ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-TUPCAV001

VERTICAL ELECTRO-POLISHING OF 704 MHz RESONATORS USING NINJA CATHODE: FIRST RESULTS

F. Éozénou†, M. Baudrier, E. Cenni, E. Fayette, G. Jullien, L. Maurice, C. Servouin
Université Paris-Saclay, CEA, Département des Accélérateurs, de la Cryogénie et du Magnétisme, 91191, Gif-sur-Yvette, France
V. Chouhan, Y. Ida, K. Nii, T. Yamaguchi, MGH, Hyogo-Ken, Japan
H. Hayano, H. Ito, S. Kato, T. Kubo, H. Monjushiro, T. Saeki, KEK, Ibaraki, Japan

Abstract

Vertical Electro-Polishing (VEP) of elliptical cavities using rotating Ninja cathodes (Marui Company patented technology) has continually been improved since 2012 and successfully applied for 1300 MHz multi-cell ILC-type resonators. The goal of the presented study is to apply this technology to 704 MHz European Spallation Source (ESS)-type resonators with both better Q_0 and accelerating gradients in mind. We intend to demonstrate the superiority of VEP compared to standard Buffer Chemical Polishing (BCP), for possible applications such as MYRRHA accelerator. We describe here the promising results achieved on β = 0.86 single-cell cavity after 200 µm uniform removal. The cavity quenched at 27 MV/m without any heat treatment. The surface resistance achieved was less than 5 nΩ at 1.8 K. Substantial performance improvement is expected after heat treatment of the cavity and additional 20 µm VEP sequence. A cathode for 5-cell ESS cavity is concomitantly under design stage.

INTRODUCTION

CEA Saclay has been developing Vertical Electro-Polishing (VEP) since 2012 [1, 2] and a collaboration has been strengthened between KEK, Marui Galvanizing Co. Ltd and CEA Saclay. The goal of this collaboration is to demonstrate the feasibility of the VEP process as a key technology and its scalability to industry mass production of SRF cavities. Marui Galvanizing Co. Ltd has developed and continuously improved the design of a rotating cathode "i-cathode Ninja" for ILC shape configuration. Extensive parameter investigation is presented in [3, 4]. For the first time, this technology is developed for a lower frequency geometry: we intend to demonstrate that VEP using a Ninja cathode can be efficiently applied in 704 MHz configuration, which is presently used for ESS linac. With this purpose in mind, a specific cathode was designed to electropolish vertically a single-cell ESS cavity, with β = 0.86. RF results as well as surface aspects will be presented. Such a study might be useful for increased performance of 704 MHz resonators for linacs such as MYRRHA [5].

EXPERIMENTAL DETAILS

Cavity

The single cell cavity (EH101) has been manufactured by Zanon Research&Innovation using fine grain high purity niobium (RRR > 300) from Tokyo Denkai. The cell shape is the same as the end cell of high beta elliptical cavities for European Spallation Source (ESS) linac [6]. In Table 1 are summarized some relevant cavity parameters.

Table 1: Cavity Parameters

Parameter	Value
R/Q [Ω] @β=0.86	113
G [Ω]	250
E_{pk}/E_{acc}	1.88
B_{pk}/E_{acc} [mT/(MV/m)]	3.86
Inner surface [m^2]	0.55
Volume [l]	14.6

VEP Set-up

The VEP set-up operated at Saclay has been described in details in a previous publications [1]. To prevent from risks of explosion, nitrogen is flown in the acid tank and in the top of the set-up. The set-up has been upgraded with water sprays dedicated to the cooling of the external surface of the cavity. Four water sprays equipped with ten nozzles each are used (see Fig. 1). The temperature at the cavity surface was recorded at three locations (middle of the top beam pipe, top iris and equator). It was less than 17 °C at the three locations during all sequences.

For the experiments presented here, 200L of HF(40%) – H_2SO_4(96%) mixture with ratio 1-9 were used. Because of a modification of the fabrication process by our electrolyte supplier (increased venting during mixing), the HF concentration is lower compared to the standard one (HF mass concentration is approximately 0.5%). As shown in [7] where similar mixture was used, a decreased hydrogen incorporation in niobium might be achieved using this lower HF concentration. Complementary experiments are necessary to confirm that point.

Ninja Cathode

The core of the cathode is a hollow 70 mm diameter aluminium cylinder. A large diameter was chosen in order to increase as much as possible the cathode area so as to optimize the electrical field during the process and reduce sulphur contamination [8]. The cathode/cavity surface ratio is approximately 0.2. The aluminium cylinder is surrounded by a 114 mm diameter PVC cylinder which aims to guide the hydrogen bubbles along the cathode and prevents them to reach the cell surface. Four Teflon wings are used to stir

† email address: fabien.eozenou@cea.fr

20th Int. Conf. on RF Superconductivity SRF2021, East Lansing, MI, USA JACoW Publishing
ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-TUPCAV001

the acid. The shape of the wing is designed to fit the internal surface of the cavity cell. A 20 rpm rotation was chosen, based on previous results achieved on 1300 MHz geometry [4].

