3½ CELL SUPERCONDUCTING RF GUN SIMULATIONS*

C.D. Beard, J.H.P. Rogers, CCLRC Daresbury Laboratory, Warrington, UK
J. Teichert, F. Staufenbiel, Forschungszentrum Rossendorf, Dresden, Germany

Abstract

This work forms part of the European Framework (EuroFEL) to carry out a design study for an injector for free electron laser. The objective of this task is to develop a superconducting gun capable of accelerating 100 mA to 10 MeV with sufficiently low emittance. The development work is initially based on the 3½ cell superconducting RF photocathode gun developed at Forschungszentrum Rossendorf (FZR). The FZR gun is designed for CW operation mode producing a 1 mA average current of 1 nC electron bunches accelerated up to energy of 9.5 MeV and is due to be installed at the ELBE superconducting electron linear accelerator [1]. The gun has a 3½ cell niobium cavity operating at 1.3 GHz. The cavity consists of 3 TESLA-type cells and a specially designed half-cell in which the photocathode will be placed. Typical ERL-based projects require ~100 mA average current, and therefore suitable upgrade paths are required. Simulations have been carried out to evaluate the design and to determine suitable ways to upgrade for higher current operation. In order to optimise beam transport and minimise beam emittance growth an alternative shape for part of the cavity around the cathode is proposed. Coupler issues have also been investigated. All the investigations that have identified possible solutions to higher current operation are discussed in this article.

INTRODUCTION

As part of the EuroFEL R&D, there is a requirement to produce a detailed study of superconducting RF photo-injectors and to develop a design capable of producing a 100 mA beam with adequate beam emittance.

In order to carry out this investigation a detailed study of the FZR gun has been carried out to verify the simulations techniques adopted. An expansion of this work is then required to evaluate proposed design changes for higher current.

The limitations of the existing gun design have been addressed and operational techniques have been highlighted in this paper that may allow higher beam currents to be delivered by superconducting RF injectors.

* Work partially supported by the EU Commission in the sixth framework programme, EuroFEL contract no 011935 and RII3-CT-2003-506395

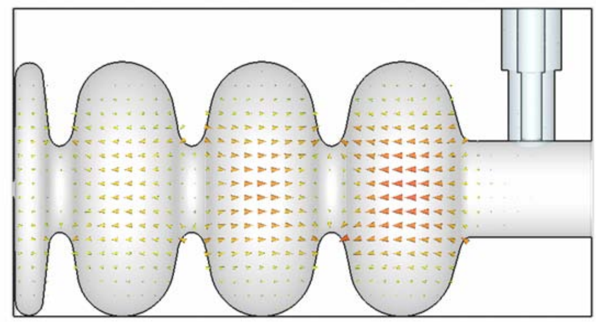

Figure 1: Profile of the electric field in the SCRF gun as calculated with the CST code.

RF SIMULATIONS

Full 3D RF simulations of the cavity and coupler have been carried out with the CST Microwave Studio electromagnetic solver™ The predicted frequencies were in agreement to within 100 kHz (0.1%) of earlier calculations made using the Superfish code. Fig. 1 shows the electric field pattern of the primary mode (1.3 GHz). The accelerating field along the cavity axis is plotted in Fig. 2.

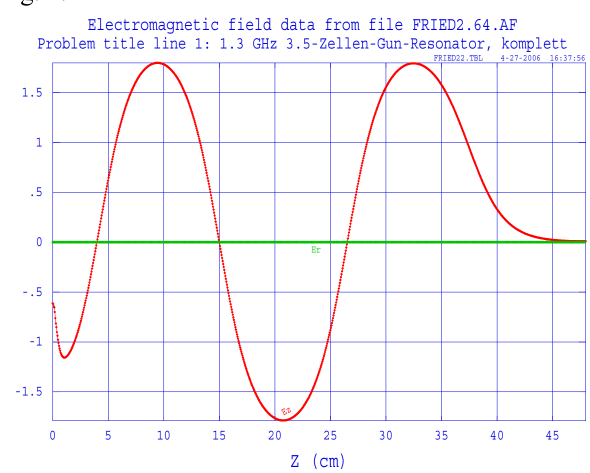

Figure 2: Distribution of the RF accelerating electrical field along the cavity axis as calculated with the Superfish code.

