HIGH GRADIENT NORMAL CONDUCTING RADIO-FREQUENCY PHOTOINJECTOR SYSTEM FOR SINCROTRONE TRIESTE

L. Faillace#, R. Agustsson, P. Frigola, Radiabeam Technologies LLC, Santa Monica CA, USA
H. Badakov, A. Fukasawa, J. Rosenzweig, A. Yakub
Department of Physics and Astronomy, UCLA CA, U.S.A.
F. Cianciosi, P. Craievich, M. Trovo', Sincrotrone Trieste, Italy
L. Palumbo, B. Spataro, INFN-Frascati, Rome, Italy

Abstract

Radiabeam Technologies is leading a multi-organizational collaboration by UCLA, INFN and MATS to deliver a high gradient normal conducting radio frequency (NCRF) 1.6 cell photoinjector system to the Sincrotrone Trieste (ST) facility. Designed to operate with a 120MV/m accelerating gradient, this single feed, fat lipped racetrack coupler design is modeled after the LCLS photoinjector with a novel demountable cathode which permits cost effective cathode exchange. Full overview of the project to date will be discussed along with basic, design, engineering and manufacturing.

INTRODUCTION

Radiabeam is currently involved in the development of new technology aimed at high average power operation for a NCRF electron gun system, the FERMI RF Gun 2, for the Sincrotrone Trieste facility.

The gun design was originally based on the UCLA-University of Roma-INFN-LNF [1] high repetition rate photoinjector, which improved upon the LCLS [2,3] version by use of large radius of curvature rounding of the input coupler irises, and by inclusion of enhanced cooling channels in the most highly dissipative regions in the structure. This basic design was re-optimized by request of ST to use cell-to-cell irises with elliptical shapes. This allows the ratio of the peak electric field at the RF surface relative to the peak on axis field to be less than unity.

RF GUN DESIGN

The RF design of the Gun has been performed by using the codes SuperFish [4] and HFSS [5]. Figure 1 shows half structure of the RF gun with surface electric field distribution calculated by HFSS. RF power is fed through one waveguide only (top one); the waveguide located 180deg. opposite the input one is above cutoff (smaller width) and thus is used to cancel the field dipole component.

#faillace@radiabeam.com

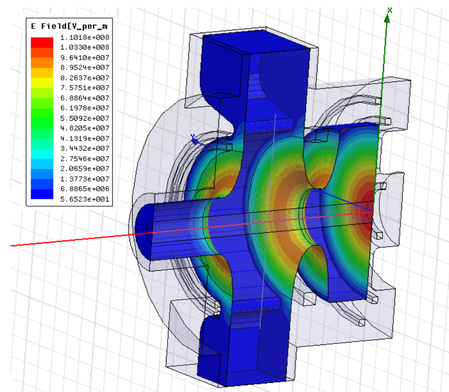

Figure 1: 3D model used for HFSS simulation. Surface electric field is shown.

Cell Design

The RF cavity shape, as proposed, has several innovative features from the viewpoint of electromagnetic performance, including Z-coupling and enhanced cell-to-cell coupling to produce higher mode separation, symmetric couplers for dipole mode minimization, racetrack geometry to minimize quadrupole field components. In contrast to the LCLS gun, which has these features, it is externally fed only on one side. This can be accomplished given the flexibility of the racetrack coupling cell shape to mitigate not only dipole, but also quadrupole fields.

Further, we have chosen the elliptical shape of the upstream side of the 0.6 cell-full cell iris to be different than that of the downstream side in order to balance the peak fields. In order to meet engineering requirements, the shape of the final iris (entrance to the beam tube) is also slightly different from that of the downstream side of the 0.6 cell-full cell iris. In order to calculate the maximum surface electric field, we normalize the on-axis field to 120 MV/m at the cathode. The peak field on the iris is found to be 102 MV/m.

The profile of the axial accelerating electric field is shown in Figure 2.

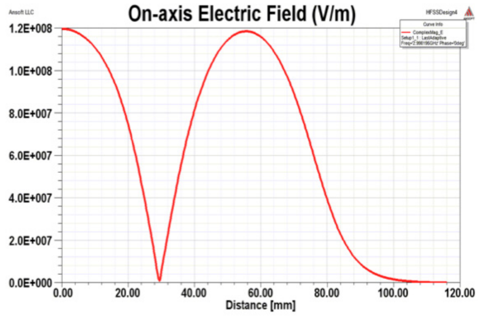

Figure 2: On-axis electric field.

Per usual procedure a first pass on the RF design was made with SUPERFISH and then HFSS was used to provide a complete picture of the RF performance, including mode frequencies, field balance, quality factor *Q,* shunt impedance and external coupling. The details of the cavity dimensions are specified in the HFSS simulation input included in this design submission.

The design parameters achieved in simulation through this process are summarized below in Table 1.

Table 1: Main RF Parameters

Parameter	Simulated value
π-mode frequency	2.998 GHz
0-π mode separation	14.4 MHz
Quality factor Q_0	13,350
External coupling β	1.225
Shunt Impedance R_{Shunt}	60.8 MΩ/m
Peak Surface *E* (120 MV/m @cathode)	102 MV/m
Input power *P*	8.8 MW

Dipole and Quadrupole Component

The dipole and quadrupole components of the RF field have been evaluated using HFSS. The symmetry of the Z-coupling structure guarantees cancellation of the RF dipole component, apart from a negligible (in high-*Q* standing wave devices) transient from the single-side RF feed. The quadruople field, on the other hand, is managed by adjusting the "race-track" spacing.

