PROCESSING AND TESTING OF THE SRF PHOTOINJECTOR CAVITY FOR bERLinPro

A. Burrill♦, W. Anders, A. Frahm, J. Knobloch, A. Neumann, Helmholtz-Zentrum Berlin, Berlin, Germany
E. Zaplatin, Forschungszentrum Jülich GmbH (FZJ), Jülich, Germany
G. Ciovati, P. Kneisel, L. Turlington, W. Clemens, JLAB, Newport News, VA, USA

Abstract

The bERLinPro project is a compact, c.w. superconducting RF (SRF) energy recovery linac (ERL) that is being built to develop the accelerator physics and technology required to operate the next generation of high current ERLs. The machine is designed to produce a 50 MeV 100 mA beam, with better than 1 mm-mrad emittance. The electron source for the ERL will be a SRF photoinjector equipped with a multi-alkali photocathode. In order to produce a SRF photoinjector to operate reliably at this beam current HZB has undertaken a 3-stage photoinjector development program to study the operation of SRF photoinjectors in detail. The 1.4 cell cavity being reported on here is the second stage of this development, and represents the first cavity designed by HZB for use with a high quantum efficiency multi-alkali photocathode. This paper will describe the work done to prepare the cavity for RF testing in the vertical testing Dewar at Jefferson Laboratory as well as report on the results of these RF tests and the future plans for the cavity.

INTRODUCTION

Helmholtz-Zentrum Berlin (HZB) has set out on a program to build a superconducting RF (SRF), high average current, Energy Recovery Linac (ERL) designed to operate at an electron beam energy of 50 MeV with 100 mA of average current.[1] The ERL is designed primarily to study the physics of operation of a high current ERL in a number of different operating modes. This includes operation with bunch charges ranging from a few pC to 77 pC and repetition rates that range from low repetition rate burst modes up to c.w. operation at 1.3 GHz, the fundamental mode of the cavities. This wide range of operating conditions will place great demands on many of the components of the ERL, and will certainly test the limits of the SRF photoinjector.[2]

In order to help mitigate the risks associated with operation of the SRF photoinjector HZB has set out on a multi-cavity photoinjector R&D program.[3] Four different SRF photoinjectors will be built and tested in order to gain experience with different aspects of the photoinjector operation. The results of the first two photoinjector cavity tests, utilizing a lead photocathode, can be found in references 4-7.[4-7] In this paper we will report on the fabrication and initial testing of the first photoinjector whose design is suitable for use in bERLinPro. The cavity is designed to deliver a 2.4 MeV electron beam from a multi-alkali photocathode, and will be our test bench with its own dedicated beamline called GunLab. If the tests go well this cavity design will be used for the final bERLinPro injector cavity, with the only differences being the final cavity will be equipped with two 115 kW RF input couplers, as opposed to the 5-10 kW available on this cavity which utilizes the c.w-modified TTF-III coupler design.[8] A picture of the cavity as fabricated is shown in figure 1, along with a CAD model cut-away showing the different parts of the cavity.

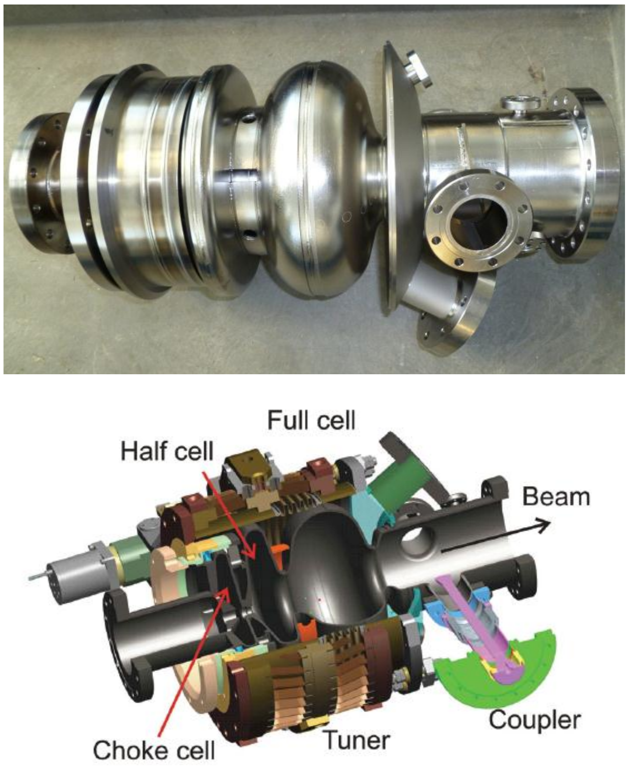

Figure 1. The SRF photoinjector for bERLinPro.

