BEAM DYNAMICS SIMULATIONS OF A HIGH CHARGE S-BAND PHOTOINJECTOR FOR ELECTRON BEAM IMAGING EXPERIMENTS

Yanru Wang, Zimin Zhang#, Shuchun Cao, IMP, CAS, Lanzhou, China
Wei Gai, ANL, Argonne, IL, USA
Jiaqi Qiu, Euclid Techlabs, OH, USA

Abstract

A major challenge for high energy density physics is to measure properties of matter under extreme states of temperature and pressure that only occur in a time scale of 10 ns to 1 µs. Here we propose to use a single shot electron beam from an S-band photocathode with enough energy to penetrate the material as a diagnostic capable of time resolution (< ns). In this paper, we report on the beam dynamics simulation of an S-band photocathode electron gun and accelerator (S-band photoinjector) capable of producing up to 10 nC charge with high enough energy. Optimizations of the system parameters, including gun, focusing solenoid and acceleration field are performed using particle tracking code. The beamline is designed to be installed in the Institute of Modern Physics (IMP) electron accelerator centre for high precision electron imaging experimental studies.

INTRODUCTION

High energy density physics aims to study the properties of matter under extreme states of high temperature and high pressure. A new scheme based on high-energy electron beam as a probe was proposed for time-resolved imaging measurement of high energy density materials, especially for high energy density matter and inertial confinement fusion (ICF) [1, 2]. A major challenge is to measure properties of matter under extreme states of high temperature and pressure that only occur in a time scale of 10 ns to 1 µs. A diagnostics system with time-resolved imaging is highly desirable, based on a single shot electron beam from an S-band photocathode with enough energy to penetrate the material and capable of time resolution (< ns).

Here we present the primary beam dynamics simulation design for high charge S-band photoinjector aiming to high quality single-shot electron imaging. A sketch of the S-band photocathode electron gun and accelerator is shown in Fig.1. It consists of a normal-conducting 1.6 cell S-band photocathode radio frequency electron gun and an S-band accelerating tube. The gun cavity is surrounded by a solenoid, which serves for the focusing of the beam as well as for the compensation of the emittance growth caused by space charge effects [3].

Taking into account the requirement of high charge beam with high energy, a parameter optimization has been performed. Simulations showed an rms projected emittance of 2.3 mm mrad/nC achieved at the accelerator exit.

zzm@impcas.ac.cn

Figure 1: The sketch of the S-band photoinjector.

DESCRIPTION & DYNAMICS SIMULATION OF S-BAND PHOTOINJECTOR SETUP

The beam-line consists of the electron gun containing the photocathode, and a second accelerating section called booster cavity. In order to meet the requirement for high charge in S-band photoinjector, a series of beam dynamics simulations have been performed. As an important input for dynamics simulation code, the following parameters have been chosen: round uniform transverse profile are increased gradually from 1.4 mm to 4.5 mm as the bunch charge increases from 1nC to 10nC (thus keeping the same bunch charge density on the photocathode), a Gaussian longitudinal distribution of the cathode laser with 2.9 ps RMS, and assumed kinetic energy of the electrons at the photocathode (for thermal emittance calculation) of 1 eV. The longitudinal centre positions of the main solenoid and the second accelerating section (booster) was fixed in this simulation: 0.22 m and 3.03 m downstream of the photocathode, respectively.

The electron gun consists of a 1.6 cell cavity with a resonance frequency of 2.856 GHz. The field in the gun cavity is showed in Fig. 2. The simulation rf gradient of 40.98 MV/m at the gun cavity with the max gradient of 100 MV/m corresponds to a beam energy of 4.7 MeV at the gun exit for a laser launch phase of 22 deg.

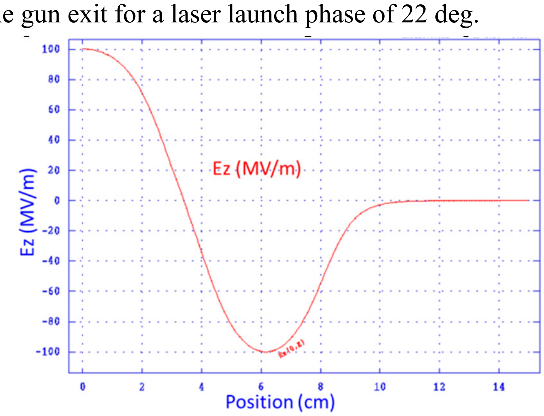

Figure 2: Field in gun cavity.

The gun cavity is surrounded by the main solenoid, which is used to compensate space charge effects in the gun, and the bucking solenoid, which is used to keep the

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magnetic field zero at the cathode. In this S-Band photoinjector, the main solenoid magnet has 8 pancake coils [4]. The bucking solenoid which produces the opposite field direction as compared to the main solenoid is placed behind the cathode. The solenoid structure is shown in Fig. 3, and its longitudinal magnetic field distribution along the z-axis is shown in Fig. 4. The centre of the main solenoid is located 0.22 m from the cathode. The central solenoid field is scanned to meet the high charge requirement of the S-band photoinjector facility for electron imaging.

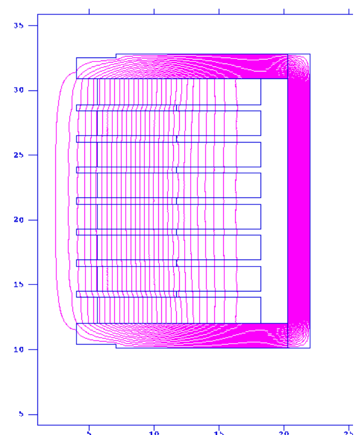

Figure 3: Poisson model of the 8 pancake solenoid coil.

