prototype production of 2 multicell β=0.61 650 MHz cavities for PIP-II. ESS specifations for medium beta cavities are $E_{acc} = 16.7\ MV/m$ with a $Q_0 > 5 \cdot 10^9$ at nominal E_{acc}. Given such moderate values, our previous experience on TRASCO low β cavities [1], and the encouraging results obtained on first prototypes [2], BCP has been the natural choice as bulk and final surface treatment for the series production of ESS cavities. Conversely, PIP-II specs are $E_{acc} = 16{,}9\ MV/m$ with a $Q_0 > 2{,}15 \cdot 10^{10}$ at nominal E_{acc} [3]. This more ambitious target for Q is unlikely to be reached with a BCP treatment, given the characteristic Q-slope of BCP-treated cavities. For this reason, the EP treatment has been chosen. The difference in size and shape requires a careful optimization of treatment parameters and also a partial refurbishment of the BCP and EP facilities.

BCP OF ESS MEDIUM BETA CAVITIES

The series production of ESS medium beta cavities is currently ongoing. Cavities are treated in the Ettore Zanon SpA BCP facility located in a ISO7 clean room. The employed acid mixture is, as usual, H_3PO_4+HNO_3+HF in 2:1:1 ratio. On the whole, in order to get rid of the damaged layer, 200 µm have to be removed by the bulk BCP treatment. As reported in [4, 5], a strong asymmetry in the removal rate can be noticed by ultrasound thickness measurement and also on cavity field flatness variation before and after the treatment. For this reason, the treatment is divided in two batches of 90 µm and 110 µm, with the cavity turned upside-down at the end of the first treatment. The acid inlet and outlet temperature are continuously monitored during the treatment. The reaction rate critically depends on acid temperature, and even a modest increase of temperature could locally result in a remarkable enhancement of etching rate, in its turn heating the cavity walls and increasing the Nb temperature. Aiming to monitor such effect, several fast reading thermocouples are installed on cavity external surface. One should expect that as long as the inlet acid temperature remains stable, also the thermocouple reading will. In order to control the etching rate during the process, an ultrasound transducer probe is placed in contact with cavity surface and the thickness is continuously readed during the process by Olympus 38DL-plus gage with a µm resolution. A Nb sample is inserted inside the main couper so to evaluate the material removal by the difference of weight before and after the treatment and to monitor potential surface contaminations. Fig.1 shows the positions of the above mentioned items for a typical bulk treatment with main coupler oriented down.

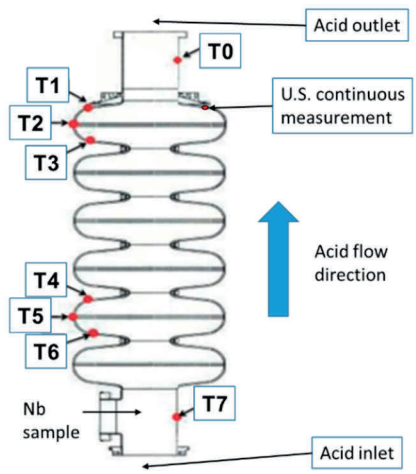

Figure 1: Thermocouples, ultrasound probe and Nb sample position during a BCP treatment with MC down.

† michele.bertucci@mi.infn.it

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS118

A typical thermocouple readout is shown in Fig. 2, with a starting inlet acid temperature of 4 °C. A 2 kW capacity heat exchanger constantly cools the acid in the barrel keeping the inlet acid temperature below 6°C and thereforemantaining the outlet acid temperature below the required value of 15°C for the whole treatment duration. Temperatures on cavity surface are also constant in time, albeit different from each other. It can be noticed that:

- Considering different points on a single cell, temperature is higher on the face opposite to acid flow, as already noticed in [6]
- Considering points with same orientation on different cells, temperature is remarkably higher (more than 5°C) near the acid outlet, meaning that the reaction rate is enhanced as the acid temperature increases.