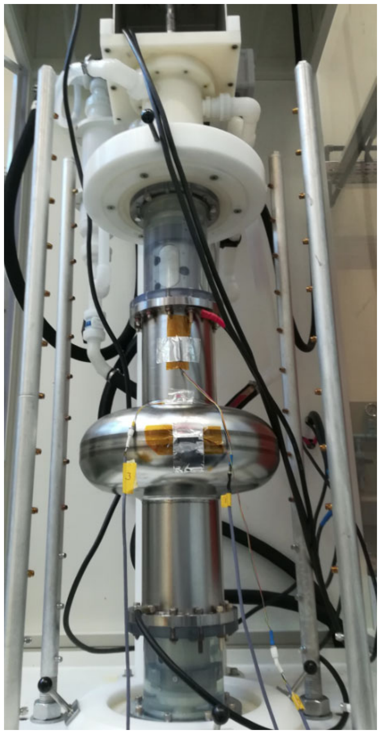

Figure 1: EH101 Single-cell cavity installed on the VEP set-up.

I(V) Curve

An I(V) curve (see Fig. 2) has been plotted. A diffusion 'plateau' favourable for smooth electropolishing is observed for voltage above 6 V. The operating voltage for long electropolishing sequences was chosen at the end of the plateau (between 19 and 20 V).

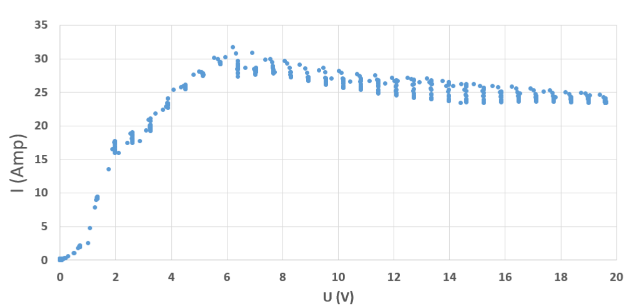

Figure 2: I(V) curve plotted at 15 °C, 20 rpm cathode rotation.

Parameters Chosen for the Bulk Electropolishing

The parameters in the Table 2 were chosen for the vertical electropolishing of the single-cell cavity.

Table 2: Parameters for Bulk EP of EH101 Cavity

Parameter	**Value**
Acid temperature (in tank)	15 °C
External cool down water	12 °C
Acid flowrate	15-20 L/min
Cathode rotation	20 rpm
Voltage	19-20 V

Several electropolishing sequences using these parameters were carried out, up to a 39 h global treatment time. The corresponding average removal is 200 µm. The removal rate was approximately 0.1 µm/min in the cell. A strong sulphur odour was noticed once the cavity removed from the VEP set-up. It should be correlated to the generation of undesirable by-products due to the high electropolishing voltage chosen for the experiment [9]. The cavity was filled with pure ethanol during 65 h with the objective to remove possible contamination, prior to High Pressure Rinsing (HPR) in ISO5 cleanroom.

RESULTS

Material Removal

Thickness measurements with an ultrasonic gauge have been done after each sequence for comparison. Twenty-two locations along the cavity are considered. The results are presented in Fig. 3 below after 80 µm average removal.

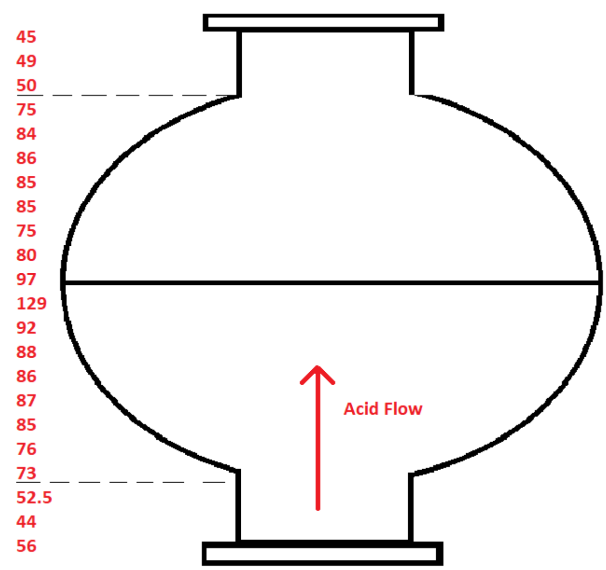

Figure 3: Niobium removal in the cavity as a function of the location (average removal: 80 µm).

