SRF PHOTOINJECTOR CAVITY FOR B*ERL*inPro *

A. Neumann†, W. Anders, A. Burrill, A. Frahm, T. Kamps,
J. Knobloch, O. Kugeler - Helmholtz-Zentrum Berlin, Berlin, Germany
E. Zaplatin - FZJ Jülich, Jülich, Germany

Abstract

For the funded B*ERL*inPro project, a 100 mA CW-driven SRF energy recovery linac (ERL), a SRF photoinjector cavity has to be developed which delivers a small emittance, 1 mm*mr @ 77 pC, high brightness beam while accelerating a high average current within given high power limitations. To achieve these goals the injector is being developed in a three stage approach. In the current design step a cavity shape was developed which fulfills the beam dynamics requirements, implements a high quantum efficiency (QE) normal conducting photocathode with the HZDR choke and insert design and allows for beam studies at currents up to 4 mA. This paper will describe the RF design process, higher order mode studies and the final layout for the cavity production at JLab.

GUN 1, A FIRST STEP TOWARDS 100 MA

The B*ERL*inPro ERL will be a prototype facility demonstrating energy recovery with a 100 mA beam at 50 MeV energy while preserving a normalized emittance of better than 1 mm mrad at a pulse length of 2 ps [1]. This accelerator is based on superconducting RF accelerator technology operated in continuous wave mode (CW). This high brightness at high average current goal places stringent requirements on the performance of the SRF photoinjector cavity. Besides the combination of a cavity with good HOM damping capabilities and optimized to meet the B*ERL*inPro beam dynamic requirements, a major issue of a high current ERLs is beam loss and halo formation by dark current. The injector cavity must therefor deliver low dark current levels, which is partially in contradiction to have a low work function cathode [2] and high launch fields during emission to counteract space charge driven beam expansion [3].

In order to address different challenges of SRF injector cavity design and operation, HZB has followed a three stage approach of different cavity systems:

1. *Gun0*: A fully SC system with a lead cathode arc deposited on the back wall allowing beam studies while avoiding the complicated insert of a high QE normal conducting (NC) cathode in a SC environment. Results are published in [4–8]

2. *Gun1, this paper*: A beam dynamic optimized design with an HZDR-style cathode insert system [9] allowing operation up to 4 mA. It should demonstrate B*ERL*inPro bunch parameters, serve as a HOM study test system and allow the usage of a high QE NC cathode within a SC environment.

3. *Gun2*: Lessons learnt from the *Gun1* design will be implemented, it will feature two modified KEK c-ERL high power coupler [10] to allow 100 mA average current operation.

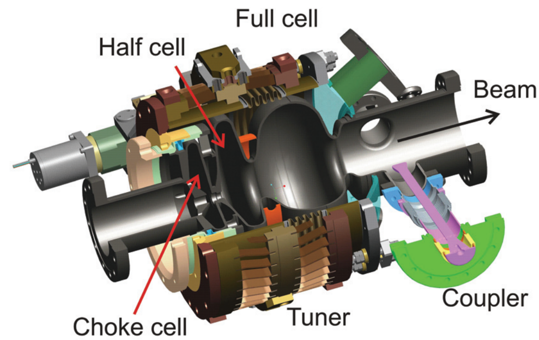

Figure 1: Drawing of the SRF photo-injector cavity with the cavity, beam tube, choke cell and cathode insert in silver grey. Also shown are ancillary components such as the helium vessel, blade tuner, stiffening ring and CW-modified TTF-III coupler.

RF design and ancillary equipment

An overview of the cavity and helium vessel is given in Figure 1. It shows the cavity with the choke cell and cathode insert followed by the enlarged beam tube, to allow HOM propagation to the absorber following downstream the coupler port and SC solenoid. The cavity will be equipped with a blade tuner, featuring a stepper motor for coarse and piezos for fine tuning. For operation up to 4 mA beam current, the cavity will be powered by two CW-modified TTF-III couplers [11], allowing 10 kW power each. The stiffening ring position was optimized to have low helium pressure sensitivity, see [12].

Figure 2 depicts the setup of the injector cavity for RF simulations using Superfish [13] for RF optimization and CST MWS [14] to study non-symmetric effects as e.g. coupler kicks. The RF cavity design was driven by the aim to allow a beam extraction at a high local field on the cathode during the laser pulse while the beam energy is fixed to 2.6 MeV. Achieving high field components at the cathode by RF design is not sufficient. These calculations needed to be accompanied by particle tracking to consider transit time effects. A particle tracker and an automated Superfish call was implemented in a Matlab^{TM} program to use

* Work supported by Bundesministerium für Bildung und Forschung and Land Berlin
† Axel.Neumann@helmholtz-berlin.de

ISBN 978-3-95450-122-9

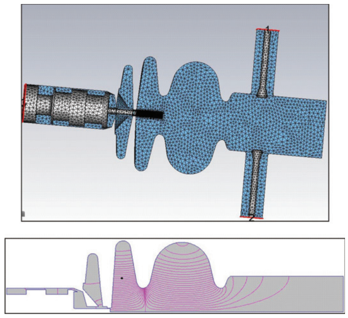

Figure 2: Setup of the cavity geometry for RF simulation with CST MWS and Superfish including the Choke cell and Petrov filter for studies of cathode retraction.

optimization schemes for achieving high emission phases of the RF field for maximum kinetic energy at a given RF power constraint. This resulted in a 1.4 cell design, as described in [15].

