RF MEASUREMENTS OF THE 1.6 CELL LEAD/NIOBIUM PHOTOINJECTOR IN HOBICAT*

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Abstract

The development of a simple and robust SRF photoinjector capable of delivering 1 mA average current in c.w. operation continues to advance with the horizontal RF testing of the 1.6 cell Pb/Nb hybrid photoinjector. This injector utilizes a sputtered lead coating on a removable Nb cathode plug as the photoelectron source and has recently been tested in the horizontal test cryostat facility, HoBiCaT, at Helmholtz-Zentrum Berlin. In this paper we will report on the status of these RF measurements and compare the performance to previous vertical RF tests performed at Jefferson Laboratory. We will also provide a summary of the cavity tuning range and microphonics measurements now that it has been installed into a helium vessel equipped with a Saclay style tuner.

INTRODUCTION

Helmholtz-Zentrum Berlin (HZB) has set out on a program to build a superconducting RF, 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 reduce the risk and uncertainty of building a single SRF photoinjector for use in the ERL, HZB has set out on a multi-cavity photoinjector R&D program.[3] Over the course of approximately 6 years 4 different SRF photoinjectors will be built and tested in order to gain experience with different aspects of the photoinjector operation. For this endeavour HZB is in collaboration with DESY, JLab, BNL and the NCBJ Institute in Poland to help leverage the respective areas of expertise of each lab.

The first step in this injector R&D program, and the focus of this paper, was the fabrication and testing of a 1.3 GHz, 1.6 cell all Nb SRF injector designed to use a Pb photocathode. Lead was chosen as it is a superconductor below 7.2K, and it has a quantum efficiency (QE) one order of magnitude higher than niobium at the same wavelength. This cavity was developed by Jacek Sekutowicz (DESY) as a robust, simple SRF injector capable of operation at an average current of up to 1 mA and may serve as the injector for a future ≤1 mA CW LINAC as required, for example, by FELs. In the first set of tests with this cavity, called Gun0.1, the back wall of the injector was coated with a 3 mm diameter Pb spot.[4] The cavity was then modified and fitted with a removal Nb plug onto which the Pb coating was applied. This cavity is referred to as Gun0.2, and the performance of Gun0.1 and Gun0.2 will be analysed in this paper.

In order to measure the cavity and photocathode performance it was installed into HoBiCaT with a superconducting solenoid and a diagnostic beamline, as shown in figure 1, to allow for the characterization of the electron beam parameters driven by a 258 nm laser operating with 2.5 ps pulses and a repetition rate of 8 kHz.[5, 6]

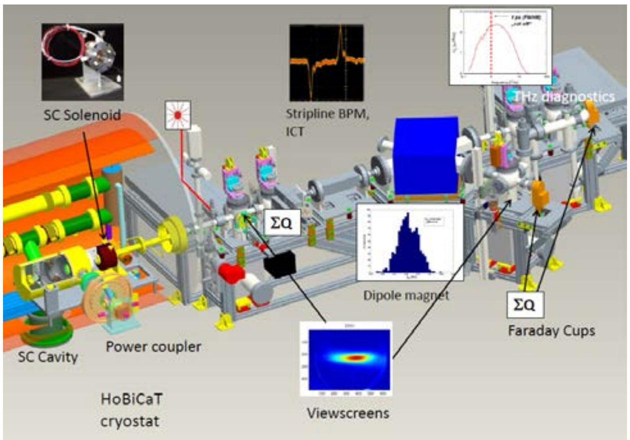

Figure 1. An overview of the SRF injector in HoBiCaT (left) connected to the diagnostic beamline.

CAVITY MODIFICATIONS

After testing Gun0.1 in HoBiCaT the overall performance was reduced compared to earlier RF cavity measurements as well as bench measurements of the Pb QE.[7] This decrease in performance was attributed to the challenges associated with sputtering the lead coating onto the back wall of the photoinjector, and subsequently chemically etching and high pressure rinsing the cavity

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surface. In order to improve the cavity and photocathode performance a modification to the injector was developed and carried out at JLab. The cavity was fitted with a removable Nb plug, onto which the Pb coating can be applied, that is installed in the back wall of the cavity (Gun0.2). This facilitated both the preparation of the cavity as well as the deposition and characterization of the lead coating.

In addition to modifying the cavity, the helium vessel, which had previously been welded onto the cavity, was re-designed as a two part helium vessel with an indium seal. This allows for easy access to the cathode plug as well as the entire cavity should the need arise. The helium vessel was designed to have a Saclay style tuner mounted onto it to allow the cavity to be tuned to a specific frequency and to facilitated the synchronization with the laser system and enabled realistic measurements of the microphonics detuning. A model of the modified cavity system along with a picture of the bare cavity can be seen in figure 2, and the key RF cavity parameters are listed in table 1.