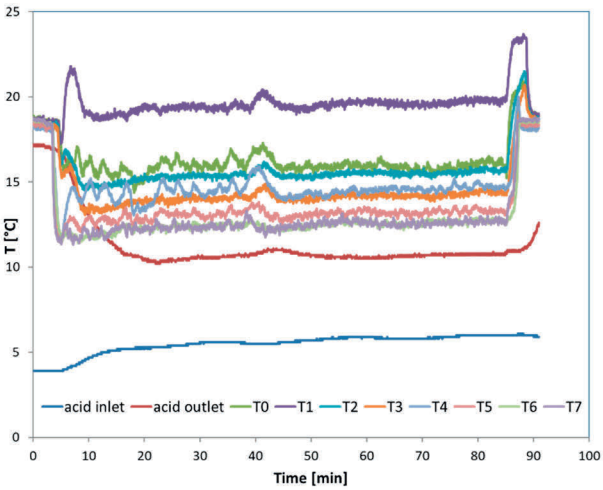

Figure 2: Temperature vs time for the first bulk BCP of se-ries cavity M001.

Given these observations, we chose to place the US probe nearby the point where the reaction rate is expected to be higher (namely close to thermocouple T1). The thickness variation during the first BCP treatment of cavity M001 is plotted in Fig. 3 together with T1 temperature registration. As it can be noticed, the constant temperature corresponds to constant etching rate.

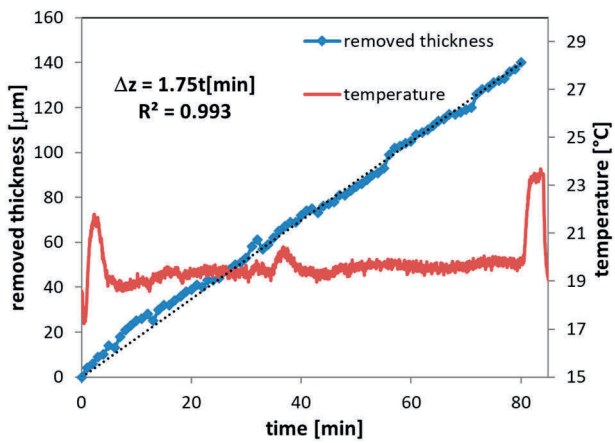

Figure 3: US thickness measurement and T1 reading vs time for for the first bulk BCP of series cavity M001.

Table 1 shows the etching rates calculated by the difference of cavity weight before and after the treatment.

Table 1: Etching Rates for the First 12 Cavities of ESS Medium Beta Series Production

cavity	1° BCP etch.rate (µm/min)	2° BCP etch.rate (µm/min)
M001	1.1	1.03
M002	1.07	0.98
M003	1.04	1.10
M004	1.01	1.07
M005	1.04	1.02
M006	0.99	0.97
M007	1.12	1.03
M008	1.08	1.01
M009	1.08	1.02
M010	1.06	1.09
M011	1.02	1.03
M012	1.05	1.06
average	1.05	1.03

All cavities show an averaged etching rate around 1 µm/min, which is significantly less than the one obtained by US measurement in the hottest cavity point (1.75 µm/min), as reported by fig.3. Besides the different equator/iris removal ratio due to different fluidodynamical regimes in the two different cavity regions, which is expected to be in a 1:2 ratio, such deviation is motivated also by the intrinsic temperature dependence of the reaction rate [7]. All things considered, the removal asymmetry is effectively compensated by the cavity reversal. Simulations by means of a fluid-dynamical finite element model are currently ongoing in order to achieve a further optimization of the process.

ELECTROPOLISHING OF PIP-II PROTOTYPE CAVITIES

Even more problematic than BCP, optimization of electro polishing of low-β 650 MHz resonators requires a careful review of all treatment parameters (current, voltage, cathode geometry, acid throughput, temperature, rotation speed) which have been historically optimized on Tesla-shape 1.3 GHz cavities. The bigger cavity size and more squeezed cell length are expected to significantly change the process behaviour. A full process simulation would require to consider the physical system of the cavity from an electrochemical, thermodynamically and fluid dynamical point of view, so to find the right balance among the many process parameters, with the goal to obtain a good smoothening (sub-µm roughness) on all inner surface and achieve at least 1:2 of equator/iris removal ratio. Being aware of the complexity of such a task, we decided to exploit a single cell PIP-II prototype cavity made in fine grain niobium (FG001) for experimentally optimize the procedure, starting with the baseline recipes employed in the past for XFEL and LCLS-II 1.3 GHz cavities [8], and scaling the parameters according to the different geometry. Anode voltage must be set so to place all the cavity surface in the