In order to calculate the frequency of a higher order TE focussing mode a model was created using the MAFIA code. The code was chosen since its eigenmode solver can select between the TE and TM modes. Using the geometry of the FZR gun the code predicted the first full cell to be resonant (instead of the third). The pattern of the focusing field is displayed in Fig. 3.

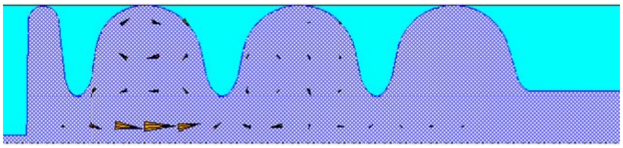

Figure 3: Profile of the magnetic field for the TE focusing mode as calculated with the MAFIA code.

Upgrading for >1mA Operation

From the experience gained through the RF simulations and operation of the ELBE linac module, a number of limiting factors that restrict operation at higher current have been identified:

- Power of couplers limited to 10 kW CW [2].
- HOM power is considerably higher for a 100 mA beam current
- A HOM extraction method is required.

Computer simulations and successful conditioning of the current coupler design has indicated a maximum of 10 kW CW due to over heating of the inner conductor. Such limitations to the current coupler design restrict the acceleration of a 1 mA beam to 10 MeV. It would be possible to reduce the total acceleration to 5 MeV, avoiding the space charge limiting region, although this would still only allow a maximum of 2 mA.

Re-engineering of the inner conductor would allow significantly increased levels of CW power to be transported, providing the possibility of accelerating up to 5 mA beam current.

In order to accelerate a 100mA beam to 10 MeV, 1 MW of RF power is required. The state-of-art design for coaxial tuneable couplers is limited to 50 kW CW. For the existing gun design, it would be possible to increase the average current by reducing beam energy to an emittance-limiting value of 5 MeV. In addition, the coupler would require a modification enabling more efficient cooling of the inner conductor. As an option, a waveguide input coupler with integrated HOM extraction may be considered.

The present gun design only includes a single power coupler that would cause asymmetric fields along the beam axis resulting in emittance degredation. By including a second coupler symmetrically opposite to the coupler would provide twice the amount of power transferred to the cavity whilst removing such asymmetric fields. For the 100 mA coupler design such a system is intended to be adopted.

INVESTIGATION OF THE BEAM FOCUSING

The position of the photocathode inside the opening in the first gun half-cell is beneficial for additional focusing of the beam by the edge electric field [3]. Fig. 4 shows the photocathode retracted 2.6 mm inside the back wall of the gun half-cell. A cathode visor provides additional focusing of the beam. In the figure a cross-section of the cathode opening is shown. A Superfish simulation in Fig. 5 shows the electrical field lines at the vicinity of the cathode opening. On the left-hand side the visor shape, and above the gap from the cathode to the cavity, can be seen.

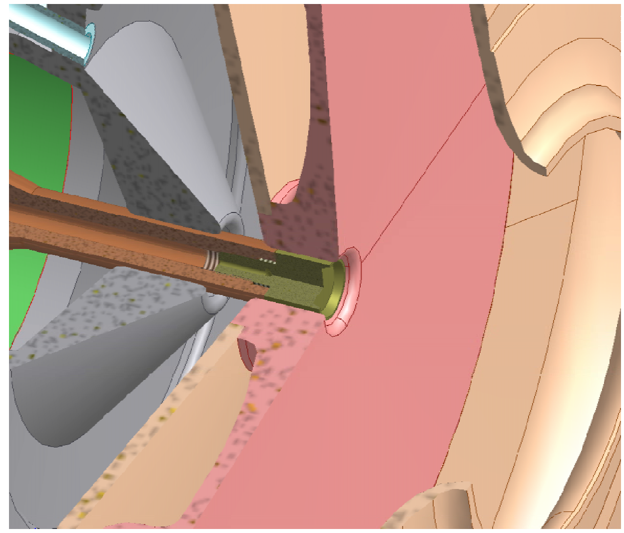

Figure 4: Retracted cathode with visor in the first half-cell of the SRF gun.

