PHOTOINJECTOR SRF CAVITY DEVELOPMENT FOR B*ERL*inPro *

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Abstract

In 2010 HZB has received approval to build B*ERL*inPro , an ERL project to demonstrate energy recovery at 100 mA beam current by pertaining a high quality beam. These goals place stringent requirements on the SRF cavity for the photoinjector which has to deliver a small emittance 100 mA beam with at least 1.8 MeV kinetic energy while limited by fundamental power coupler performance to about 230 kW forward power. In oder to achieve these goals the injector cavity is being developed in a three stage approach. The current design studies focus on implementing a normal conducting cathode insert into a newly developed superconducting photoinjector cavity. In this paper the fundamental RF design calculations concerning cell shape for optimized beam dynamics as well as SRF performance will be presented. Further studies concentrate on HOM properties, the field-flatness and tuning mechanism for that design.

REQUIREMENTS TO THE CAVITY DESIGN

The B*ERL*inPro ERL will be a prototype facility demonstrating energy recovery with a 100 mA beam at 50 MeV beam energy while preserving a normalized emittance of better than 1 mm mrad at a pulse length of 2 ps or less [1]. This machine will make fully use of superconducting RF technology operated in continuous wave (CW). The injector has to deliver a high brightness beam at a high repetition rate, filling every RF bucket, a low emittance allowing for emittance compensation and a compression of the longitudinal phase space in the ps regime. At this high average current also higher order mode excitation and damping have to be considered as well as coupling strongly to the fundamental. The high beam brightness will be achieved by inserting a high quantum efficiency normal conducting semi-conductor cathode within the SC environment of the cavity. This cathode insert will mainly rely on the design by HZDR used in the ELBE SC 3.5 cell injector cavity [2]. As these are demanding goals, the injector and cavity are developed in a three stage approach. First results of an all superconducting gun cavity with a SC lead cathode were published in [5][6].

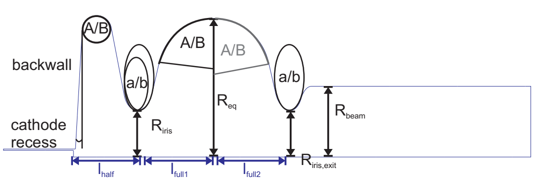

Figure 1: Geometry design parameters used for the cavity optimization scheme.

RF DESIGN STUDIES

The gun cavity has to fulfill several objectives while limited by some fundamental boundary conditions. The available total power will be limited to about 230 kW by using two KEK-style [3] fundamental power couplers (FPC), whereas the maximum electric peak field E_{peak} was recently demonstrated to reach 45 MV/m [4]. To name a few, regarding SRF and beam based properties the injector cavity has to be designed regarding the following aspects:

- Minimize E_{peak}/E_0 with $E_{\text{cathode}} < E_0$: This maximizes the field during beam extraction $E_{\text{launch}} = E_{\text{cathode}} \cdot \sin\Phi$ compared to the field anywhere on the surface E_{peak}, while it might be helpful to have the maximum on-axis field E_0 away from the cathode to reduce the probability of dark current.
- Minimize $H_{\text{peak}}/E_{\text{peak}}$ and maximize R/Q to minimize losses. Consider the cutoff of the beam tube and iris diameter for a compromise between R/Q and HOM propagation and cell-to-cell coupling.
- The resonators length determines the launch phase Φ and field level during emission and thus energy gain and emittance. Thereby it also defines the field level for the field emitted dark current at about $\Phi = 90 \pm 20$ degrees.
- Transverse beam properties are influenced by the field during emission (>10 MV/m [7]) as by the transverse focussing due to e.g. retraction of the cathode, backwall inclination and the transverse field component when the bunch leaves the RF structure.

Figure 1 shows the geometric parameters used in this work to run different optimization steps to converge to a suitable design. The design iteration was done by implementing different optimization schemes, like golden section search and Nead-Melder Simplex algorithms within a MATLAB™ wrapper to run the 2-D RF field solver Superfish [8]. The obtained fields were used in the same loop to perform a first field-phase scan of the longitudinal phase space using a simple self written tracking code. Following, a set of candidates were included in ASTRA-based [9] beam dynamics simulations including the solenoid or the whole injector

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chain of B*ERL*inPro . The outcome of these calculations delivered the feedback for further changes to the cavity's geometry.

