

IMPROVED ELECTROSTATIC DESIGN OF THE JEFFERSON LAB 300 kV DC PHOTOGUN AND THE MINIMIZATION OF BEAM DEFLECTION*

M. A. Mamun[†], R. Suleiman, C. Hernandez-Garcia, B. Bullard, J. Grames, M. Poelker
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
S. A. K. Wijethunga, G. Palacios-Serrano, J. R. Delayen, G. A. Krafft¹
Old Dominion University, Norfolk, VA 23529, USA

¹also at Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

Abstract

Electron beam with high bunch charge and high repetition rate is required for electron cooling of ion beam to achieve the required high luminosity of proposed electron-ion colliders. Improved design of the -300 kV DC high voltage photogun at Jefferson Lab was incorporated toward overcoming the beam loss and space charge current limitation as experienced in the original design. To reach the bunch charge goal of \sim few nC within 75 ps bunches, the existing DC high voltage photogun electrodes and anode-cathode gap were modified to increase the longitudinal electric field (E_z) at the photocathode. The anode-cathode gap was reduced to increase the E_z at the photocathode and the anode aperture was spatially shifted with respect to the beamline longitudinal axis to minimize the beam deflection introduced by the geometric asymmetry of the inverted insulator photogun. The electrostatic design and the beam dynamics simulations were performed to determine the required modification. Beam based measurement from the modified gun confirmed the reduction of the beam deflection which is presented in this contribution.

INTRODUCTION

DC high voltage photo-guns have been employed by accelerator facilities to produce both polarized and non-polarized beam for different application. The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab uses a DC high voltage photogun to produce highly polarized electron beams at currents \sim 100 μ A and sub-pC bunch charge for nuclear physics research [1,2]. Other applications that employ DC high voltage photoguns and typically require very high average current (mA) and high bunch charge ($>$ 100 pC) include free electron lasers (FELs) [3-6], energy recovery linacs (ERLs) [7,8], and electron cooling [9-10].

The majority of these photo-guns have a Pierce geometry at the cathode front to focus the beam [11,12]. In addition, inverted insulator geometry photoguns like the Jefferson Lab design serve to connect the high voltage cable to the cathode electrode, and have a shield to minimize the electric field at the insulator metal-vacuum interface known as the triple point junction [12]. However, the

Pierce geometry reduces the E_z at the cathode, thus increasing space charge effects and reducing bunch charge extraction. Additionally, the inverted insulator and triple point junction shield, asymmetric NEG pumps altogether introduce asymmetric electric fields in the anode-cathode gap which then result in deflecting the beam vertically at the exit of the anode, causing difficulty in beam steering, and ultimately beam losses [11-14]. This work explored the beam based performance of the Jefferson Lab's redesigned -300 kV photogun to address the above design issues. The electrostatic design of the modified photo-gun was achieved using CST Studio Suite's electromagnetic field solver to obtain a higher E_z at the cathode while keeping the beam on-axis in comparison with the original photogun [15]. Beam simulations were conducted using GPT software [16] implementing the electrostatic field map obtained from the modified electrodes which are presented in detail by Wijethunga et al [17].

This contribution presents the beam based results from the redesigned photogun to confirm the beam deflection minimization in the offset anode design.

MODIFICATION OF THE PHOTOGUN

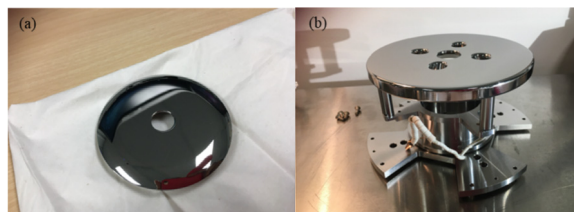


Figure 1: For the modified (flat) design: (a) front surface of the flat cathode that mates the spherical ball electrode and (b) the flat anode. The anode aperture (the hole at the center of the anode) is shifted by -1.6 mm.

The 300 kV DC high voltage photogun at Jefferson Lab was redesigned to deliver electron beams with much higher bunch charge and improved beam properties. The modifications include removing the 25° Pierce geometry of the cathode electrode and decreasing the anode-cathode gap from 9 to 5 cm to enhance the longitudinal electric field magnitude E_z from -2.5 to -7.8 MV/m. To correct the beam deflection with minimum changes, the anode offset with respect to the beamline longitudinal axis is incorporated.

* Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177. Additional support comes from JSA initiatives fund program and Laboratory Directed Research and Development program.

[†] mamun@jlab.org

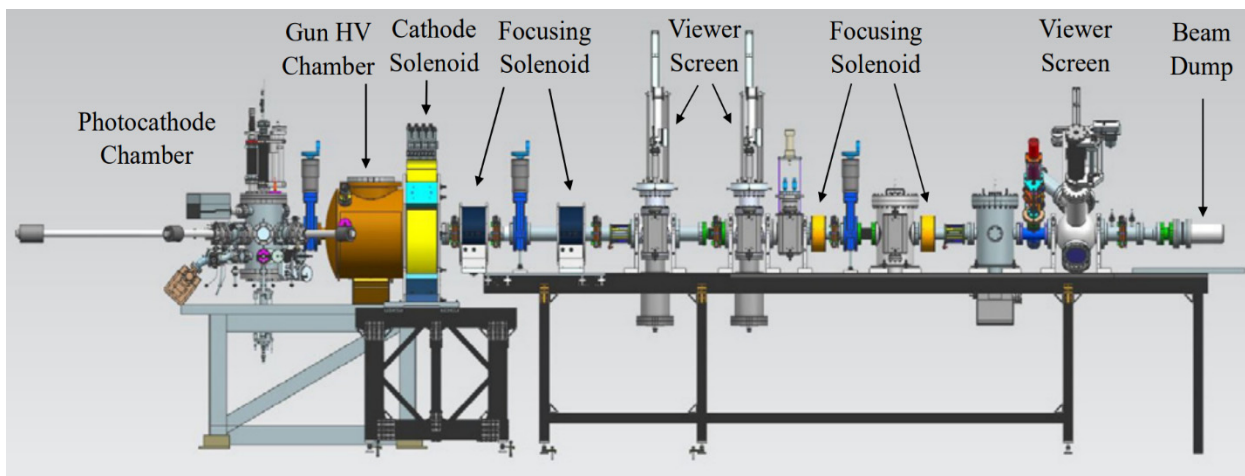


Figure 2: Beamline schematic of the beam test stand used to drive the electron beam for the beam deflection study.

To implement the offset anode, it is not easy to shift the whole anode as it breaks the symmetry of the anode mounting flanges and the laser path. Therefore, after confirming how much shift is required, a new model was designed with only the anode aperture shifted by -1.6 mm while keeping the anode structure centered and aligned with the cathode and beam pipe. According to the simulations, both give the same results. Each electrode was polished to obtain a mirror-like surface condition using various grades of sandpaper, diamond-paste polishing, and finally barrel polishing [18]. Figure 1 shows both electrodes. The two of the other four holes are for laser in and out and the other two for viewing the photocathode with a camera.

EXPERIMENTAL VERIFICATION

The required beam steering is measured for the modified design and compared to the original design in an experimental beamline set up. The beamline consists of photogun high voltage chamber, photocathode preparation chamber, cathode solenoid, laser system, three fluorescent YAG screens, four focusing solenoids and beam dump. A schematic diagram of the beamline is shown in Fig. 2

The compact gun high voltage chamber includes an inverted insulator and spherical cathode electrode operating at or below -225 kV. An alkali antimonide (Cs_3Sb) photocathode deposited on GaAs substrate was used with full active area of 6 mm radius and quantum efficiency (QE) of 5.2% with 523 nm laser. The photocathode activation involved steps of overnight heat cleaning at 450 °C and followed by cooling to 120 °C. At this point, the Sb source was heated to get target partial pressure of $\sim 1.5 \times 10^{-11}$ Torr with 24 A current supply to the tungsten heater. Antimony is deposited for 10 minute to get very thin (<20 nm) layer. The Sb source was retracted and the heater supply was turned off. Meanwhile, the Cs effusion source was heated to reach 262 °C at the Cs reservoir (J-tube) and 200 °C at the dispenser tube. The effusion heater was maintained at 300 °C. During heating of effusion source, the vacuum pressure increased from base pressure of 68 nA to 270 nA on the ion pump. The Cs partial pressure indicated on RGA