This procedure is intricate, as one must simultaneously optimize cell frequencies, mode separation, field balance, external coupling, and quadrupole strength.

THERMAL AND STRESS ANALYSIS

In the thermal analysis, we assume an overall 50 Hz repetition rate, with a 3µs RF pulse, yielding a duty factor of 1.5E-4 and thus, with 8.8 MW peak power, an average power of P_{avg}=1.32 kW. As stated above, it is conceivable that one may run with an effective pulse length a factor of 2 to 3 shorter using RF overdrive as well as SLED-like phase switching. Thus, one may immediately extrapolate the achievable repetition rate by this factor without considering changes to the structure or its cooling system.

The water cooling channel placement is as shown in Figure 3, with a flow velocity of 4 m/sec, within the agreed upon limits (mitigating turbulence effects) in the collaboration. The water temperature is chosen to be 38°C to optimize thermal gradients, while the ambient laboratory temperature is assumed to be 27°C.

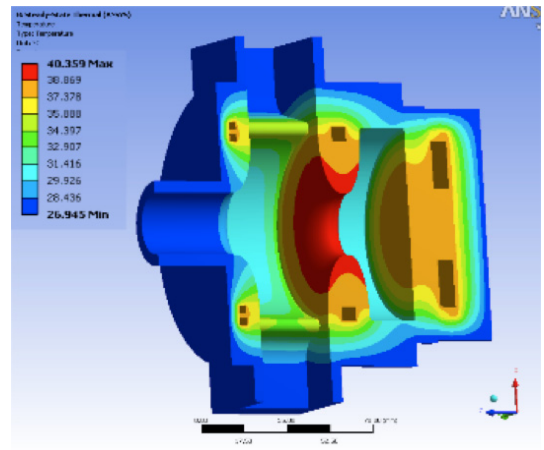

Figure 3: Temperature distribution.

The peak temperature in the structure is < 41°C, only slightly above the water channel temperature. This temperature distribution produces stresses that have been analyzed consistently in the ANSYS [6] modeling codes. The resultant distortion of the copper structure produces a small change in the resonant frequency of the structure that is easily managed by real-time adjustments in the cooling water temperature, as is used at the LCLS.

CATHODE DESIGN

Cathode cooling is carried out by adapting a straightforward scheme similar to that of the LCLS, as illustrated in Figure 4. The main difference between the LCLS design and the FERMI RF gun 2 design will be the incorporation of an exchangeable cathode system. RadiaBeam has evaluated several different solutions to this request. The final selection and engineering of the cathode system will be made during the engineering phase, with input and approval from ST.

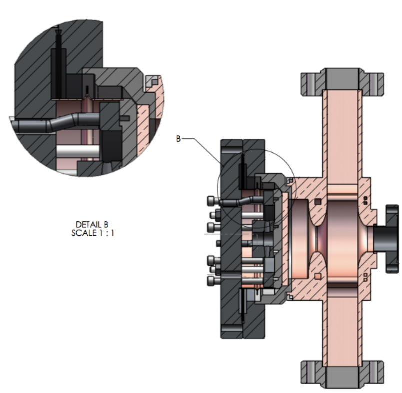

Figure 4: Cathode system mechanical drawing.

SOLENOID DESIGN

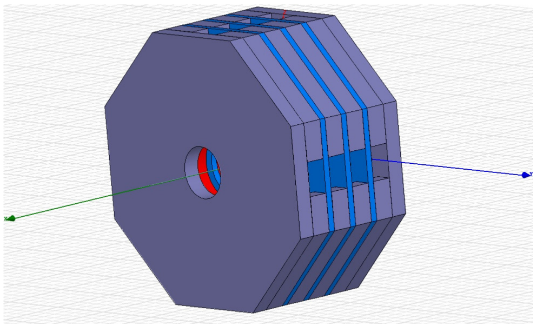

Figure 5: Solenoid for emittance compensation.

We are presently considering the options of sandwich style coils as well as large cross-section coils with internal water channels for the solenoid. In order to guide the choice between these two designs, we have developed a detailed 3D model using the code Maxwell 3D, which includes all current-carrying material geometries, including crossovers (see Figure 5). This model is useful for exploring the performance of different cooling types, including all 3D effects such as magnetic multipole moments. As we proceed to construction, it will be used in tandem with PARMELA to ensure that the choice of coil design avoids degradation of beam quality, particularly through quadrupole effects. We note that such effects are nearly eliminated in any case when the mirror mode is employed, as quadrupole-induced emittance growth mainly arises through rotation of the phase planes during application of the quadrupole forces.

CONCLUSIONS

We have presented the RF design of a high gradient normal conducting radio frequency (NCRF) 1.6 cell photoinjector system for the Sincrotrone Trieste (ST) facility. Innovative features to the class of RF Guns, such as elliptical irises and an exchangeable cathode system, will improve the performance of this gun in terms of power handling and robustness.

REFERENCES

[1] L. Faillace *et al.,* " An Ultra-high repetition rate S- band RF Gun", FEL Conference 2008.

[2] C.Limborg *et al.,* "RF Design of the LCLS Gun", LCLS Technical Note LCLS-TN-05-3 (Stanford, 2005).

[3] D.H. Dowell *et al.,* "The development of the Linac Coherent Light Source RF Gun", SLAC Menlo Park CA, published in the ICFA Beam Dynamics Newsletter No. 46.

[4] http://laacg1.lanl.gov/laacg/

[5] http://www.ansoft.com/products/hf/hfss

[6] http://www.ansys.com