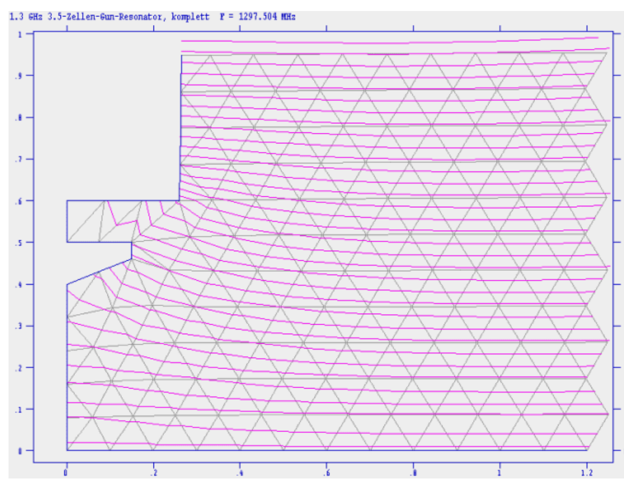

Figure 5: SUPERFISH sketch of the field lines near the retracted photocathode with visor.

The design of the visor depends on the beam parameters and is sensitive in the range of about 0.2 mm in overall dimensions. But in principle one can find an optimal solution for every beam parameter.

The ASTRA simulation in Fig. 6 shows the effect of the cathode visor on the transverse emittance with the beam parameters specified in Table 1. The cathode visor evidently leads to an improved normalized transverse emittance.

Table 1: Beam parameters used in ASTRA calculations

bunch charge	**1 nC**
laser profile	**flat top**
rise time	**1 ps**
bunch length (FWHM)	**20 ps**
rms transverse bunch size	**1.5 mm**
thermal emittance	**not included**
cathode	**2.6 mm backtracked (+ visor)**
calculated long. emittance	**≈ 70 π keV·mm**

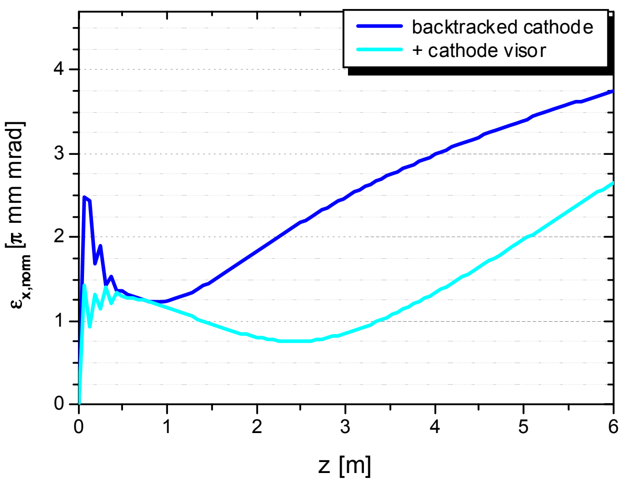

Figure 6: Normalized transverse emittance as calculated with the ASTRA code for the beam focusing with and without cathode visor.

Utilising the Pierce gun concept looks to be advantageous for transverse emittance, however sacrifices towards an increased longitudinal emittance and energy spread could be suffered.

The testing of the mechanical design of the gun will allow investigations to be carried out which will crucial to evolving this design towards a future 100 mA concept gun.

CONCLUSIONS

There is a strong correlation between the RF simulations and the initial calculations using the Superfish code. However, as there were discrepancies with the higher order focusing TE mode, additional optimisation would be required.

There are options available to enhance the design of the gun for higher current operation; however this is still limited to only a few milliamps (4-6 mA). In order to develop a gun able to deliver 100 mA, a new system for RF power transfer and HOM extraction is required.

Beam dynamics simulations with the ASTRA code for alternative cathode geometry have suggested a much improved transverse emittance of the beam at the output of the cavity. Verification of the presented results will be of particular importance once the gun is operational.

Early indications, suggest that such modifications to the cathode geometry would allow for a much improved emittance and improved flexibility in the gun operation.

ACKNOWLEDGEMENT

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395 and EuroFEL, contract number 011935) and the support of the German Federal Ministry of Education and Research grant 05 ES4BR1/8.

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