was from 3.5×10^{-10} to 7.8×10^{-10} Torr over the duration of deposition. During Sb addition no photocurrent was detected. During Cs deposition after 40 minutes the rate of rise in photocurrent appeared to increase and took about 26 minutes to maximize the photocurrent. Afterward the Cs valve was closed followed by cooling down of the source and the puck. The photocurrent kept rising as the source cooled down and Cs being pumped down from the chamber. The optimized QE reached 5.2%. A fiber optic pulsed laser system was employed for driving electron beam from the photocathode. The photogun drive laser provided up to 3 Watts of power at 533 nm, with 22 picoseconds rms optical pulses at 374.25 MHz pulse repetition rate.

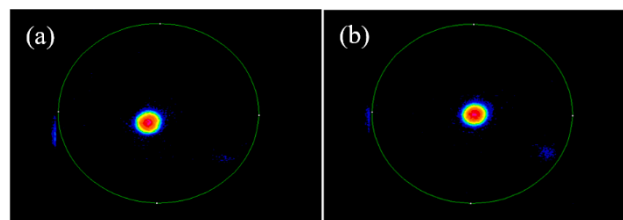


Figure 3: Electron beam for the redesigned photogun imaged on the first viewing screen 1 (a) with no beam steering, and, (b) beam centered on the first viewing screen with a very little steering by the first corrector set. For applied gun high voltage of -200 kV and laser spot of 0.35 mm rms size located at the center of the photocathode.

The new photogun design was tested with electron beam to verify that the shifted anode (by -1.6 mm) produced an electron beam centered in the downstream beam-pipe and with minimal vertical deflection (Fig. 3). When operating the old photogun, to the center of the beam on the first viewing screen 1.5 m from the gun, two steering magnets located between the photogun and the viewing screen provided the necessary field integral of 80 G cm to kick the beam vertically upward. Only 20 G cm horizontal was necessary to compensate for the deflection due to the NEG's. For the new design, less than 5 G cm was required (Table 1) in both the vertical and horizontal directions to compen-

sate for the background magnetic fields and any misalignment in the gun and beamline. The required field integral for the two steering magnets were further investigated to center the electron beam on the viewing screen for different laser spot positions on the photocathode with 3 mm offset from the center. Less than 10 G cm of steering field (Table 2) was adequate to center the electron beam on the first viewing screen. This is a clear indication of the minimization of beam deflection in the new design compared to the original version.

Table 1: Integrated Field (G cm) Applied on Horizontal and Vertical Steering Magnets to Center the Beam on the First Viewing Screen. Listed for the Original and Redesigned Photogun for the Laser Spot Positioned at the Center of the Photocathode

Magnet	Original Gun	Modified Gun
Horizontal	21.3 G cm	-4.0 G cm
Vertical	83.0 G cm	3.0 G cm

Table 2: Integrated Field (G cm) Applied on Horizontal and Vertical Steering Magnets to Center the Beam on the First Viewing Screen. Listed for Various Laser Spot Locations on the Photocathode for the Modified Photogun

Laser Spot Position	Horizontal	Vertical
Center	-4.0 G cm	3.0 G cm
12 O'clock	-3.2 G cm	5.0 G cm
6 O'clock	-8.0 G cm	0.8 G cm
3 O'clock	-9.6 G cm	3.6 G cm
9 O'clock	-6.0 G cm	3.0 G cm

CONCLUSION

The vertical beam deflection due to the asymmetric electric fields in between the anode-cathode gap of the Jefferson Lab's -300 kV photogun with inverted insulator geometry was minimized after a relatively easy to implement modification in the original design. A modest downward shift of anode aperture by just 1.6 mm corrected the beam trajectory at the exit of the anode by eliminating the vertical beam deflection experienced in the original design. This simple modification will benefit all photoguns with inverted insulator design by reducing beam loss at the anode, thus improving the photocathode lifetime, particularly those at high bunch charge. Similarly, a horizontal beam deflection from asymmetry in electric field can be corrected by introducing a horizontal offset in anode aperture. A tilted anode can also be used to accomplish the same goals of eliminating beam deflection, and that will be studied by the group in future.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics (Contract No. DE-AC05-06OR23177), JSA initiatives fund program, and the Laboratory Directed Research and Development program.

