FIRST CHARACTERIZATION OF A FULLY SUPERCONDUCTING RF PHOTOINJECTOR CAVITY*

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Abstract

As a first step towards a high brightness, high average current electron source for the B*ERL*inPro ERL a fully superconducting photo-injector was developed by HZB in collaboration with Jefferson Laboratory, DESY and the A. Soltan Institute. This cavity-injector ensemble is made up of a 1.6-cell superconducting cavity with a superconducting lead cathode deposited on the half-cell backwall. A superconducting solenoid is used for emittance compensation. This system, including a diagnostics beamline, has been installed in the HoBiCaT facility to serve as a testbed for beam dynamics studies and to test the combination SRF cavity and superconducting solenoid. This paper summarizes the characterization of the cavity in this configuration including Q measurements, dark current tests and field-stability analyzes.

INTRODUCTION

In the framework of the B*ERL*inPro Energy Recovery Linac project [1] HZB needs to develop a high current CW photoinjector delivering an average beam current of 100 mA at a normalized emittance of 1mm mrad and an exit kinetic energy above 1.5 MeV. To achieve these challenging goals HZB will follow a three stage approach [2]. The first step is a fully superconducting system of a 1.6 cell cavity, a superconducting lead photocathode and a superconducting solenoid. It is being developed in a collaboration with DESY, Jefferson Laboratory and the A. Soltan Institute. This photoinjector will be used to demonstrate the short-pulse beam dynamics in the ERL parameter range. This paper will give an overview about the horizontal cavity tests, dark current studies and beam energy measurements. An overview of the beam dynamic studies and quantum efficiency (QE) measurements is shown in [3].

* Work supported by Bundesministerium für Bildung und Forschung and Land Berlin

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Table 1: Cavity Electromagnetic Design Parameters

Frequency π-mode	1300 MHz
Frequency 0-mode	1281 MHz
E_{peak}/E_{cath}	1.0
E_{peak}/E_{acc} (β=1)	1.86
H_{peak}/E_{acc}	4.4 mT/(MV/m)
Geometry factor	212 Ω
R/Q (linac, β=1)	190 Ω
Q_{ext}	$1 \cdot 10^9$- $6 \cdot 10^6$

Cavity Design and Fabrication

The cavity electro-magnetic design is based on a 1.6 cell all SC structure originally designed by Jacek Sekutowicz (DESY) with a lead cathode deposited on the half cell's backwall [4]. The cell shapes are optimized for maximum field on the cathode surface to allow a high launch field. Table 1 gives an overview of the figures of merit. The cavity fabrication and optimization of the passive mechanical design to reduce microphonics detuning, as no tuning system was foreseen, is described in detail in [5] and [6]. Figure 1 shows both the gun cavity after full assembly and chemical treatment and first vertical tests at Jefferson Lab and (on the right) the cathode lead spot after plasma arc deposition at the A. Soltan Institute. After a final treatment the cavity was sent to HZB for installation into the horizontal test facility HoBiCaT [7].

HORIZONTAL RF MEASUREMENTS AND DARK CURRENT STUDIES

After installation of the cavity and beamline in the HoBiCaT shelter the first horizontal RF test was performed to compare these with Q_0 measurements in the vertical test stand at JLab. Figure 2 summarizes the most important measurements. It also depicts results before and after laser cleaning of the lead cathode with an excimer krypton-fluoride 248 nm laser.

The first vertical test of the fully assembled cavity

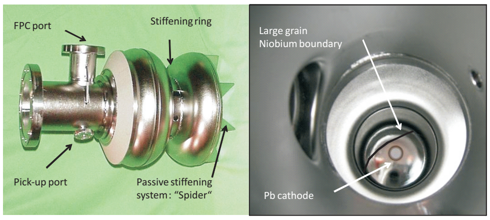

Figure 1: The picture on the left shows the 1.6 cell SC gun cavity after production and assembly of all ancillary components at JLab, the right picture shows the greyish lead cathode on the half cell backwall. The cavity is equipped with the TTF-III power coupler.

