CW SUPERCONDUCTING RF PHOTOINJECTOR DEVELOPMENT FOR ENERGY RECOVERY LINACS

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Abstract

ERLs have the powerful potential to provide very high current beams with exceptional and tailored parameters for many applications, from next-generation light sources to electron coolers. However, the demands placed on the electron source are severe. It must operate CW, generating a current of 100 mA or more with a normalized emittance of order 1 μm rad. Beyond these requirements, issues such as dark current and long-term reliability are critical to the success of ERL facilities. As part of the B*ERL*inPro project, Helmholtz Zentrum Berlin (HZB) is developing a CW SRF photoinjector in three stages, the first of which is currently being installed at HZB's HoBiCaT facility. It consists of an SRF-cavity with a Pb cathode and a superconducting solenoid. Subsequent development stages include the integration of a high-quantum-efficiency cathode and RF components for high-current operation. This paper discusses the first stage towards an ERL-suitable SRF photoinjector, the present status of the facility and first cavity tests.

INTRODUCTION

The planned ERL demonstrator project at HZB, B*ERL*inPro [1], places high demands on the operational parameters of the SC photoinjector. It must operate CW at a high laser pulse rep rate of 1.3 GHz to generate a beam current of 100 mA with a normalized emittance of 1 μm rad. This implies the usage of a normal conducting cathode, operate at peak fields as high as possible to reduce space charge dominated emittance growth and thus couple power in the 100 kW regime to the cavity to compensate the strong beam loading. The electro-magnetic design should allow high peak fields at the cathode region and an exit energy above 1 MeV, also the avoidance and damping of higher order modes needs to be studied. Further, the mechanical design has to be optimized to achieve low microphonics detuning of the cavity and therefore a high field stability in amplitude and phase. To achieve this complex design with these manifold requirements HZB follows a three stage approach [2]. The first stage is an all superconducting photoinjector based on the design described in [3]. The cavity is a 1.6 cell TESLA shaped design with a about 3mm diameter lead spot as a cathode on the 0.6 cell backwall. This cavity will be used to demonstrate the emittance compensation scheme using a SC solenoid, evaluate the solenoid's location and its effect on the cavity performance. The electro-magnetic parameters of the cavity are summarized in Table 1.

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Table 1: Cavity Electro-magnetic Design Parameters

Frequency π-mode	1300 MHz
E_{peak}/E_{acc} (β=1)	1.86
H_{peak}/E_{acc}	4.4 mT/(MV/m)
Geometric factor	212 Ω
R/Q (linac, β=1)	190 Ω

CAVITY DESIGN AND FABRICATION

The cavity was fabricated and tested at Jefferson Lab. Figure 1 displays pictures of the cavity 0.6 cell's backwall with the stiffening bar design, the multi-grain niobium half-cells, the large grain niobium backwall, the tuning setup and the fully assembled cavity with beampipe, coupler ports and helium vessel endplate. As the cavity

Figure 1: Top left: Cathode backwall with "spider" stiffening bars, top right: Cavity half-cells and large grain Niobium backwall, lower left: Cavity tuning setup at JLab, lower right: Fully assembled cavity with helium vessel endplate and coupler ports.

was designed without a tuning scheme special emphasis was laid on the mechanical design to lower the mechanical detuning, such improve the expected field stability and thus allow meaningful studies of the beam parameters. Mechanical ANSYS^{TM} simulations complemented by electromagnetic field simulations evaluated the optimum mechanical design for a low detuning. Figure 2 depicts the deformation of the upper half of the cavity backwall at 1.8 K and 16 mbar for different stiffening designs. The material parameters for large- and multi-grain Niobium were taken from [4, 5]. The resultant deformation were included into different electro-magnetic field codes to calculate the dependency of the cavity detuning to helium pressure fluctuations of the 1.8 K helium bath, a main error source for CW cavity detuning [6]. The results are given in Table 2.

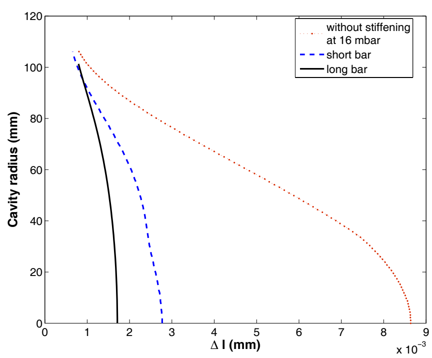

Figure 2: ANSYS^{TM} simulations of backwall deformations at 1.8 K, 16 mbar and cavity under vacuum for various stiffening configurations (Note that the final spider configuration is better than the long bar but is not shown). The abscissa depicts the longitudinal deformation and the ordinate the cavity radius from the cathode region to the equator of the 0.6 cell.

To even perform better a "spider"-like design of the long stiffening bars had been constructed. Measurements of the static detuning to pressure dependency showed an improvement of a factor of three compared to the short bar design. Also the static Lorentz-force detuning constant $\Delta f / E^2_{\text{peak}}$

Table 2: Helium Pressure Dependency in Hz/mbar for Different Backwall Stiffening Methods as Measured and Calculated.[1]

Type	JS	SuperFish	CST MWS	measured
without	662	527	615	-
short bar	199	200	-	474
long bar	131	130	-	-
spider	-	-	-	146

had been measured as 1.33 Hz/(MV/m)^2. In total the simulations seem to underestimate the detuning compared to the measured properties.

