PERFORMANCE OF CEC POP GUN DURING COMMISSIONING*

I. Pinayev#, W. Fu, Y. Hao, M. Harvey, T. Hayes, J. Jamilkowski, Y. Jing, P. Kankiya, D. Kayran, R. Kellermann, V.N. Litvinenko, G. Mahler, M. Mapes, K. Mernick, T. Miller, G. Narayan, M.Paniccia, W. Pekrul, T. Rao, F. Severino, B. Sheehy, J. Skaritka, K. Smith, J. Tuozzolo, E. Wang, G. Wang, W. Xu, A. Zaltsman, Z. Zhao, BNL, Upton, NY 11973, USA
K. Mihara, I. Petrushina, SBU, Stony Brook, NY, USA

Abstract

The Coherent Electron Cooling Proof-of-Principle (CeC PoP) experiment [1, 2] employs a high-gradient CW photo-injector based on the superconducting RF cavity. Such guns operating at high accelerating gradients promise to revolutionize many sciences and applications. They can establish the basis for super-bright monochromatic X-ray and gamma ray sources, high luminosity hadron colliders, nuclear waste transmutation or a new generation of microchip production. In this paper we report on our operation of a superconducting RF electron gun with a record-high accelerating gradient at the CsK_2Sb photocathode (i.e. ~ 20 MV/m) generating a record-high bunch charge (above 3 nC). We give short description of the system and then detail our experimental results.

INTRODUCTION

The purpose of the coherent electron cooling experiment is to demonstrate reduction of the energy spread of a single hadron bunch circulating in the relativistic heavy ion collider (RHIC). A superconducting RF gun operating at frequency of 113 MHz serves as a source of the electron beam. The CsK_2Sb photocathode is illuminated by 532 nm laser. The designed electron beam parameters are shown in the Table 1.

Table 1: Design Parameters of the Electron Beam

Parameter	Value
Energy	2 MeV
Bunch charge	1-5 nC
Normalized emittance	< 5 mm mrad

GUN DESIGN

The CeC PoP gun has quarter-wave structure and its design is shown in the Fig. 1. The gun cavity is placed inside cryostat with thermal and magnetic shields. The cathode stalk is inserted inside the cone and is kept at room temperature as well as CsK_2Sb cathode. Such design allows preservation of quantum efficiency of the photocathode. The stalk itself serves as a cavity field pick-up.

The hollow fundamental power coupler (FPC) is inserted from the flat side of the cavity and let the generated beam go outside. 2-kW solid-state amplifier provides the RF power. The FPC is surrounded by a gun solenoid, which is the first focusing element.

Two manual tuners are used for coarse tuning of the cavity while the fine frequency change is performed with help of the FPC, which is placed on a translation stage.

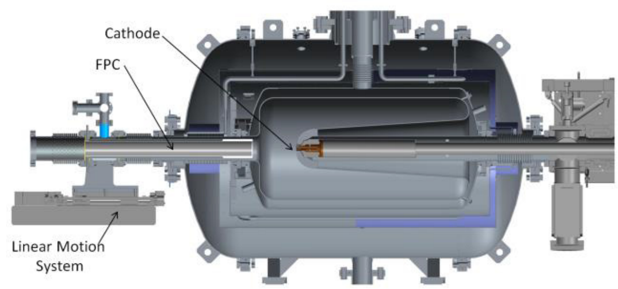

Figure 1: Layout of the superconducting gun.

The fundamental power coupler is followed by a laser cross which serves for launching of the drive laser beam onto the cathode.

EXPERIMENTAL SET-UP

The tests were performed with fully installed equipment and the low energy beam line components are shown in Fig. 2. The main systems components are:

- cathode manipulation system with "garage", which serves for storage and insertion of the photocathodes.
- the gun itself.
- six solenoids for the beam focusing.
- two copper 500 MHz cavities for energy chirp.
- 704 MHz accelerator cavity.
- dipoles and quadrupoles in the high energy part.
- beam diagnostics.
- drive laser.

The brief description of the systems is below.

Drive Laser

The drive laser is built by NuPhotons. It generates up to 0.5 μJ pulse at 532 nm wavelength. The pulse duration is variable from 100 ps to 1 ns and maximal repetition rate is 78 kHz.