CAVITY DESIGN & FABRICATION

The design of the photoinjector for bERLinPro has been reported on previously, so only a brief summary will be given here.[2] The cavity consists of a 1.4 cell cavity attached to a non-resonant choke cell which allows for the

♦andrew.burrill@helmholtz-berlin.de

insertion of a normal conducting multi-alkali photocathode on an electrically isolated cathode stalk. The latter is based on HZDR's photoinjector design.[9]

All of the cavity fabrication and processing testing took place at Jefferson Laboratory. The full cell and the first part of the half-cell were formed from high RRR 3 mm sheet material, while the rest of the ½ cell and the choke cell were machined from ingot niobium. All of the flanges on the cavity were made from Niobium-titanium and the entire cavity is electron beam welded together. The cavity is designed to be equipped with a pair of tuneable c.w.-modified TTF-III coaxial RF power couplers to deliver up to 10 kW c.w. of RF power to the cavity. The cavity is enveloped in a titanium helium vessel and equipped with a blade tuner which should provide approximately 1 MHz of tuning range.

Table 1 shows the RF parameters of the cavity as designed along with the estimated RF parameters of the cavity as fabricated.

Table 1. The RF parameters for the bERLinPro photoinjector design, as well as the fabricated geometry.

Parameter	**Design**	**Fabricated**
Frequency (MHz)	1300	
E_0 (MV/m) –peak on axis field	30	
E_{peak}/E_0 (peak surface field v. peak on axis field.)	1.5-1.45	1.66
$E_{cathode}/E_0$	1-0.58	0.76
B_{peak}/E_{peak}	2.27	2.18
E_{launch} (MV/m)	26-13.3	8.9
E_{kin} (MeV)	2.6	1.5
Cathode position relative to back wall	0-2.5 mm	1.5 mm
G (Ω)	174	154
R/Q (Ω)	150	132.5
K_{cc} (%)	1.6	1.7
Q_{ext}	$1.5 - 8x10^6$	$0.35- 2x10^7$
U (J)	6.09	
Electric cavity length (m)	.1558	.1488

As a result of schedule and funding constraints a copper prototype was not build first; instead the niobium cavity was built with the understanding that it would be a prototype and first article for use in our demonstration facility GunLab. Unfortunately, the fabricated cavity was shorter than the RF design, and the length was lost entirely in the cells of the cavity. Additionally the FPC ports were both fabricated 5 mm too long, thus increasing our Qext of the FPC as shown in table 1. Following the chemical processing and cavity tuning for field flatness and frequency compensation the cavity ended up being 7 mm shorter than designed.

CAVITY PROCESSING AND RF TESTING

Following the cavity fabrication the cavity was chemically etched at Jefferson Laboratory in the production buffered chemical polishing (BCP) tool to remove 120 µm of material from the cavity as measured utilizing an in-situ ultrasonic thickness gauge placed at the equator of the full cell. The material removal was done in 2 steps, removing 60 µm and then flipping the cavity to reverse the acid flow for the removal of the additional 60 µm. Following the chemical treatment the cavity was hydrogen degassed at 600 °C for 10 hours and then tuned for frequency and field flatness. Then an additional 30 µm of material was removed via BCP and the cavity was high pressure rinsed (HPR) from both sides of the cavity prior to assembly and low temperature 120°C baking for 24 hours prior to the RF test.

The RF test results are shown in figure 2. The cavity nearly reached the design specification during the second test (blue diamonds), but due to the strong multipacting (MP) barrier, further processing was carried out in order to try and improve the cavity performance.

Two additional BCP chemical etches were performed in order to try and reach the desired performance goal of E_0 = 30 MV/m (peak on axis field). Unfortunately after these BCP steps the gradient deteriorated and then following HPR only the Q dropped to the present value of Q_0 = 2.0e+9. Presently the cavity quenches at E_0 = 14 MV/m (green diamonds), near the maximum of the MP band. Pulsed RF processing with a 250 W amplifier was not able to surpass this barrier after several hours of processing.

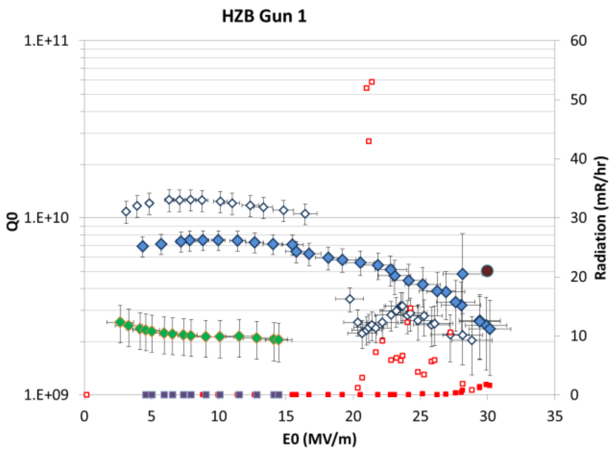

Figure 2. The vertical RF test results from the JLab VTA at 2K for the bare cavity. The open and solid blue diamonds are the initial and final power rise from the intial test. The final power rise was obtained after 2 hours of pulsed RF processing. The open and closed red squares are the associated radiation measurements. The green diamonds are the most recent test results. The design specification is shown in purple at E_0 = 30 MV/m – the peak on axis field.