Half-cell optimization

In a first iteration the half-cell was optimized to maximize the launch phase via a scan of the half cell's length taking transit time effects into account. Figure 2 shows the launch phase for maximum energy gain for half-cells varying from 0.4-0.6 $\lambda/2$. The 0.4 cell design shows the best performance with respect to launch phase, as all of them after fine tuning achieved comparable RF properties. Going to even shorter half-cells was omitted due to mechanical stability and peak field considerations. As can be seen in Table 1 the resultant E_{launch} of a pure 0.4 design is still rather low. Hence another full cell, starting from a TESLA shape, was added to the design. As can be seen in the energy-field-phase scan presented in Figure 3, a 1.4 cell design features a quite high launch field making full use of the offered 230 kW at $E_0 = 30$ MV/m. The corresponding field distribution is shown in Figure 4. A 1.X cell design has the further advantage, that the dark current emitted at field maximum on the cathode still can propagate out of the cavity which limits the danger of back bombardment.

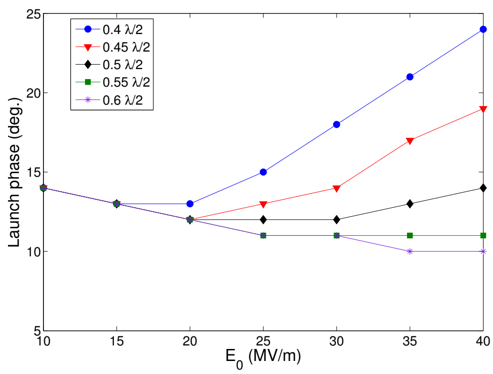

Figure 2: Energy-phase-field scan vs. half-cell length showing the phase with the highest energy gain in the half-cell.

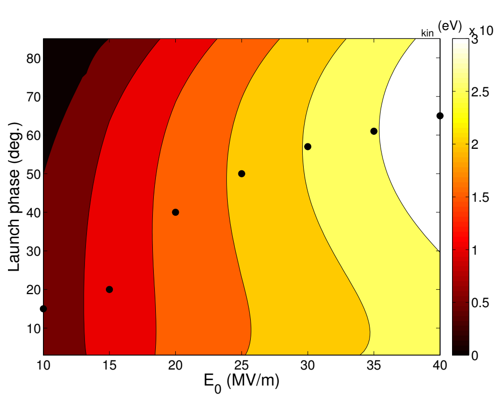

Figure 3: Energy-phase-field scan of a 1.4 cell cavity. The black dots denote the phase with the maximum energy gain at the given maximum on-axis field E_0.

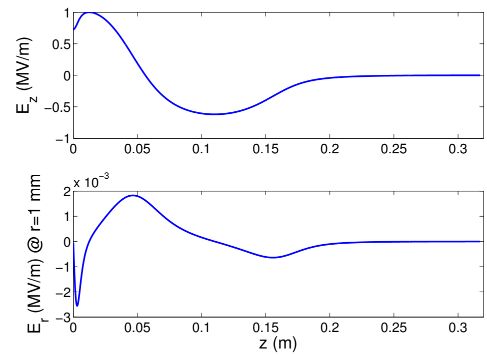

Figure 4: Field distribution (E_z, E_r) of a 1.4 cell gun cavity design with 35 mm exit iris and 53 mm beam tube radius.

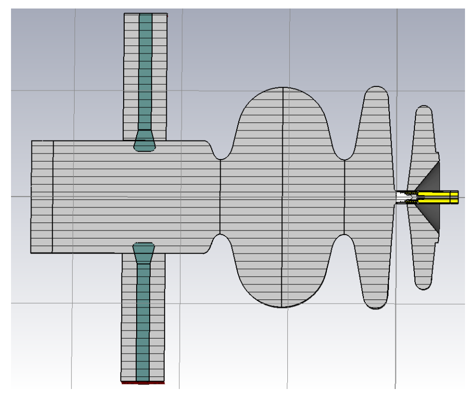

Figure 5: Possible design of the next 1.4 cell gun cavity featuring the HZDR-style choke cell, a modified cathode stock, two TTF-III type FPC having a 35 mm exit iris.