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#pinayev@nnl.gov

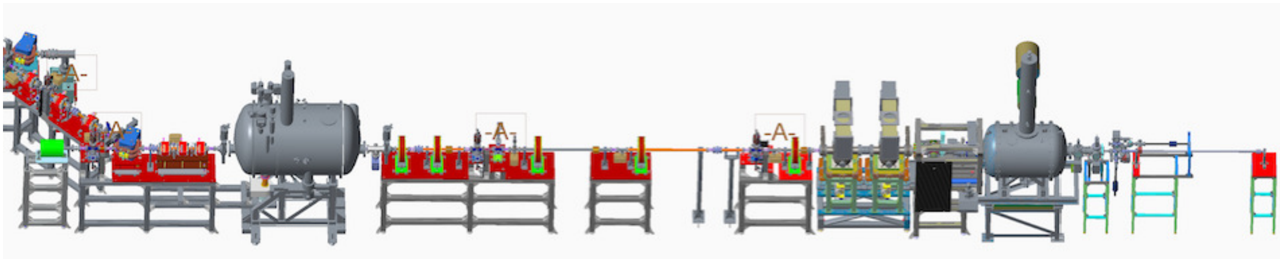

Figure 2: Rendering of the CeC beamline until its merge with RHIC. The overall length is about 20 meters. The gun on the right hast cathode launch mechanism attached. The green on the left is low power beam dump used for the accelerator tuning.

Diagnostics

The beam diagnostics include integrating current transformer (ICT) with sensitivity of 0.8 nV s/nC. During test the ICT output was connected to the LeCroy digital oscilloscope. The ICT is installed immediately after the laser cross allowing observing beam leaving the gun.

After June 6th the output of the ICT was connected to the digitizer and charge extracted from the gun was logged. We also added filtering and amplifier to improve signal to noise ratio.

The transverse beam profile can be viewed with four profile monitors equipped with 1.3 MP GigE cameras. In front of the second profile monitor there is a set of slits for the emittance measurement of the beam. The slits width is 0.2 mm and separation is 2 mm. The third profile monitor is placed after the dipole and allows to measure beam energy as well as energy spread.

Beam position can be monitored with BPMs with Libera Single Pass E+ receivers.

Low power beam dump serves as Faraday cup for the independent charge measurement.

BEAM TESTS

The first tests were performed at the end of RHIC run 15 in parallel with conditioning of one of the RF cavities [3]. These tests demonstrated 1.6 nC beam charge.

During summer shutdown all equipment was installed and we started operations after start of Run 16 [4]. We rebuild the cathode launch system which was prone to vacuum failures.

After the start we re-conditioned the cavity with helium processing. After conditioning we inserted the cathode with photoemissive coating. With turning on of the RF power we developed strong multipacting, which substantially reduced quantum efficiency of the cathode. Nevertheless, we were able to test diagnostics equipment such as BPMs, ICT, Faraday cup, profile monitors, emittance measurement system and magnetic elements of the beamline.

After developing procedure of fast overcoming of the multipacting barriers we were able to operate photocathode with high efficiency. On the first day it demonstrated 2.1 nC charge. Later we were able to demonstrate even higher 3.7 nC charge (see Fig. 3). The cavity voltage was 1.2 MV, and the laser spot size on the cathode was 1 mm. The duration of the laser pulse was 1 nanosecond.

We studied dependence of the cathode quantum efficiency on the extracted charge. It is shown in Fig. 4.

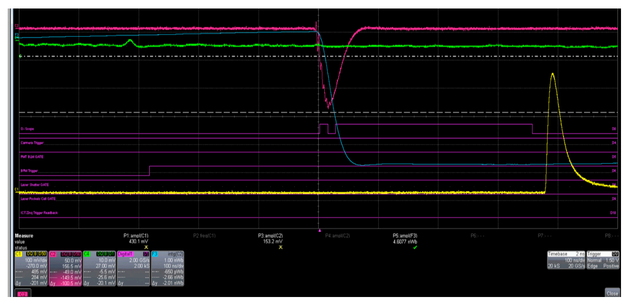

Figure 3: Oscilloscope trace (magenta) of the record 3.7 nC charge extracted from the gun.

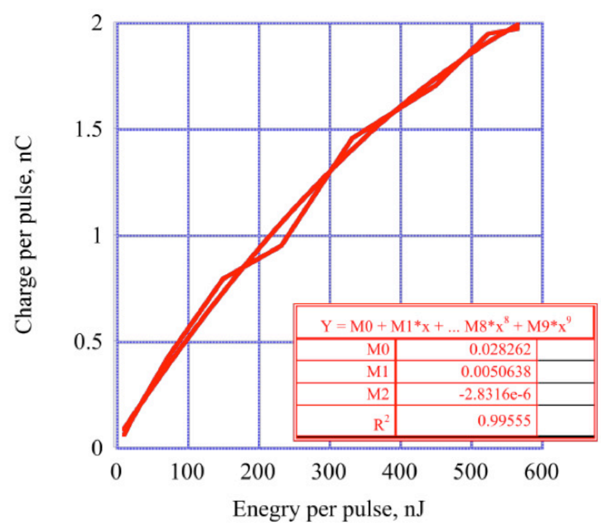

Figure 4: Dependence of the extracted charge vs. laser pulse energy. At high charge we observe drop of the quantum efficiency due to the space charge effects.

