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DESIGN OF THE TEST PLATFORM FOR HIGH AVERAGE CURRENT VHF ELECTRON GUN

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Abstract

Recently a high-average-current CW VHF electron gun is under construction at Shanghai Advanced Research Institute, which is aimed to develop the high average current and high beam quality technologies. The high average current electron source is the key component of a kW-power-order free electron laser facility. The average current and the frequency of this electron gun is 1-10 mA and 216.7 MHz, respectively. The energy of electron is over 500 kV, and repetition rate is about 1-9 MHz. To validate the performance of this instrument, a test platform has been designed. The R&D of its vacuum and diagnostics design are presented in this work.

INTRODUCTION

In recent years, several projects involving free electron lasers (FEL) and energy recovery linacs (ERL) facilities have been proposed and commissioned. These facilities require high repetition rates, low emittance, and high power. Some facilities, such as LCLS-II, SHINE, and APEX, have employed normal-conducting (NC) RF electron guns [1–4]. The electron gun (VHF) test platform in this work is under construction based on a NC continuous-wave (CW) RF photogun at the Shanghai Advanced Research Institute (SARI). The core of our photogun is a NC copper RF cavity operating at the VHF band, specifically at 216.7 MHz. This cavity generates a 22.5 MV/m accelerating field when supplied with nearly 90 kW of power. The accelerating gap measures 4 cm. To operate high quantum efficiency semiconductor photocathodes (Cs2Te), an expected vacuum level of 10^{-10} – 10^{-9} mbar is necessary.Beam quality, including energy, normalized emittance, beam size, beam current, and the thermal emittance of the photocathode, significantly influences the electron source. The layout of the test platform is outlined in this paper, focusing mainly on diagnostics and vacuum design. The theoretical vacuum levels for the electron gun and test line are 3×10^{-8} mbar and 1×10^{-7} mbar, respectively. The main tube diameter is 50 mm, and the entrance diameter of the dump is 80 mm.

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The design objectives are presented in Table 1, and the layout of the test platform is illustrated in Fig. 1. The height of the beamline is 1.3 m. The beamline comprises a load lock, electron gun, solenoids, dipole, profile monitors, ICT (Integrated Current Transformer), and BPMs (Beam Position Monitors). The positions of the main elements are indicated in Table 2.

Table 1: Design Objectives

Parameter	Value	Unit
Energy	>500	keV
Average current	>1	mA
Frequency	216.7	MHz
Repetition rate	1-9	MHz
Charge	200	pC

Table 2: Test Platform Layout

Element	Position	Unit
Electron gun	0	m
Solenoid 1,2	0.27,1.8	m
Laser injector	0.92	m
Profile 1,2,3	1.5,0.4(to the line),2.2	m
Dump	0.65(to the line)	m

Diagnostics Design

The essential characteristics of the electron gun's photocathode are crucial for the electron source. Therefore, this work includes simulations to measure beam energy, dark current, normalized emittance, and transverse momentum.

Dark current imaging Dark current is a primary focus of the electron source, particularly because superconducting linacs such as LCLS-II and SHINE require low dark currents for optimal acceleration quality and extended lifespan. Dark current imaging plays a role in enhancing the photo-cathode manufacturing process. As depicted in Equation 1, dark current emitted from the same position with varying transverse momentum should reach the same position on the profile by matching the strength of the solenoid ($M_{12} = 0$). The relationship between imaging magnification and the distance between the photo-cathode and the profile is demonstrated in Fig. 2b, where the primary emission of dark current is from the 5 mm center of the photo-cathode. As depicted in Fig. 2a, the dark current is imaged, resulting in a loss of transmission of the profile.

$$\begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \begin{bmatrix} r_0 \\ r_0' \end{bmatrix} = \begin{bmatrix} r \\ r' \end{bmatrix} \quad (1)$$