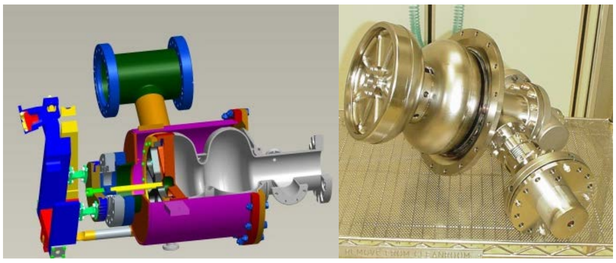

Figure 2. A model of the 1.6 cell Pb/Nb plug gun with the helium vessel and tuner alongside a picture of the cavity with the cold part of a TTF-III input coupler attached.

Following the cavity modifications it was tuned, chemically etched (BCP), heat treated at 800°C for 3 hours, high pressure water rinsed (HPR) and assembled for testing. Prior to testing the cavity was baked at 90°C for 18 hours.

Table 1. Cavity Parameters.

Frequency π - mode	1300 MHz
E_{peak}/E_{acc} (β=1)	1.86
H_{peak}/E_{acc}	4.4 mT/(MV/m)
Geometry Factor	218.3 Ω
r/Q (Linac β=1)	190 Ω

RF TEST RESULTS

Gun0.2 was tested at 2.0K in the vertical testing area (VTA) at Jefferson Laboratory with a bare Nb plug as well as with a Pb coated plug. The final test results for these two configurations are shown in figure 3 where the quality factor is plotted as a function of peak electric field. The VTA test results for Gun0.1 are also shown on the same plot for comparison.[8] Two significant factors stand out from a comparison of the data. First, the cavity performance of Gun0.2 shows a better low field Q and overall maximum gradient achieved with no Pb coating as compared to Gun0.1. Second, the Pb coated plug test results for Gun0.2 are significantly better than Gun0.1, both in terms of cavity Q and maximum gradient achieved. The performance improvements from adding the removable cathode plug, and thus facilitating BCP and HPR as well as cathode preparation, has resulted in a 20% increase in cavity gradient for the un-coated and Pb coated cavity as measured at the same Qo value.

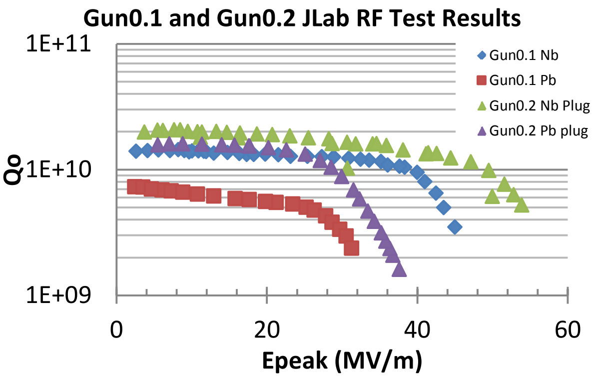

Figure 3. Results from Gun0.1 and Gun0.2 measurements in the JLab VTA measured at 2K. The green triangles are from a bare Nb plug, while the red diamonds are from a Pb coated plug. The blue diamonds and red squares are from the bare and Pb coated Gun0.1.

Following the RF tests at JLab the cavity was taken into an ISO-5 cleanroom and vented with filtered dry nitrogen so that the cold portion of a TTF-III input coupler could be attached. The helium vessel was then bolted on and the cavity was shipped to HZB for further assembly and installation into HoBiCaT for RF and beam measurements.[9]

HoBiCaT RF Test Results

Once the cavity was received at HZB a Saclay style lever arm tuner was mounted onto the cavity. The tuner pushes on the rear wall of the cavity with a plunger that is mounted on a bellows assembly and through the helium vessel wall. The cavity was then installed in the HoBiCaT cryostat, wrapped with superinsulation, attached to the warm section of the TTF-III coupler and the diagnostic beamline. It should be noted that the cavity only has a single layer of magnetic shielding in HoBiCaT, and this is a warm 1 mm thick layer of mu-metal that is mounted adjacent to the inner surface of the HoBiCaT vacuum vessel. There is no magnetic shielding between the cavity and the tuner assembly, or the FPC.