We have made substantial efforts for measuring beam emittance. The beam transverse profile after passing through the slits is shown in Fig. 5. Beam energy was 1.2 MeV, pulse length 0.5 ns, and beam charge 0.25 nC.

We also measured beam size while varying solenoid current. Figure 6 shows dependency on the focusing strength of the LEBT_1 solenoid place 0.65 m away from the profile monitor. From the analysis [5] we can estimate beam emittance of 1.3 mm mrad for the horizontal plane and 1.9 mm mrad for the vertical plane. This measurement was performed in the set up close to the one during measurements with slits. Increase of the gun solenoid current to 9.5 A allowed us to measure emittance of the 0.6 microns.

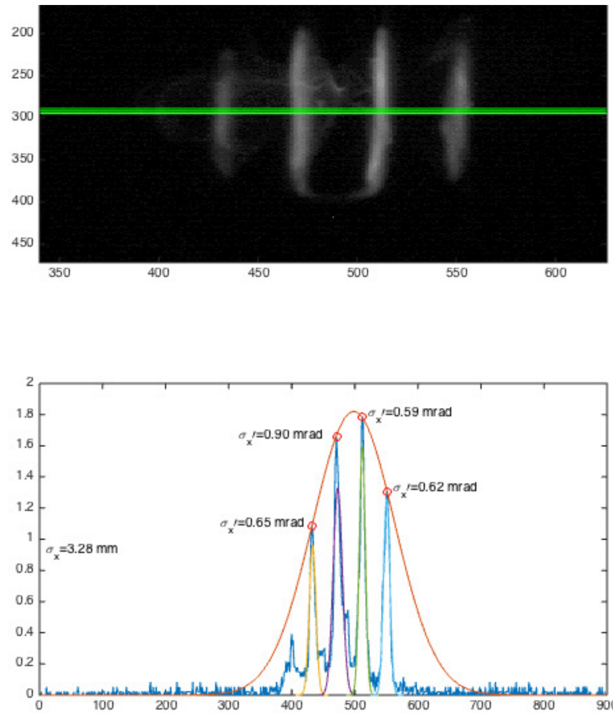

Figure 5: Beam distribution at the second profile monitor after coming through the set of the vertical slits. Distance between slit and profile monitor is 0.35 m and was used for beam divergence calculations. Vertical beam size is 3.28 mm r.m.s. The geometrical emittance is about 2 microns.

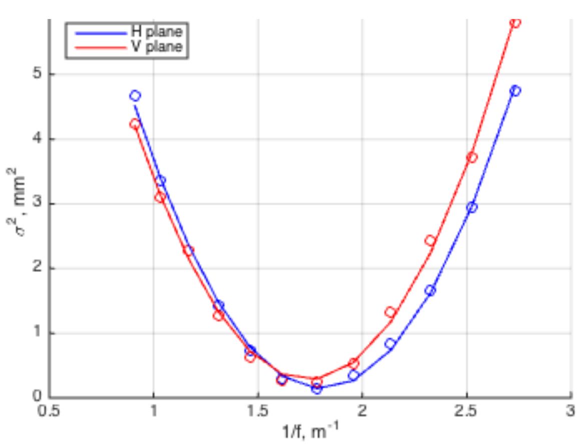

Figure 6: Dependence of beam size on the focusing strength of the LEBT_1 solenoid. Measurements were performed using the first profile monitor.

The multialkaline cathodes demonstrated substantial lifetime [6]. One of the cathodes was operating stably for a few weeks (see Fig. 7). The main reason for the loss of the emissivity was multipacting in the gun developing with turning on RF.

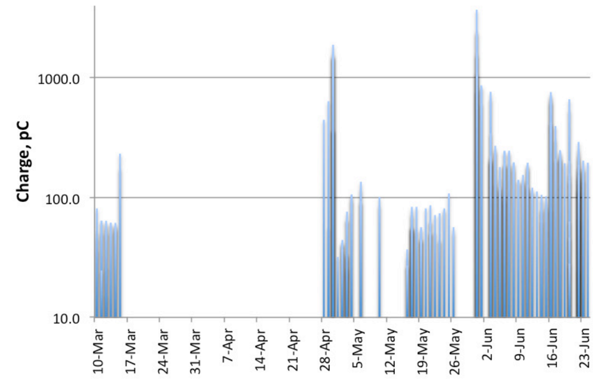

Figure 7: Charge extracted from the cathode during Run 16.

CONCLUSION

We have demonstrated the record beam charge for the SRF gun. The charge level and cathode lifetime are sufficient for the CeC PoP experiment.

We will continue our efforts to improve emittance and achieve higher energy during Run 17.

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