The low Q_0 corresponds to a residual resistance is ~70 nΩ, nearly five times higher than previously measured. A vertical test of the cavity utilizing second sound detection was carried out at JLab and indicates a region along the equator of the half-cell as the likely location of what may be MP induced quench.

The multipacting analysis of the cavity geometry as designed showed a reasonably low MP barrier in the half cell with a field onset near 15 MV/m and a maximum around 18 MV/m. After the initial test results showed a strong barrier at much lower field an analysis of the "produced" geometry was carried out which takes into account the shortened cell geometry, based on CMM measurements of the cavity. The most significant finding is in the shortened half-cell the MP barrier moved to lower energy onset and showed a much more intense and broad MP range. Figure 3 shows the MP barrier curves obtained using CST-Microwave Studio for the two cases under consideration.

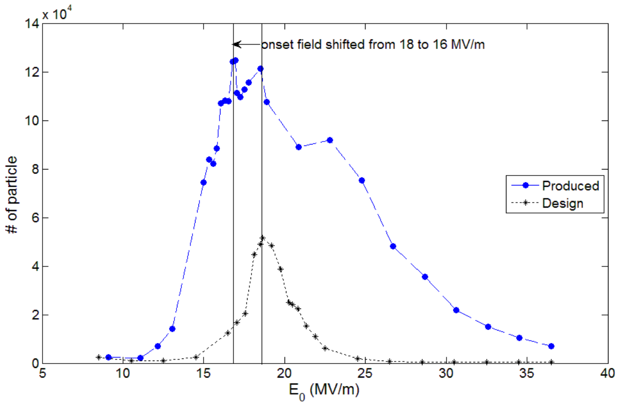

Figure 3. The multipacting barrier in the half cell of the SRF photoinjector. The black curve shows the expected barrier for the cavity design, while the blue curve is for the "produced" geometry.

An internal visual inspection of the cavity was carried out at JLab and indicates there are some areas along the half-cell equator which could be contributing to the quench. There was also a defect noted along the iris between the half-cell and full cell which requires further investigation. Due to the complicated structure of this cavity it is very challenging to perform the visual inspection of the half-cell, and it also makes possible repair work very difficult.

In addition to the RF measurements the pressure sensitivity and Lorentz force detuning were also measured, and found to be in good agreement with simulations carried out utilizing ANSYS® for the case of the unconstrained cavity.[10, 11] The Lorentz force detuning was measured at -17 Hz/(MV/m)^2 while the pressure sensitivity of the unconstrained cavity was measured to be -590 Hz/mbar. When the cavity is constrained in the helium vessel the pressure sensitivity is expected to be around -5 Hz/mbar or less.[11]

FUTURE PLANS

As the current performance of the cavity is not optimal from a beam dynamics standpoint, it is still capable of providing valuable insight into the operation of a 1.3 GHz SRF gun with a multi-alkali photocathode in GunLab, which is of great value to the bERLinPro project and to the community.

Once the helium vessel is attached the cavity will be re-tested at JLab to ensure no performance degradation from the welding process, as well as to measure the pressure sensitivity in the constrained case, as this is nearly 3 orders of magnitude less than unconstrained case.

Following these vertical tests the cavity will be shipped to HZB for testing in both the vertical and horizontal orientation. The first test will be done in our new vertical testing Dewar and the second test will take place in HoBiCaT, our horizontal test cryostat, and will allow us to measure the cavity performance with the TTF-III power couplers, as well as measure the performance of the cavity tuning system which will be mounted at that point. Following these tests the cavity will be built into the cryomodule so that beam tests can begin.

ACKNOWLEDGEMENTS

We would like to thank Grigory Eremeev for his help with the second sound detection set-up and analysis as well as Mircea Stirbet for the detailed internal inspection of the cavity. We would also like to thank the technician at Jefferson Lab who helped make these cavity tests possible.

REFERENCES

[1] J. Knobloch, et al., ICFA Newsletter, 58 p. 118 (2012)

[2] A. Neumann, et al., Proceedings of 2013 International Particle Accelerator Conference, Shanghai, China, p. 285 (2013)

[3] T. Kamps, et al., Journal of Physics: Conference Series, 298 p. 012009 (2011)

[4] A. Burrill, et al., Proceedings of 2013 International Particle Accelerator Conference, Shanghai, China, p. 2313 (2013)

[5] J. Völker, et al., IPAC'12, New Orleans, Louisiana, USA, p. 1518 (2012)

[6] A. Neumann, et al., Proceedings of SRF2011, Chicago, IL USA, p. 962 (2011)

[7] R. Barday, et al., PRST-AB, 16 p. 123402 (2013)

[8] V.F. Khan, et al., These proceedings, p. (2014)

[9] A. Arnold, et al., NIM:A, 577 p. 440 (2007)

[10] E. Zaplatin, Private communication, p. (2014)

[11] E. Zaplatin, et al., Proceedings of 2013 International Particle Accelerator Conference, Shanghai, China, p. 2328 (2013)