Figure 5 shows the current design for the next gun cavity which should demonstrate a beam of some mA using two modified TTF-III FPCs [10]. This cavity will mainly be used to study the cathode insert mechanism within the SC environment, beam dynamics and the HOM properties.

CELL TUNING

Preliminary investigations of the cell mechanical properties (the structure without helium vessel and any stiffening rings) showed that by simultaneous tuning of both cells E_z along the beam path varies within 2%. At the same time because of the cell deformations under external LHe pressure the field profile in the 0.4-cell changes up to 10%. With an installation of stiffening rings there are possibilities to find ring positions that the total effect of external pressure applied on the whole cavity and liquid helium vessel walls results in nearly complete compensation of the frequency shifts caused by cavity and vessel wall deformations (df/dp is close to zero, Figure 6). For df/dp=0 the field profile change is within 5%, being near the accuracy limit of that calculation.

Table 1: Cavity figures of merit for the TM_{010}-π mode of three gun cavity options at E_0= 30 MV/m and cathode retracted by 1.5mm. Note, that Q_{ext} relates to the limit in total forward power of 230 kW. All values are for β =1 as calculated by Superfish.

Parameter	0.4 cell	1.4 cell 35 mm exit iris	1.4 cell 40 mm exit iris
$R/Q(\Omega)$	93	151	146
E_{peak}/E_0	1.5	1.5	1.57
$E_{cathode}/E_0$	0.75	0.75	0.75
H_{peak}/E_{peak} (mT/(MV/m))	1.9	2.2	2.1
$\Phi_{launch}(E_{kin,max})$ (deg.)	18	52	50
E_{launch} (MV/m)	6.9	17.7	17.3
E_{kin} (MeV)	1.2	2.67	2.6
k_{cc} (%)	-	1.6	1.5
Q_{ext} at 100 mA	$1.44 \cdot 10^5$	$1.52 \cdot 10^5$	$1.58 \cdot 10^5$

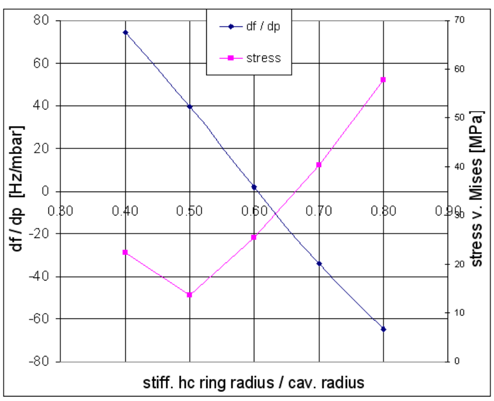

Figure 6: Detuning vs. LHe pressure coefficient and v. Mises stress versus position of a stiffening ring for the 1.4 cell design.

OUTLOOK

The current design work focusses on studying 3-D aspects using CST MWS [11] of the gun cavity design including optimizing the FPC's position and beam tube size for a minimized coupler kick by the fundamental to the beam while preserving the HOM damping capabilities. Further studies aim for calculation of the HOM losses and damping, especially taking the $\beta(z,t)$ dependent loss factor into account as depicted in Table 2. Beam dynamics based tolerance studies have to show how susceptible the beam properties are with respect to field flatness variations with respect to cavity tuning to decide whether two independent tuners for each cell are needed.

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Table 2: Launch field dependent $R/Q(\Omega)$ of the TM monopole modes

f (MHz)	$R/Q_{\parallel}$ ($\beta = 1$)	$R/Q_{\parallel}$ E_0=16MV/m	$R/Q_{\parallel}$ E_0=30MV/m
1270	59	4.9	0.51
1300	150	125	147
2403	16.1	3.0	14.8
2510	49	24.9	20.8
2663	36.8	3.5	0.9
2750	28.6	3.5	0.04

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