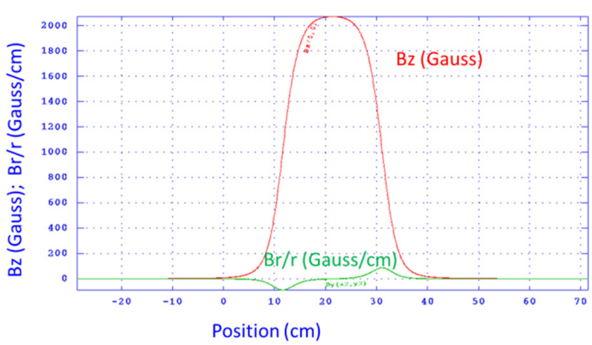

Figure 4: B_z distribution in the main solenoid along the longitudinal z-axis.

The booster was simulated under the average gradient of 19 MV/m corresponds to a beam energy of 61 MeV at the end of the booster for rf phase 3.7 deg. off the crest.

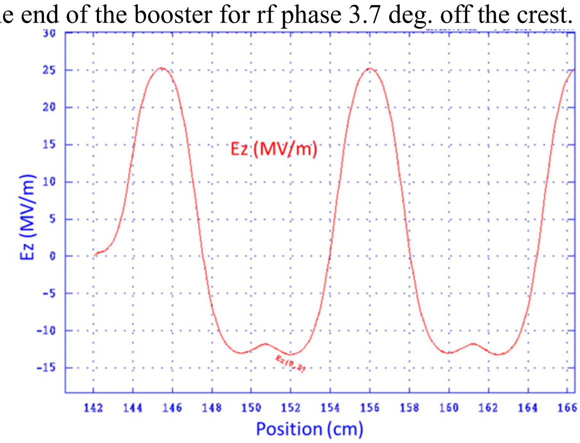

Figure 5: Field in the booster.

The beam dynamics optimization considers the gun phase, the main solenoid peak field (with the magnetic field at the cathode cancelled by appropriate current in the bucking solenoid), rf gradient in the booster, rf phase of the booster relative to the gun, and the transverse rms size (for each bunch charge) of the laser spot on the photocathode. The results of the optimization from 1 nC to 10 nC are plotted in Fig. 6, which the corresponding round uniform transverse profile are increased gradually from 1.4 mm to 4.5 mm to keep the same bunch charge density on the photocathode. The corresponding parameters are summarized in Table 1.

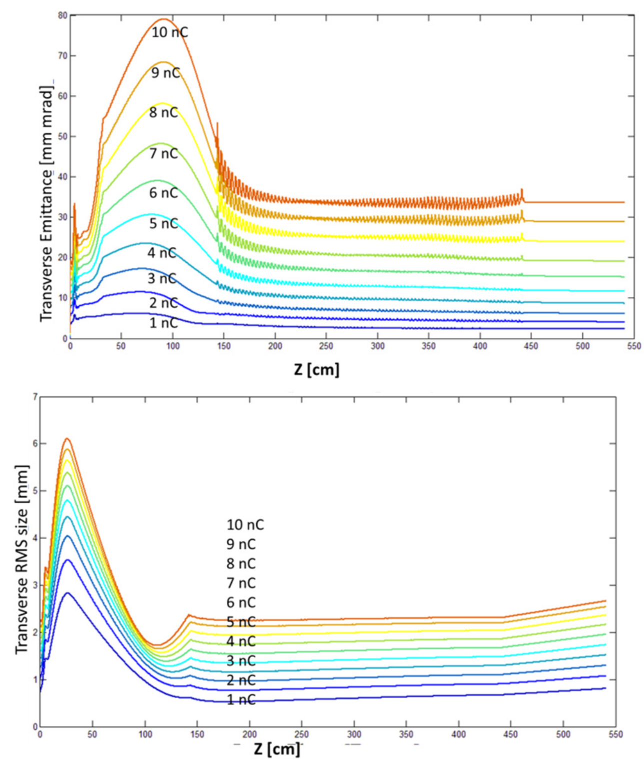

Figure 6: Transverse emittance & RMS size variation along Z with different bunch charge.

Table 1: Beam Dynamics Parameters

Input Parameters	
Bunch Charge (nC)	1-10
Laser Radius (mm)	1.4-4.5
Laser Length RMS (ps)	2.9
Injection Phase (Deg.)	22.3
Thermal Emittance (eV)	1
Field at Cathode (MV/m)	100
Average Field in booster (MV/m)	19
Optimization Parameters	
Electron Energy at Gun Exit (MeV)	4.7
Electron Energy at Booster Exit (MeV)	61
The central solenoid field (Gauss)	2070
Normalized Emittance (mm.mrad)	2.34-28.7

CONCLUSION

This paper has described the primary simulation results of a high charge S-band photoinjector designed to be installed in the Institute of Modern Physics.

This high charge S-band photoinjector was simulated at a peak cathode electric field of about 100 MV/m, and produced a projected normalized transverse emittance of 2.3 mm mrad per nC of bunch charge and 61 MeV beam energy after the booster. The emittance and high energy meet the requirements for high quality single-shot electron imaging. Further optimization including lower energy spread needs to be done in next step.

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