After the cavity was installed in the cryostat and cooled down to 1.8K, two small helium leaks were discovered. The first was into the cavity beamline vacuum, while the second was from the helium space into the insulating vacuum. The location of the beamline vacuum leak is most likely at the cathode plug, as it is the only seal that is in the liquid helium bath. This leak resulted in a cavity vacuum pressure of 1×10^{-7} mbar as measured approximately 1 meter from the cavity on a Pfeiffer IKR070 Cold Cathode gauge. The impact of this leak was noted during the initial power rise on the cavity when vacuum excursions and RF breakdown in the cavity were noted at a peak field of 3 MV/m. After several days of RF processing it was possible to achieve a field of 20 MV/m with a radiation level of 11 μSv/hr, reduced from 7 mSv/hr earlier in the day, as measured 1.5 meters from the cryostat. The gains from RF processing were partially maintained from day to day suggesting that the processing was removing some of the helium gas that had adsorbed onto the cavity surface, as well as removing some of field emission sites.

The cavity was kept cold for approximately 1 month, during which time numerous other tests were performed. Towards the end of the testing period several Q vs. E curves were acquired using a calorimetric measurement to determine the power dissipated into the helium bath. The resulting curve can be seen in figure 4 along with the previous test data from JLab for comparison. To acquire this curve the cavity input power is set at a given power level and run c.w. for 10 minutes before progressing to the next data point. A LabVIEW program averages the relevant RF and cryogenic data over the 10 minute period, and these average values are used to prepare the Q vs. E curve.

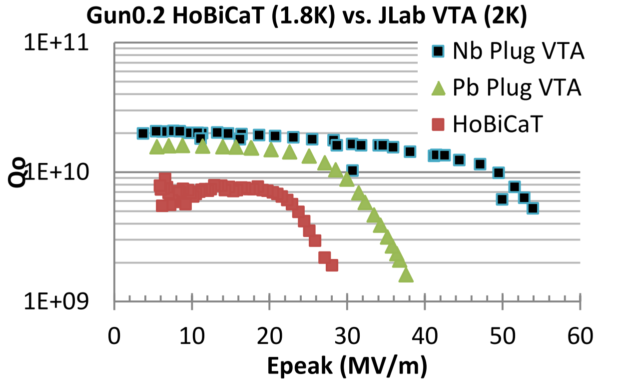

Figure 4. The Q vs. E_{peak} curve of Gun0.2 taken in HoBiCaT at 1.8 K compared to the data from the JLab VTA at 2K.

The cavity performance in HoBiCaT showed significant degradation compared to the previous tests at JLab. In HoBiCaT the cavity performance was limited at 28 MV/m due to repeated cavity quenching, which coincided with large vacuum spikes as well as significant temperature increases that were noted on the temperature sensors that was mounted to the cathode plug in the helium bath. The second item of note is the low field Q value of 7e9. This is significantly lower than was expected given the performance demonstrated at JLab and the fact that HoBiCaT is operated at 1.8K versus 2K at JLab, which alone should account for an approximately 2x increase in low field Q values, not a decrease. The most likely causes of this degradation in Q are the lack of magnetic shielding adjacent to the cavity and the helium leak into the beamline. The single layer of magnetic shielding in HoBiCaT does not protect the cavity from remnant fields from the tuner assembly, the stepper motor, or the other components inside HoBiCaT. Preliminary measurements of the residual magnetic field inside HoBiCaT following these tests revealed that one of the field probe cables, as well as the stepper motor both showed magnetic permeability greater than 2, while a few other components were greater than 1.3.

Additionally the tuning range of the cavity and the microphonics sensitivity were measured. The tuner has linear tuning range of 940 kHz, while the piezo tuner to cavity detuning transfer function, seen in figure 5, showed the lowest frequency resonance at 225 Hz, indicating that the cavity is easy to control with the LLRF system. The helium pressure sensitivity (δf/δp) is -151 Hz/mbar, the same order of magnitude, yet with the opposite sign, as a TESLA cavity.

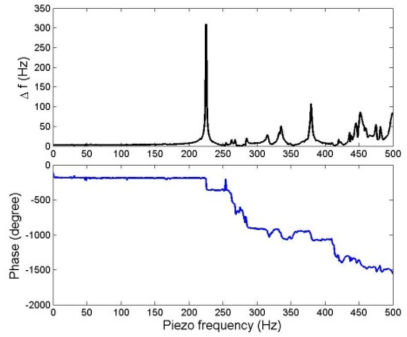

Figure 5. Piezo tuner to cavity detuning transfer function.

FUTURE PLANS

The future of Gun0.2 will require analysis of the Pb coating, repairing the leaks and improving the magnetic shielding for future horizontal tests in an attempt to achieve the same performance as in the JLab VTA.

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