[1] JS: Calculations by J. Sekutowicz, SuperFish: Poisson Superfish LANL, CST MWS: CST Microwave Studio^{TM}

CATHODE DEPOSITION

The Pb cathode is deposited on the large grain Niobium half-cell backwall by means of Plasma arc deposition. The setup at the A. Soltan Institute is shown in Figure 3. The cavity is installed in a 30 degrees angle to the plasma source to avoid the formation of droplets while still allowing a quite high lead deposition efficiency. After up to 16 short deposition runs of about 5 minutes typically a lead cathode with a thickness of about 0.5 µm and a 3 mm diameter has formed. The right picture shows the inner cavity surface with the lead cathode on the large grain Niobium backwall in the center. The cathode is located within a single crystal lattice domain to have an isotropic thermal contact between the lead cathode and the backwall. After the deposition and

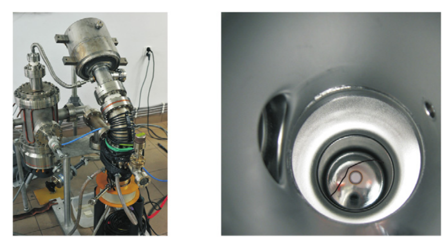

Figure 3: Left: Setup at Swierk for plasma arc deposition of the lead cathode in a 30° configuration between source and deposition target area. Right: Picture of the inner cavity surface after deposition of the lead cathode. The cathode is visible as a greyish spot in the middle of the backwall next to the visually emphasized grain boundary.

inspection of the cathode, the cavity was sent to the JLab for the final BCP and high pressure rinsing treatment, following the final vertical tests and assembly of the couplers.

CAVITY VERTICAL TESTS

The following overview of the cavity vertical tests at JLab shows the history of the cavity fabrication and corresponding tests during the production steps. The cavity was tested first after the assembly and welding of the cells, tuning and a BCP-high pressure water rinsing treatment. This quality factor versus peak electric field measurement is shown in Figure 4 by the blue-dotted curve. At that time the cavity had a field flatness of only 66%. Further tuning and another BCP treatment resulted in an improvement of the RF performance (grey squares) with $Q_0 \geq 1 \cdot 10^{10}$ for $E_{\text{peak}} \leq 35$ MV/m. Also the field flatness was improved to 94%. Another test was done after the installation of the helium vessel. There was no significant change in RF performance. The curve degrades in Q_0 for fields above 35 MV/m due to slight field emission. After that successful reference test the cavity was sent to Poland for the cath-

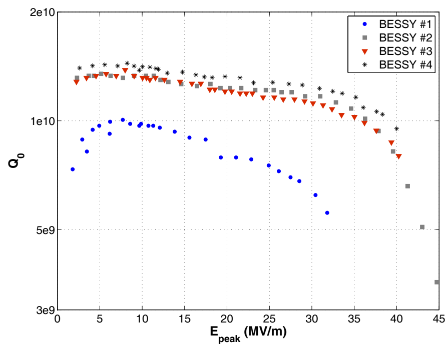

Figure 4: Cavity vertical tests after assembly (♯1), further tuning and cleaning (♯2), after following installation of the helium vessel (♯3) and after loss of the lead cathode and removal of remnants by grinding and BCP (♯4).

ode deposition (see the cathode Section). The lead cathode was deposited and after optical inspection showed the typical greyish color. Back at the Jefferson Lab. another inspection showed a yellowish color of the cathode hinting at some Pb_yO_x contamination. The cavity was again etched with a BCP treatment to remove the remnants of the plasma deposition from the cavity surface. The cathode is thereby covered by a special protective mask which also defines the final diameter of the cathode. During the first vertical

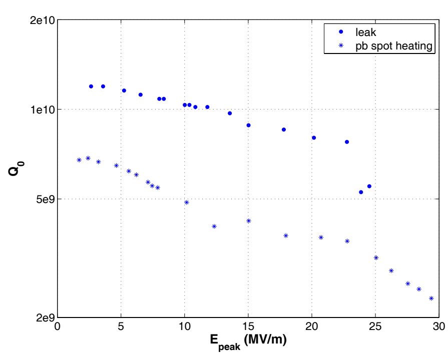

Figure 5: Cavity vertical tests after the lead coating and further cleaning. The blue dot curve shows a test where a vacuum leak occurred. The second test with sealed conditions showed a degradation of Q_0 with the field and also the temperature at the cathode position was abnormally high.

RF test (Figure 5) a vacuum leak was observed and thus the Q_0 obviously degraded. But also a second test under sealed conditions resulted in a low Q_0 at lower fields and a strong degradation of the curve to higher fields. In parallel a temperature sensor at the cathode position showed abnormal high temperatures. Possible reasons might be a bad thermal contact between the lead cathode and the Niobium surface leading to heating and a local quench. After a following high pressure water rinsing a optical inspection showed a total loss of the cathode. To fully clean the backwall to prepare for another cathode deposition the backwall was ground, etched again with BCP and high pressure water rinsing. A vertical test soon after proved a fully recovered RF performance (Figure 4 red triangled curve).

In the meantime the cavity was for another successful coating in Poland and will be tested again in the next weeks in the vertical test stand at the Jefferson Lab.

OUTLOOK

The cavity will undergo a vertical testing after final treatment to remove the remnants of the cathode deposition. Following the cavity will be send to the HZB to be installed

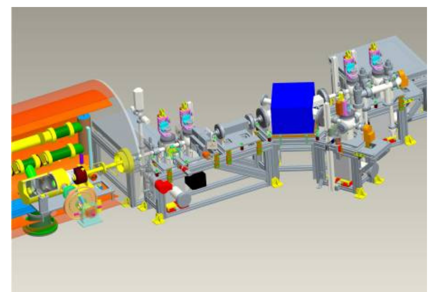

Figure 6: Setup of the gun cavity in the HoBiCaT cavity test facility and the new diagnostic beamline.

in the HoBiCaT cavity horizontal test facility including a SC solenoid and a warm section with a diagnostic beamline. First horizontal RF tests are expected to start this autumn.

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