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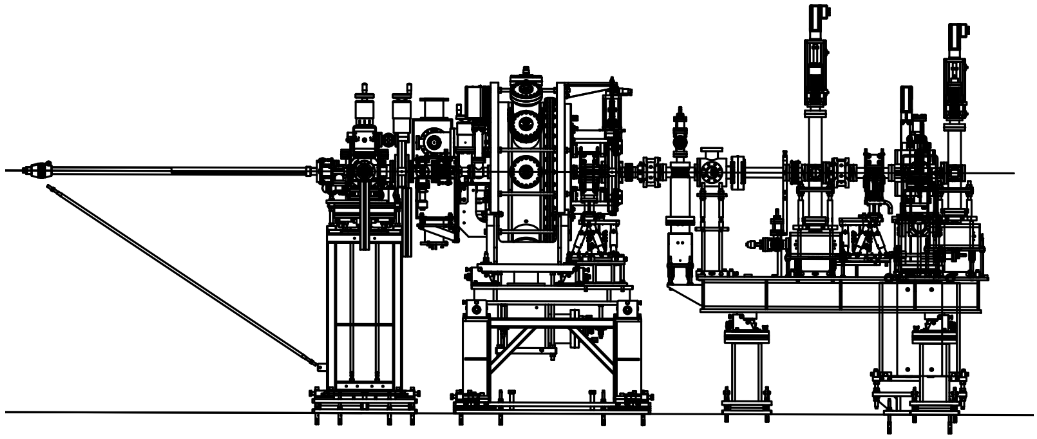

Figure 1: Layout of VHF electron gun test platform. The test line include photo-cathode system, electron gun system, diagnostics system, vacuum system, magnet system and radiapretection system. The elements include solenoids, dipole magnet, profile, ion pump, correctors, SBPMs, BBPM, ICT and dump.

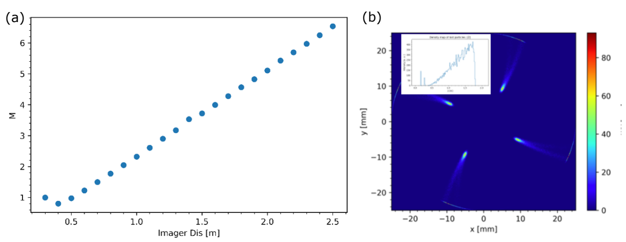

Figure 2: The simulation of dark current. (a) The relationship between position of profile and imaging magnification. (b) The dark current is imaging in profile of 1.5 m distance, and the beam transmission loss is also shown.

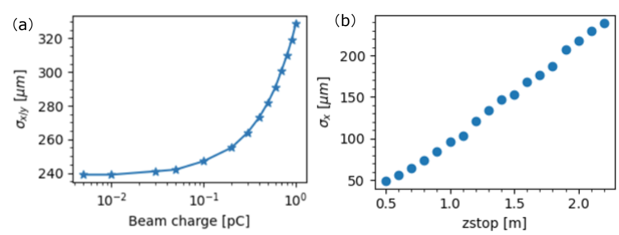

Figure 3: The theoretical simulation of transverse momentum imaging. (a) The influence of space charge for imaging the transverse momentum of 2.2 m profile. (b) The relationship between the imaging magnification and position of profile.

Transverse momentum imaging Transverse momentum is the key characteristic of photo-cathode. As shown in Equation 1, the dark current emitted from the different position with same transverse momentum should arrive the same position of profile through matching the strength of solenoid ($M_{11} = 0$). The relationship between the distance between the profile and the photo-cathode and the imaging magnification was simulated using ASTRA. As shown in Fig. 3(b), the distance of the profile is 2.2 meters, in addition to the resolution of the CCD. The influence of space charge is also presented in Fig. 3(a), the space charge can be ignored when the beam charge is below 0.05 pC. Additionally, GAGG with high quantum efficiency will be chosen.

Normalized emittance measurement The normalized emittance is significant for FEL lasing. In this work, the single-slit method was used to measure the normalized emittance. However, the space charge will increase the measured normalized emittance. As shown in Fig. 4, the space charge influence was simulated with different slit gaps. The red and blue lines represent the intensity distribution with and without space charge, respectively. Different slit gaps of 60, 100, 140, and 200 µm were simulated using ASTRA. Additionally, the gap of slit should be below 100 µm to avoid the influence of space charge.