(without cathode) achieved excellent results with a field emission (FE) onset between 35-40 MV/m. The vertical test with the second cathode deposited[1] showed already a degradation of Q_0 down to $5-7 \cdot 10^9$ still allowing peak fields of 30 MV/m with an FE onset at 25 MV/m. The first horizontal measurement showed a further reduction of the Q_0 values down to $4 \cdot 10^9$ with FE onset at 12 MV/m peak field. The low-field Q_0 was even lower after another cooldown cycle, possibly the cold cavity collected residual gas of the beamline during cooldown. After the laser cleaning of the cathode the surface resistance not only recovered to the initial horizontal value, but also the onset of field

[1] The first was accidentally lost during the vertical tests and BCP/HPR treatments

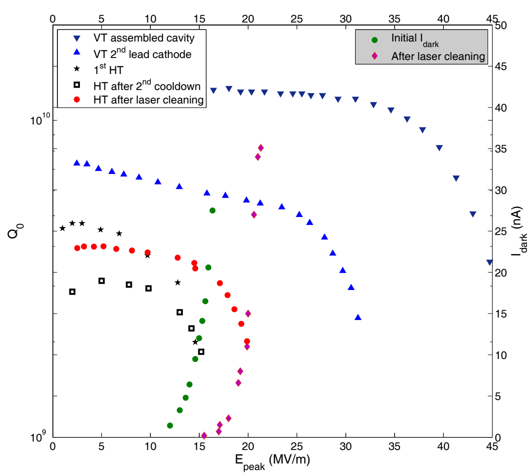

Figure 2: Measured unloaded quality factor versus peak electric field after cavity assembly and treatment in the vertical test (VT) stand (dark blue triangles) at JLab, after deposition of the second cathode (light blue triangles), the first horizontal test after installation and beam line assembly at HZB (black stars), after second cooldown at HZB (black boxes) and after laser cleaning of the lead cathode (red circles). The green and purple data points show the dark current before and after laser cleaning respectively.

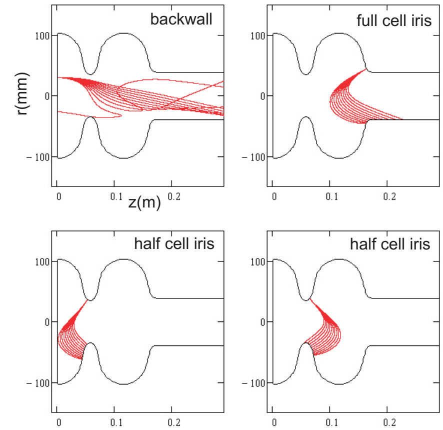

Figure 3: Tracking studies of possible dark current sources by V. Volkov for the 1.6 cell gun cavity.

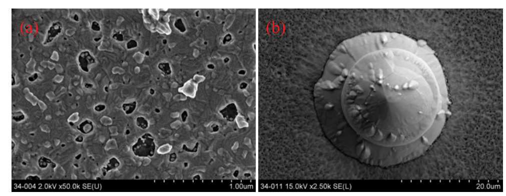

Figure 4: The pictures show SEM images (taken at FHI) of arc deposited lead samples by A. Soltan Institute similar to the gun cavity cathode. Small surface defects, droplets and tip on tip like structures in the 1-20 μm scale were observed.

emission was shifted to a much higher level of 18 MV/m.

Laser cleaning resulted in a reduction of the dark current and radiation dose from the cathode, suggesting that some field emitters were removed. Tracking studies by V. Volkov suggest that the only possible field emitter at high electric field regions which may contribute to the dark current is within the cathode area (see Figure 3). From this viewpoint laser cleaning of cavity niobium surfaces might be an interesting option, something we will try in the future.

Figure 4 [8] shows a SEM image of arc deposited lead films on a multigrain niobium surface which were produced by the A. Soltan Institute in the same way as the lead cathode. Droplets and tip on a tip like structures [9] on the 1-20 μm scale were detected, possible candidates for strong field emitters. Possibly the laser cleaning process leveled these field emitters, an observation supported by a Nordheim-Fowler fit to the dark current data. A reduction of the field enhancement factor was determined.

