

FABRICATION, TUNING, TREATMENT AND TESTING OF TWO 3.5 CELL PHOTO-INJECTOR CAVITIES FOR THE ELBE LINAC

A. Arnold[#], P. Murcek, J. Teichert, R. Xiang, HZDR, Dresden, Germany
 P. Kneisel, L. Turlington, M. Stirbet, G. Ereemeev, Jefferson Lab, Newport News, VA 23606

Abstract

As part of a CRADA (Cooperative Research and Development Agreement) between Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and Thomas Jefferson Lab National Accelerator Facility (TJNAF) we have fabricated and tested two 1.3 GHz 3.5 cell photo-injector cavities from polycrystalline RRR niobium and large grain RRR niobium, respectively. The cavity with the better performance will replace the presently used injector cavity in the ELBE linac [1].

The cavities have been fabricated and pre-tuned at TJNAF, while the more sophisticated final field tuning; the adjustment of the external couplings and the field profile measurement of transverse electric modes for RF focusing [2] was done at HZDR.

The following standard surface treatment and the vertical test were carried out at TJNAF's production facilities. A major challenge turned out to be the rinsing of the cathode cell, which has small opening ($\varnothing 10$ mm) to receive the cathode stalk. Another unexpected problem encountered after etching, since large visible defects appeared in the least accessible cathode cell.

This contribution reports about our experiences, initial results and the on-going diagnostic work to understand and fix the problems.

INTRODUCTION

The development of the superconducting photo-injector at HZDR started in 1998. A very successful demonstration of an electron beam from a superconducting gun in 2002 led to the present injector design for the ELBE LINAC (Electron Linear accelerator with high Brilliance and low Emittance).

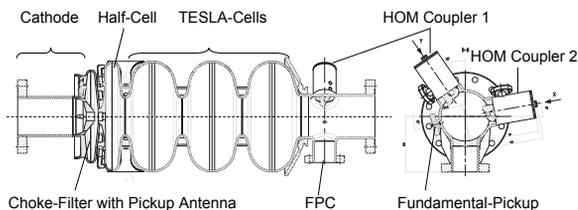


Figure 1: Cross-section of the modified 3.5 cell SRF-Gun cavity.

The injector cavity is shown in Figure 1. It consists of three cells with the TESLA cell shape and one velocity optimized half cell. The cathode insertion was designed for an easy exchange and precise positioning of Cs₂Te

cathodes. Additionally, a resonant superconducting choke filter surrounding the cathode is needed to prevent RF leakage out of the cavity. Two TESLA type HOM dampers and one 10 kW CW input coupler, developed at HZDR are attached to complete the design.

The commissioning of the cavity started in September 2007 and even though the cavity performance in the vertical test showed some respectable values, it became obvious that in the injector configuration the cavity was limited by field emission, limiting both the Q-value and the achievable gradient [3]. Therefore this project described here was launched with the idea to hopefully replace the present injector with a better performing cavity.



Figure 2: Both fabricated SRF-Gun cavities made from fine (left) and large grain material (right).

CAVITY FABRICATION AND TUNING

We fabricated two units: one cavity was made from polycrystalline (fine grain: FG) niobium of RRR~300 and the second one was made from large grain ingot material of RRR~300 (LG). This material from CBMM was previously used for single cell cavities, which performed very well [4]. The nomenclature [LG, FG] describes only the cell structure; beam pipes, coupler ports, HOM dampers and stiffeners, were made from polycrystalline niobium which was of lower RRR-value (~40). Beam line flanges, fundamental power coupler flange and HOM – probe flanges as well as helium vessel end dish were made from NbTi. The TESLA shaped cells and a part of the half cell was deep drawn from sheet by standard practices; the components beyond the 3½ cell structure

Corresponding author.
[#]a.arnold@hzdr.de

(endplate of the half cell and the choke filter) were machined in both cases from ingot large grain material. All components were joint by electron beam welds, starting with dumbbells, which were pre-tuned.

At the end of the fabrication process both cavities were off in frequency by 1-2 MHz and the field profile was strongly detuned. Main deviations occurred in the half-cell, which could be pre-tuned in the assembly only after softening the material by a 600 °C and 10 hrs heat treatment. Both finalized cavities are shown in Figure 2.