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS118

limiting current plateau in the V-I polarization curve, which is known to be the best polishing condition. This means that no significant current increase must be noticed by increasing the anode voltage. The EP plant – shown in Fig. 4 – is the same used for XFEL and LCLS-II, with the rotating frame properly adapted to host PIP-II single cell cavities. In order to reduce the removal at beam tubes, the cathode will be properly shielded (50% of coverage) with a PTFE tape in correspondence of the beam tubes. Aiming to obtain a more uniform temperature distribution, an external water cooling system is installed on the beam tubes. The fresh acid will enter in the cavity volume through a hole in the cathode placed exactly in correspondence of equator, with a throughput of 1 l/min. Thermocouple sensors and a US probe for online thickness measurement are installed on cavity surface.

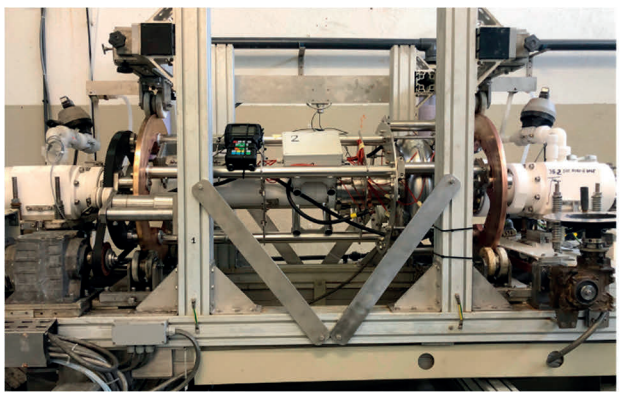

Figure 4: The EP bench with cavity FG001 mounted on the frame.

In order to analyze the V vs I response of the cavity, the voltage has been ramped from 0 to 20 V continuously acquiring the current. Acid inlet and outlet temperature (respectively 12 °C and 15°C) and the thermocouple readings during the treatment remain constant during the ramp so that one can assume no change in reaction rate due to heating. Fig. 5 shows the polarization curve. The three typical regimes of etching, current oscillation and polishing can be clearly identified. In the polishing region, a modest increase of current with voltage can be noticed.

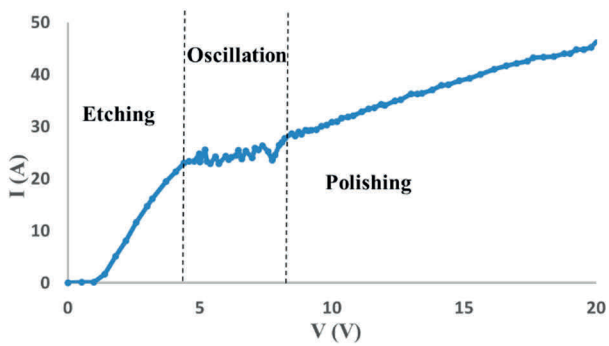

Figure 5: V-I polarization curve for cavity FG001.

Aiming to get a shiny surface, voltage must be set in the polishing region [9], possibly not too close to oscillating region. For this reason, we restrict our investigation in the 13-17 V zone. Current in its turn will be of the order of 40 A, which corresponds to a 0.124 µm/min removal rate [8].

Fig. 6 shows the temperature and current trend during a 2 hours treatment at 15V. Even at such relatively low voltage, after 30 minutes the temperature of beam tubes reaches 25°C, while only 17°C on equator. Then, the external water cooling system is turned on.