REFERENCES

- [1] C. K. Sinclair *et al.*, "Development of a high average current polarized electron source with long cathode operational lifetime," *Phys. Rev. ST Accel. Beams*, vol. 10, p. 023501, 2007. doi:10.1103/PhysRevSTAB.10.023501
- [2] R. Barday and K. Aulenbacher, "Polarized electron source operation at average currents of several milliamperes," *AIP Conf. Proc.* 915, 1019 (2007). doi:10.1063/1.2750946
- [3] G. Neil *et al.*, "The JLab high power ERL light source," *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 557, p. 9, 2006. doi:10.1016/j.nima.2005.10.047
- [4] S. Benson *et al.*, "High power operation of the JLab IR FEL driver accelerator," in *Proc. 22nd Particle Accelerator Conference (PAC'07)*, Albuquerque, NM, USA, Jun. 2007, paper MOOAAB03, pp. 83-85. doi:10.1109/PAC.2007.4440128
- [5] J. Feldhaus, J. Arthur and J. B. Hastings, "X-ray free-electron lasers," *J. Phys. B: At. Mol. Opt. Phys.* 38, S799, 2005. doi:10.1088/0953-4075/38/9/023
- [6] C. Hernandez-Garcia, P. G. O'Shea, and M. L. Stutzman, "Electron sources for accelerators," *Physics Today* 61, pp. 44-49, 2008. doi:10.1063/1.2883909
- [7] E. J. Minehara, "Development and operation of the JAERI superconducting energy recovery linacs," *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 557, p. 16, 2006. doi:10.1016/j.nima.2005.10.049
- [8] D. Trbojevic *et al.*, "CBETA - Cornell University Brookhaven National Laboratory electron energy recovery test accelerator," in *Proc. 8th International Particle Accelerator Conference (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 1285-1289. doi:10.18429/JACoW-IPAC2017-TU0CB3
- [9] A. V. Fedotov, "Bunched beam electron cooling for the low energy RHIC operation," *ICFA Beam Dyn. Newslett.* 65, 22, 2014.
- [10] M. A. Mamun *et al.*, "Production of magnetized electron beam from a DC high voltage photogun," in *Proc. 9th International Particle Accelerator Conference (IPAC'18)*, Vancouver, BC, Canada, Apr.-May 2018, pp. 4567-4570. doi:10.18429/JACoW-IPAC2018-THPMK108
- [11] P. Adderley *et al.*, "Load-locked DC high voltage gas photogun with an inverted-geometry ceramic insulator," *Phys. Rev. ST Accel. Beams*, vol. 13, p. 10101, 2010. doi:10.1103/PhysRevSTAB.13.010101
- [12] C. Hernandez-Garcia *et al.*, "Compact 300 kV DC inverted insulator photo-gun with biased anode and alkali-antimonide photocathode," *Phys. Rev. ST Accel. Beams*, vol. 22, p. 113401, 2019. doi:10.1103/PhysRevAccelBeams.22.113401
- [13] G. Palacios-Serrano *et al.*, "Electrostatic design and conditioning of a triple point junction shield for 200 kV DC high voltage photo-gun", Review of scientific instruments, vol. 89, p. 104703, 2018. doi:10.1063/1.5048700

- [14] N. Nishimori *et al.*, “Experimental investigation of an optimum configuration for a high-voltage photoemission gun for operations at > 500 kV,” *Phys. Rev. ST Accel. Beams*, vol. 17, p. 053401, 2014.
doi:10.1103/PhysRevSTAB.17.053401
- [15] CST Studio Suite’s,
<http://www.cst.com>
- [16] General Particle Tracer, <http://www.pulsar.nl/gpt>
- [17] S. A. K. Wijethunga *et al.*, “Improving the electrostatic design of the Jefferson Lab 300 kV DC photogun,” *Rev. Sci. Instrum.*, vol. 93, 073303, 2022.
doi:10.1063/5.0091134
- [18] Y. Wang *et al.*, “Thermal emittance and lifetime of alkali-antimonide photocathodes grown on GaAs and molybdenum substrates evaluated in a -300 kV DC photogun,” *Phys. Rev. Accel. Beams* 23, 103401, 2020.
doi:10.1103/PhysRevAccelBeams.23.103401