CAVITY FIELD TRIPS

During beam operation at different field levels frequent cavity field trips were observed when illuminating specific spots on the cathode with the drive laser. Simultaneously

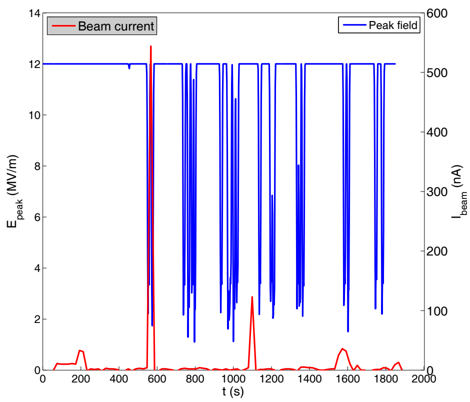

Figure 5: E_{peak} and average beam current versus time during the observation of cavity field trips at specific cathode positions. Sometimes currents above 500 nA were observed.

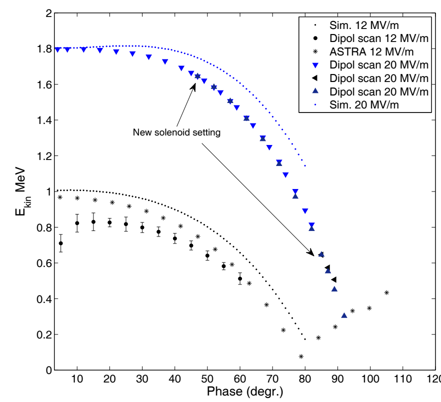

Figure 6: Measured beam kinetic energies for 12 and 20 MV/m launch field versus phase compared to ASTRA and longitudinal tracking simulations.

significant electronic activity was observed on the screens. It was shown, that these spots inhibited a stronger fluorescence in the visible range by observing the cathode with the CCD cathode camera. Sometimes increased average beam currents of above 500 nA were measured just in coincidence with a field trip (Figure 5). Measuring the time constant of the transmitted power probe signal during such an event ruled out a cavity trip by a quench of the superconductor. Merely the strong beam current emitted in a short time interval extracts too much energy of the accelerating mode such that the LLRF system cannot supply enough RF power and the field trips within hundreds of ns.

This effect was further investigated by stepwise increasing the laser pulse energy from the lowest possible energy where still some current above the resolution limit of the Faraday cup could be detected. It was shown that below a certain threshold pulse energy no trip occurred. Furthermore, above that level the time after which a trip occurred depended on the laser power level. Also the beam current was at a level as expected from the QE at these spots. Only during the trip the beam current increased to several hundred nanoamperes.

Interestingly, the such processed cathode spot showed less fluorescence after this measurement without a significant change of the QE.

FIELD STABILITY AND BEAM ENERGY

The cavity was operated CW at peak field levels between 10 and 20 MV/m at loaded quality factors of $1.4{\cdot}10^7$ down to $6.6{\cdot}10^6$. The rms detuning seems to be slightly increased at a higher field level ranging from 5-7 Hz, but probably this is mainly due to the increased cavity-loop system bandwidth at the lower Q_L. Field stabilities of better than 0.02 degrees in phase and $1.2{\cdot}10^{-4}$ in relative amplitude error were achieved.

Figure 6 displays two scans of the beam energy over launch phase at 12 and 20 MV/m field at the cathode. The obtained result were reconstructed with a self written longitudinal tracking code and ASTRA [10] simulations. It was not fully possible to fit the curvature of the measurement which did not show the small local maximum at a phase of about 30 degrees for 20 MV/m, even when taking into account the imperfect field flatness. For the next measurements a careful calibration of the dipole and the cavity field level and phase is foreseen.

OUTLOOK

Lessons learned with this cavity will be incorporated in the RF design of the future B*ERL*inPro injector cavity, optimizing the cavity shape for higher launch phases.

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