A uniform removal is observed in the cell. Furthermore, the surface was observed at the equator weld bead and a shiny aspect is noticed in this high magnetic area (Fig. 4). No feature such as pits or bubbles stripes are visible at the cavity surface. The process using a Ninja rotating cathode is superior compared to the one with a fixed cathode tested on 704 MHz SPL cavity (β = 1) which is likely to generate features at the upper side of the cells [2].

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-TUPCAV001

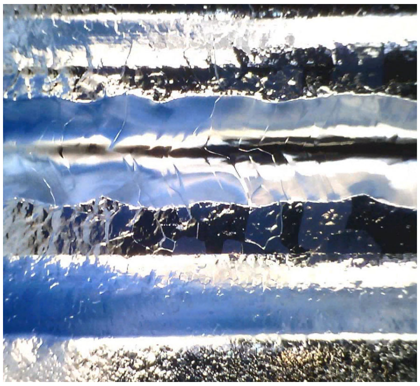

Figure 4: Surface at the equator after 80 µm average removal.

Tests in Vertical Cryostat

The cavity EH101 was tested in vertical cryostat after 200 µm average VEP without any thermal treatment. The temperature dependence of the surface resistance is represented in Fig. 5. The achieved residual resistance is lower than 3 nΩ.

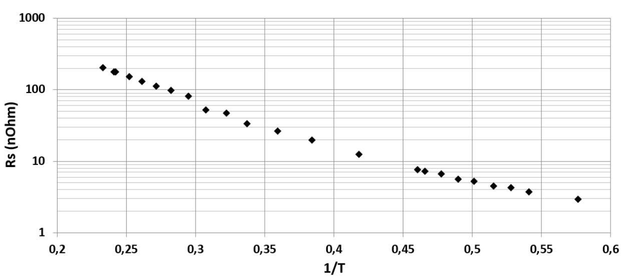

Figure 5: Surface resistance as a function of 1/T measured at 1 MV/m.

The curve $Q_0 = f(Eacc)$ was plotted at 2 K (Fig. 6).

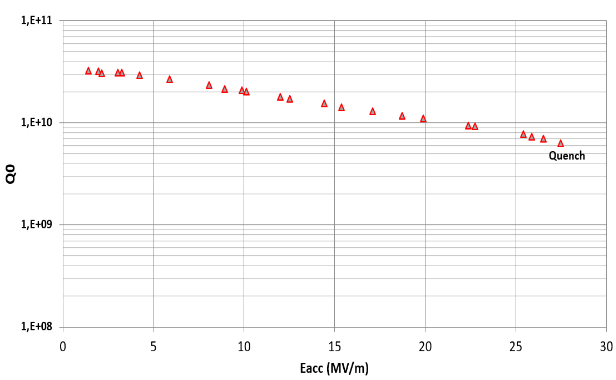

Figure 6: $Q_0 = f(Eacc)$ measured at 2 K.

The cavity reached a 27MV/m gradient @ $Q_0 = 6E9$, limited by quench.

DISCUSSION AND OUTLOOK

The electropolishing parameters with controlled temperature and efficient evacuation of hydrogen bubble with the Ninja cathode made it possible to obtain promising results. In terms of:

- Homogeneous surface removal
- RF performance (low Rs and high accelerating gradient).

The results achieved on EH101 have been obtained without any heat treatment. Substantial improvement might be achieved going further in the process including such steps in the protocol. In Fig. 7 below, we have compared the result achieved on EH101 with typical performance of a ESS β = 0.86, 5-cell prototype cavity prepared at CEA Saclay (chemical treatment in the acid mixture made of HF(40%), HNO_3(65%) and H_3PO_4(85%) with proportions 1-1-2.4). EH101 and the 5-cell cavity are made with the same niobium material. A very low Q_0 was measured (black dots) after the bulk treatment of the 5-cell prototype cavity in BCP mixture, due to the precipitation of niobium hydrides, also known as the as '100 K effect'. The Q_0 drop is all the more pronounced that the temperature of the acid mixture is high. Fortunately, a heat treatment makes it possible to recover the performance, as we can observe on the curve with blue dots in Fig. 7.

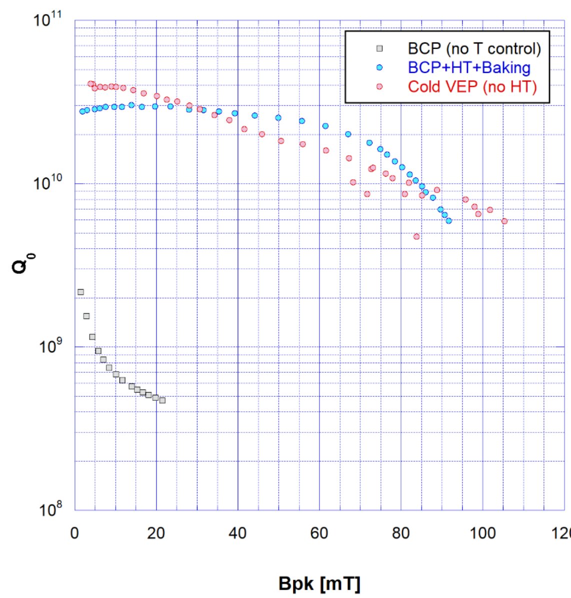

Figure 7: Comparison $Q_0 = f(Bpeak)$ at 2 K obtained on the single-cell electropolished cavity (red dots) vs typical result achieved on ESS 5-cell cavity after Buffered Chemical Polishing (BCP) before/after heat treatment at 600 °C.