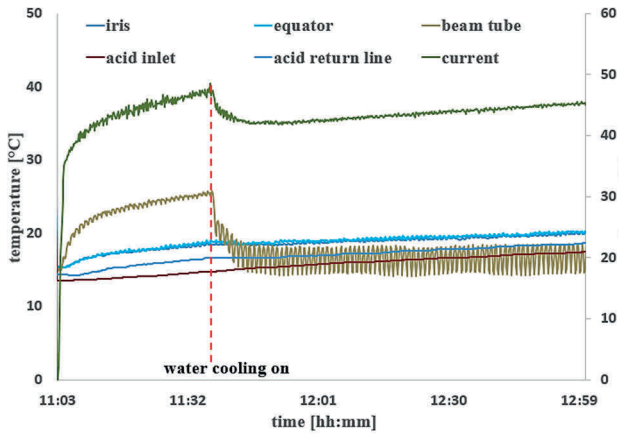

Figure 6: Temperature and current vs time for 2 h 15V EP without and then with external water cooling.

Indeed, the temperature on beam tube drastically reduces in few minutes, so that a more uniform temperature distribution on whole cavity surface is obtained, with a modest decrease in current.

As next step, we are currently planning a modification of cathode geometry so to increase its active area in correspondence of cavity equator and then obtain a higher removal. Once the process will be fully optimized, the cavity will undergo a full bulk EP removal in view of a vertical test allowing the complete validation of EP treatment.

CONCLUSIONS

The current activity of LASA-INFN on low-beta resonators surface treatment has been presented. ESS series production is ongoing: the acceptance tests so far performed are all above the ESS specifications [10] so one can assume that the BCP treatment recipe grants reproducible results in terms of removal rate and surface quality. In the meantime, the activities on EP treatment for the PIP-II low beta cavities are gaining momentum. First the single-cell, then the multi-cell prototypes will allow a full EP process optimization. Further results, expected in the next months, will be presented in a future work fully dedicated to a full discussion of the EP recipe optimization.

REFERENCES

[1] A. Bosotti et al., "Characterization of an Elliptical Low Beta Multicell Structure for Pulsed Operation", in Proc. 12th Int. Workshop on Applied Superconductivity (SRF '05), Ithaca, New York, USA, July 2005, pp. 612-615, THP62

[2] D. Sertore et al., "INFN- LASA Medium Beta Cavity Prototypes for the ESS LINAC" in Proc. 18th Int. Conference on RF Superconductivity (SRF 17), Lanzhou, China, July 2017 pp. 494-498. doi:10.18429/JACoW-SRF2017-TUPB048

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS118

[3] PIP-II Preliminary Design Report, March 22nd, 2019.

[4] L. Monaco et al., "Fabrication and Treatment of the ESS Medium Beta Prototype Cavities", in Proc. 8th Int. Particle Accelerator Conf. (IPAC'17), Copenhagen, Denmark, May 2017, pp. 1003-1006, doi: 10.18429/JACoW-IPAC2017-MOPVA060.

[5] E. Cenni et al., "Vertical Test Results on ESS Medium Beta Elliptical Cavity Prototype", in Proc. 28th Linear Accelerator Conference (LINAC '16), East Lansing, USA, September 2016, pp.631-633. doi: 10.18429/JACoW- LINAC2016 - TUP106006

[6] F. Éozénou et al., "Investigation of BCP Parameters for Mastery of SRF Cavity Treatment", in Proc. 18th Int. Conf. on RF Superconductivity (SRF'17), Lanzhou, China, July 2017, pp. 558-562. doi: 10.18429/JACoW-SRF2017-TUPB072

[7] C. Boffo et al.,"Optimization of the BCP Processing of Elliptical Nb SRF Cavities", in Proc. 10th European Particle Accelerator Conference (EPAC '06), Edinburgh, Scotland, June 2006, pp. 558-562. MOPCH174.

[8] M. Rizzi et al, "Electropolishing for EXFEL Cavities Production at Ettore Zanon SpA", in in Proc. 16th Int. Conference on RF Superconductivity (SRF '13), Paris, France, Sept. 2013, pp 217-220. MOP045

[9] G. Yang, et al., "Electropolishing of surfaces: theory and applications", Surface Engineering. Vol. 33. 1-18, July 2016 doi: 10.1080/02670844.2016.1198452.

[10] A. Bosotti et al., "Vertical Tests of ESS Medium Beta Cavities" presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper WEPRB023, this conference