Field distribution

Figure 3 shows the longitudinal and transverse electric field components versus z for different cathode positions relative to the backwall.

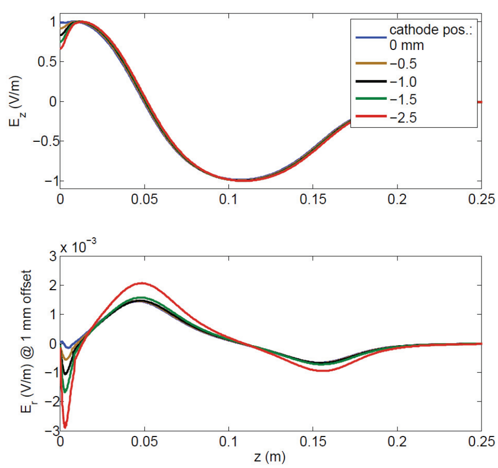

Figure 3: Longitudinal electric field component at r=0 and radial electric field at r=1mm versus z for different cathode positions.

Table 1 summarizes the RF and operational properties of the cavity as expected by the simulations. The calculated dependance of beam energy with respect to launch phase and maximum on-axis field E_0 was bench-marked by measurements with *gun0* [5], [7]. The field distribution was optimized such, that there is maximum on-axis field as close as possible to the cathode, but not on the cathode itself. This helps to minimize the danger of field emission (FE) and results in radial field components for initial focussing. Due to manipulation of the arc shape merging the skew back wall with the cathode opening, the electric peak field was moved from there to the center iris (Figure 4).

Table 1: Cavity figures of merit for the TM_{010}-π mode of injector cavity1 at E_0= 30 MV/m and cathode retracted from 0-2.5mm. Note, that Q_{ext} is optimized for 4 mA beam current.

Parameter	Cavity 1.1
$R/Q(\Omega)$	150-149.5
E_{peak}/E_0	1.5-1.45
$E_{cathode}/E_0$	1-0.58
H_{peak}/E_{peak} (mT/(MV/m))	2.2
$\Phi_{launch}(E_{kin,max})$ (deg.)	60-50
E_{launch} (MV/m)	26-13.3
E_{kin} (MeV)	2.6
k_{cc} (%)	1.6
Q_{ext}	$3.6 \cdot 10^6$
$f_{1/2}$(Hz)	185
$P_{forward}$ (kW)	8.4
Δf_{peak} (Hz)	20 (expected)

The latter being a position where FE current less probably leaves the structure with the beam. Figure 5 shows gained

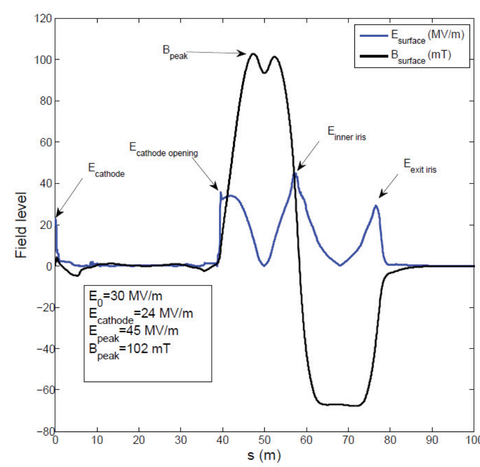

Figure 4: Surface electric and magnetic field of the gun cavity including cathode stock and choke cell normalized to maximum on-axis field E_0 of 30 MV/m versus surface path length s starting from the cathode, through the Petrov/choke filter part and finally the cell surfaces.

kinetic energy versus emission phase for E_0=30 MV/m using the tracking code and CST's PIC solver for 1.5mm cathode position. A maximum is at 55 degrees with 2.6 MeV. Dark current emitted around 90 degrees phase, most probably from or next to the cathode will leave the structure with 1.5-2.4 MeV.