After the pre-tuning of both cavities at JLab, the more sophisticated final frequency- and field tuning as well as the measurement and the adjustment of coupling factors took place at HZDR. This procedure has already been described in detail in [5] and will be summarized only shortly below:

- Measuring field profiles and frequencies of all four modes of the “as fabricated” cavities,
- Applying an algorithm to determine the amount of tuning for each cell to achieve the desired field and target frequency of the π -mode,
- Iterative tuning of each cell until the desired field profile and frequency is reached (see Figure 3),
- Tuning of the choke filter and both HOM filters to minimize the power transmission of the π -mode ($Q_{ext} > 10^{12}$),
- Calibration of external Q-values of input coupler and both transmission probes,
- Identification of TE-modes for TE-mode focussing [2] using inductive coupling loop and bead-pulling.

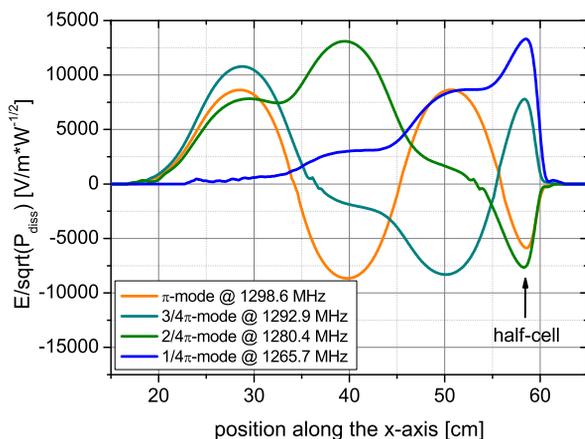


Figure 3: Measured field profiles and frequencies of all 4 passband modes, shown for the LG cavity after tuning.

CRYOGENIC TESTING

After the tuning of the cavities at FZD they were returned to JLab for final surface treatment and cold testing.

Large Grain (LG) Cavity

In preparation for the first cold test, the cavity was degreased, received 50 μm of material removal by bcp (1:1:2 solution of HF:HNO₃:H₃PO₄) in JLab’s production facility, followed by hot water rinsing, high

pressure ultrapure water rinsing, drying in a class 10 clean room, assembly of auxiliary parts, attachment to the vertical test stand and evacuation. The cavity reached a vacuum of $\sim 4 \times 10^{-8}$ mbar after 12 hrs and was subsequently cooled down to 2 K. In this test an electric peak field of $E_{pk} \sim 25$ MV/m with a Q-value of 1.3×10^{10} , limited by a quench, was measured (Figure 4, LG Test#1). Since the frequency at 2 K was still too high, indicating that the material removal was less than anticipated, a second surface preparation and cold test was carried out. Much to our disappointment, the cavity degraded drastically (LG Test#2).

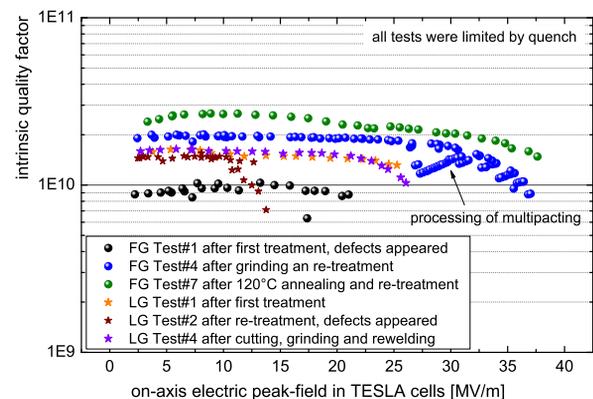


Figure 4: Summary of significant cold tests @ 2 K of both cavities.

After disassembly of the cavity, a “strange” defect pattern on the endplate of the cathode cell as shown in Figure 5 was discovered; a similar pattern was also seen in the subsequent test with the FG cavity.



Figure 5: Photography of the defect pattern on endplate of the LG half-cell after re-treatment when defects appeared.

We could rule out mechanical damage from the high pressure rinse wand because the damage was outside the wand movement. Since in both cases these parts of the cavities were made from ingot niobium, we suspected defects/voids in the niobium from the melting process. Therefore another slice from the same ingot was subjected to the same depth of material removal as the cavity in order to find material defects. Nothing showed up. Since the defects appeared in both cavities nearly at the same position and with a similar defect pattern, another idea is that the defects were produced during turning of both large grain endplates.

The idea of re-melting the defective areas with the electron beam welder had to be abandoned after some

testing on samples, because the distance of the gun to the area of repair seemed to be too far and the alignment of the gun/beam was too uncertain. Additionally, it was not clear, if some foreign material was involved in the defect, which would be melted into the niobium. We therefore opted for cutting the cavity apart by wire EDM [electro discharge machining] at the equator of the first TESLA-cell next to the half-cell and mechanically removed the defects as good as possible by grinding. It turned out that the defects, which appeared to be very deep when observed through the full cavity were quite shallow.