Vacuum Design

An excellent vacuum level is necessary for an RF cavity system, and a low vacuum level will result in radiation passing through activated air. In our test platform, the vacuum level of the RF cavity should be maintained at the order of 10^{-8}. Simultaneously, the vacuum level of the test line should achieve an order of 10^{-7}. The RF cavity maintains a high vacuum level using nine Z400 NEG pumps and a 200 L/s ion pump. To attain such a high vacuum level, four dump ports will also be utilized. Three of these consist of one 50 L/s ion pump and one Z400 NEG pump each. The pump port in front of the copper dump contains a 400 L/s ion pump. This pump will prevent the main line from experiencing a poor vacuum level resulting from the high average current. As shown in Fig. 5, the top figure depicts the 3D grid of the entire test platform in Molflow+, while the bottom figure illustrates the vacuum level distribution from the photocathode to profile 3. The vacuum level of the electron gun is nearly 3×10^{-10} mbar, and the test line measures around 2.7×10^{-9} mbar.

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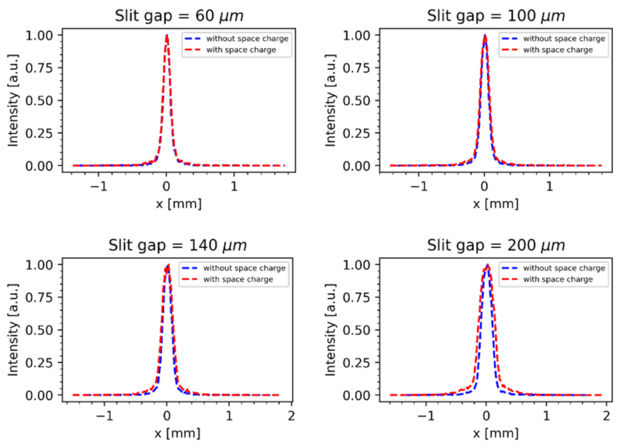

Figure 4: The space charge influence for measuring normalized emittance. The read line and blue line is the rms beam size without and with space charge, respectively. The slit gaps of 60, 100, 140, and 200 μm are presented. The influence of space charge can be ignored when the slit gap less than 100 μm.

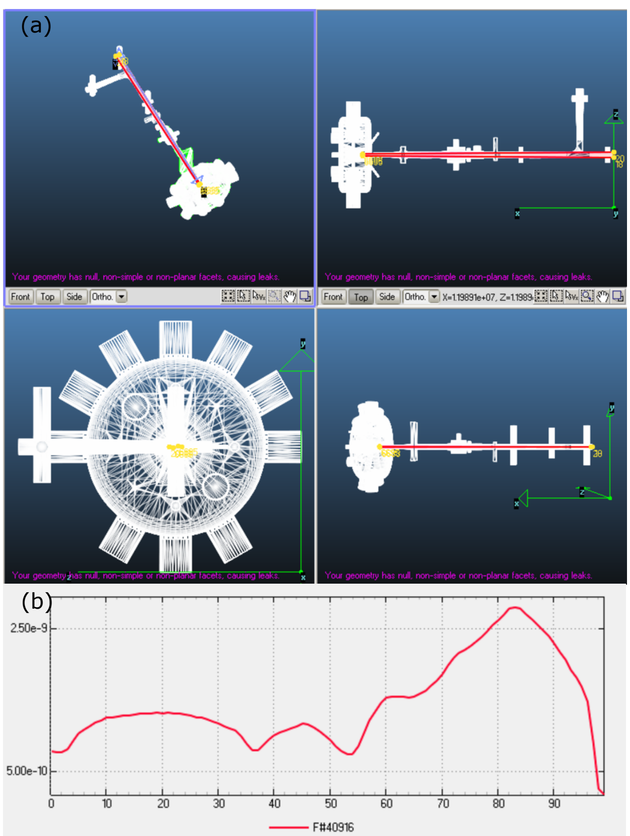

Figure 5: The simulation of vacuum. (a) The 3D grid of test platform in Molflow+. (b) The vacuum level distribution from photo-cathode to the profile 3.

SUMMARY

In this work, the electron gun test platform at SARI is described. Additionally, the diagnostic and vacuum design are presented. The test platform can be used to validate the quality of electrons by measuring dark current, average current, normalized emittance, transverse momentum, charge, and more. The theoretical vacuum level is also discussed in this work, with the vacuum level of the test line and electron gun being approximately 3×10^{-10} mbar and 2.7×10^{-9} mbar, respectively.

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