Retraction of the cathode allows for stronger RF focussing of the beam during extraction by the laser pulse, but leads to a slight decrease of the normalized shunt impedance R/Q from 150 to 149.5 Ω and further decreases the ratio cathode field to maximum on-axis field from about 1 to 0.58. The launch phase for maximum energy gain is shifted by 10 degrees from 60 at zero position to 50 at the 2.5 mm position. This reduces the effective launch field by 49%, but the dark current emitted from the cathode by about a factor of eight according to the Fowler-Nordheim (β_{FN}=1) equation. Nevertheless, as depicted in Figure 6,

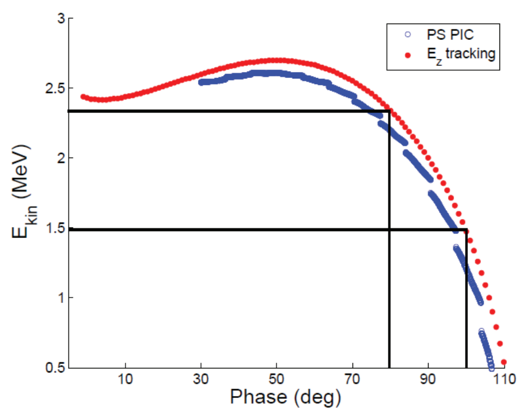

Figure 5: Comparison of kinetic energy versus emission phase at E_0=30 MV/m for several bunches (blue) using a simple tracking program compared to CST's PIC Solver. The black lines denote a possible phase and resulting energy range of field emitted dark current near the cathode.

shifting the cathode too much leads to an overlap of the choke and π-mode frequency. Thus tuning of the choke cell is mandatory in order to avoid high losses, discharges or multipacting in the cathode insert section.

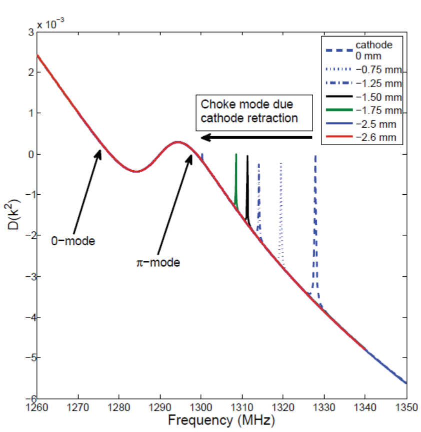

Figure 6: $D(k^2)$ function of Superfish showing the TM_{010} monopole passband and the resonance of the choke structure, which varies with the cathode position. At -2.6 mm position the π-mode and choke mode overlap.

HOM Studies

HOM studies are performed combining 2-D codes, such as Superfish and SLANS/CLANS with 3-D simulations. Figure 7 shows the long. and transverse normalized shunt impedance R/Q up to 3 GHz. There is a strong dependance of the R/Q on the evolution of β within the RF gap. Whereas in this design the beam tube was chosen such to theoretically propagate all HOMs, studies with this cavity will show, whether a reduction of the beam tube is possible for future designs, allowing more efficient solenoid designs.

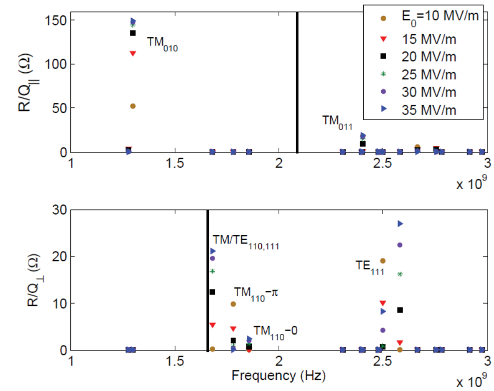

Figure 7: Longitudinal and transverse R/Q for different peak on axis fields E_0 obtained by integrating the Lorentz forces in steps with respect to $t = z/(\beta(t)c)$. The black lines denote the TE_{11} and TM_{01} cutoffs of the beam tube.

OUTLOOK

The design for this cavity is finished and the construction of the cryo-module is being finalized. Currently the first dies for the half cell manufacturing are produced at JLab, so that the first vertical RF tests may be expected for this summer. In the meantime studies for the high power injector cavity have started.

REFERENCES

[1] J. Knobloch et al., ICFA Beam Dynamics Newsletters, No.58, p. 118, August 2012,

[2] R. Barday et al., MOPFI001, this conference

[3] T. Kamps et al., Proc. of LINAC'12,2012.

[4] P. Kneisel et al., Proc. of PAC'10, 2010.

[5] A. Neumann et al., Proc. of IPAC'11, 2011.

[6] T. Kamps et al., Proc. of IPAC'11, 2011.

[7] M. Schmeisser et al., MOPFI002, this conference

[8] A. Burrill et al., WEPWO002, this conference

[9] A. Arnold et al., NIM A, Vol. 593, Iss. 12, 1 August 2008, Pages 57-62, DOI 10.1016/j.nima.2008.04.035.

[10] S. Noguchi et al., Proc. of IPAC'10, 2010.

[11] O. Kugeler et al., Proc. of SRF'09, 2009.

[12] E. Zaplatin et al., WEPWO009, this conference

[13] K. Halbach and R.F. Holsinger, SUPERFISH - a computer program for evaluation of RF cavities with cylindrical symmetry, Part. Acc., 7:213222, 1976

[14] CST AG, Microwave Studio®, 64289 Darmstadt, Germany `http://www.cst.com`

[15] A. Neumann et al., Proc. of LINAC'12, 2012.

ISBN 978-3-95450-122-9