After some practice welds on cut-apart single cell cavities made from the same material had been done, the first TESLA-cell was re-welded at the equator. Of course, the cavity lost its field flatness and frequency but both will be corrected later during a final tuning before the helium vessel assembly.

After 50 μm of material removal by bcp and the same rinsing, drying and assembly procedures as before the cavity was retested with the results shown in Figure 4 (LG Test#4). The cavity performance could be restored but the field was limited by quench. The quench location was roughly detected by measuring the passband modes and in a following test using second sound detectors [6]. Both revealed a defect in the half self cell that could be clearly identified via optical inspection at the equator weld (Figure 6).

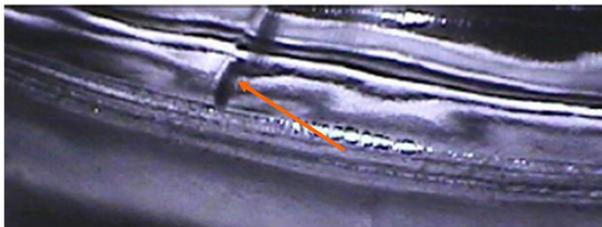


Figure 6: Suspected quench area in cathode cell of the LG cavity.

Unfortunately, this cell is very shallow and not accessible with our existing mechanical grinding tools. We will attempt to improve the cavity performance by additional chemical treatment (possibly locally first) and heat treatment.

Fine Grain (FG) Cavity

The polycrystalline cavity was subjected to the same surface treatment and assembly procedures as the large grain cavity. The performance in the first test was quite disappointing as shown in Figure 4 (FG Test#1). After the test the cavity inspection revealed not only a defect pattern similar to that shown in Figure 5, but also an unusual severe etching of the surfaces of the cavity, which might have been caused by an aged bcp solution.

In preparation for the next test and based on the experience of the LG cavity, the defective endplate of the half-cell was mechanically ground through the whole cell structure with a long arm grinding tool. Subsequently the cavity was bcp'd by removing nominally 50 μm of

material. Additionally, the half-cell was separately bcp'd for several minutes by dipping it into acid.

As shown in Figure 4 (FG Test#6) this approach was very successful. The cavity achieved much better performance which could be further improved up to $E_{pk} \sim 38 \text{ MV/m}$ @ $Q_0 \sim 1.5 \times 10^{10}$ after applying 120°C annealing (FG Test#7). Nevertheless in both tests the cavity was limited by a quench that was localized by field measurement to be in the TESLA cell next to the coupling section.

DISCUSSION AND VIEW FORWARD

As pointed out above we ran into serious and unexpected difficulties with cavity preparation and cavity performance. This forced us to carry out several time-consuming diagnostic tests and attempts to repair the cavities. This effort is ongoing and at least in the case of the FG cavity we achieved an acceptable performance for further string and module assembly.

However, it is very disconcerting that we could not find any “smoking gun” to explain the unusual defect pattern at the endplates of the half-cells in both cavities.

ACKNOWLEDGEMENT

We are greatly indebted to Peter Kneisel, who mainly realized the fabrication, the preparation and especially the repairing of both cavities. We also like to thank all our colleagues at JLab and HZDR, who supported this work. Finally, we acknowledge the support of the European Community-Research Infrastructure Activity under the FP7 programme (EuCARD, contract number 227579), as well as the support of the German Federal Ministry of Education and Research grant 05 ES4BR1/8.

REFERENCES

- [1] J. Teichert, et al., “Status of the SRF-Gun Operation at ELBE”, Proc. FEL 2010, Malmoe, Sweden, p. 453.
- [2] V. Volkov, D. Janssen, Phys. Rev. ST Accel. Beams 11, 061302 (2008).
- [3] A. Arnold et al., AIP Conf. Proc. 1149, 1125 (2009).
- [4] P. Kneisel, “Progress on Large Grain and Single Grain Niobium”, SRF 2007, Beijing, China, paper TH102.
- [5] A. Arnold et al., “1st RF-Measurements @ 3.5-cell SRF-Photo-gun cavity in Rossendorf”, Proc. FEL 2006, BESSY, Berlin, Germany, THPPH007.
- [6] Z. A. Conway, D. L. Hartill, H. Padamsee, E. N. Smith, “Defect Location in Superconducting Cavities Cooled with He-II using Oscillating Superleak Transducers”, SRF 2009, Berlin, Germany, paper TUOAAU05.