The result achieved with the electropolished single cell without any heat treatment is similar compared to the performance of the 5-cell cavity, after BCP treatment followed by a heat treatment at 600 °C during 10 h. So two different heat treatments will be tested to push further the performance of the single-cell cavity:

- Heat treatment at 600 °C to remove hydrogen from the material
- 'Mild baking' at 120 °C.

Baking at 120 °C was previously investigated on ESS 5-cell cavity after BCP treatment. A reduction of BCS resistance by 60% at 4.2 K and an increase of the residual resistance by 35% were observed [10]. Following steps

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-TUPCAV001

will be carried out with the EH101 single-cell cavity, having in mind to demonstrate superiority of the electropolishing compared to standard Buffer Chemical Polishing (BCP):

- Heat treatment at 650 °C during 10 h.
- 20 µm removal by VEP
- RF test at 2 K
- Baking (120 °C during 48 h)
- RF test at 2 K.

The Ninja cathode will be then scaled to the 5-cell ESS cavity case. The cathode is presently under fabrication.

CONCLUSION

Promising results have been achieved after vertical electropolishing of a β = 0.86 single-cell ESS cavity without any heat treatment. Different heat treatments and additional electropolishing sequences will be carried to push further the cavity performance. The process will finally be scaled to the 5-cell cavity case.

ACKNOWLEDGEMENTS

This work was supported by the French-Japan FJPPL/TYL Particle Physics Laboratory.

REFERENCES

[1] F. Eozénou *et al.*, "Development of an advanced electropolishing setup for multicell high gradient niobium cavities", *Phys. Rev. Spec. Top. Accel. Beams*, vol. 15, p. 083501, 2012. doi:10.1103/PhysRevSTAB.15. 083501

[2] F. Eozénou *et al.*, "Development of vertical electropolishing process applied on 1300 and 704 MHz superconducting niobium resonators", *Phys. Rev. Spec. Top. Accel. Beams*, vol. 17, p. 083501, 2014. doi:10.1103/PhysRevSTAB.17.083501

[3] V. Chouhan *et al.*, "Effort towards symmetric removal and surface smoothening of 1.3-GHz niobium single-cell cavity in vertical electropolishing using a unique cathode", *Phys. Rev. Accel. Beams*, vol. 20, p. 083502, 2017. doi:10.1103/PhysRevAccelBeams.20.083502

[4] V. Chouhan *et al.*, "Vertical electropolishing for 1.3 GHz single- and nine-cell superconducting niobium cavities: a parametric optimization and rf performance", *Phys. Rev. Accel. Beams*, vol. 22, p. 103101, 2019. doi:10.1103/PhysRevAccelBeams.22.103101

[5] H. Podlech *et al.*, "The MYRRHA project", in *Proc. NA-PAC'19*, Lansing, MI, USA, Sep. 2019, paper THZBA2, pp. 945-950.

[6] J. Plouin and G. Devanz, "Conceptual design of the = 0.86 cavities for the superconducting linac of ESS", in *Proc. SRF'11*, Chicago, IL, USA, Jul. 2011, paper MOPO041, pp. 180-183.

[7] F. Eozénou *et al.*, "Optimization of vertical electro-polishing process: experiments with updated cathode on single-cell cavity and performance achieved in vertical test", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 2662-2664. doi:10.18429/JACoW-IPAC2018-WEPMK015

[8] L. Zhao *et al.*, "Sulfur residues in niobium electropolishing", in *Proc. SRF'11*, Chicago, IL, USA, Jul. 2011, paper TUPO024, pp. 421-423.

[9] F. Eozénou *et al.*, "Aging of the HF-H_2SO_4 electrolyte used for the electropolishing of niobium superconducting radio frequency cavities: origins and cure", *Phys. Rev. Spec. Top. Accel. Beams*, vol. 13, p. 083501, 2010. doi:10.1103/PhysRevSTAB.13.083501

[10] E. Cenni *et al.*, "Vertical test results on ESS medium and high beta elliptical cavity prototypes equipped with helium tank", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 948-950. doi:10.18429/JACoW-IPAC2017-MOPVA041