RECORD PERFORMANCE OF SRF GUN WITH CSK2SB PHOTOCATHODE*

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Abstract

High-gradient CW photo-injectors 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 CsK2Sb photocathode (i.e. ~ 20 MV/m) generating a record-high bunch charge (i.e., 2 nC). We briefly describe the system and then detail our experimental results.

INTRODUCTION

The coherent electron cooling experiment (CeC PoP) [1, 2] is expected to demonstrate cooling of a single hadron bunch in RHIC. A superconducting RF gun operating at 112 MHz frequencies generates the electron beam. 500-MHz normal conducting cavities provide energy chirp for ballistic compression of the beam. 704-MHz superconducting cavity will accelerate beam to the final energy. The electron beam merges with the hadron beam and after cooling process is steered to a dump. The FEL-like structure enhances the electron-hadron interaction. The electron beam parameters are shown in the Table 1.

Table 1: Parameters of the Electron Beam

Parameter	Value
Energy	22 MeV
Bunch charge	1-5 nC
Normalized emittance	< 5 mm mrad
Energy spread	$< 10^{-3}$

GUN DESIGN

The CeC PoP gun has quarter-wave structure and operates at 113 MHz. 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 into cone and is kept at room temperature. Such design allows having at room temperature a CsK_2Sb cathode, which is inserted inside of the stalk. 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. The RF power is provided by 2-kW solid-state amplifier. The FPC is surrounded by a gun solenoid, which is the first focusing element.

The cavity is coarsely tuned with two manual tuners while the fine frequency change is performed with help of the FPC, which is placed on a translation stage.

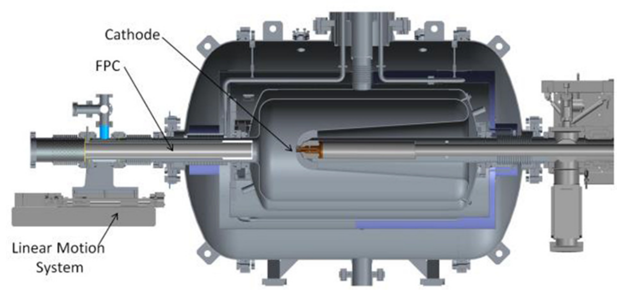

Figure 1: Layout of the superconducting gun.

The fundamental power coupler is followed by a laser cross which serves for launching of the drive laser beam onto the cathode and allows to serve the cathode as well.

TEST SET-UP

The tests were performed with fully installed equipment and the 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.
- beam diagnostics.
- drive laser.

The brief description of the systems is below.

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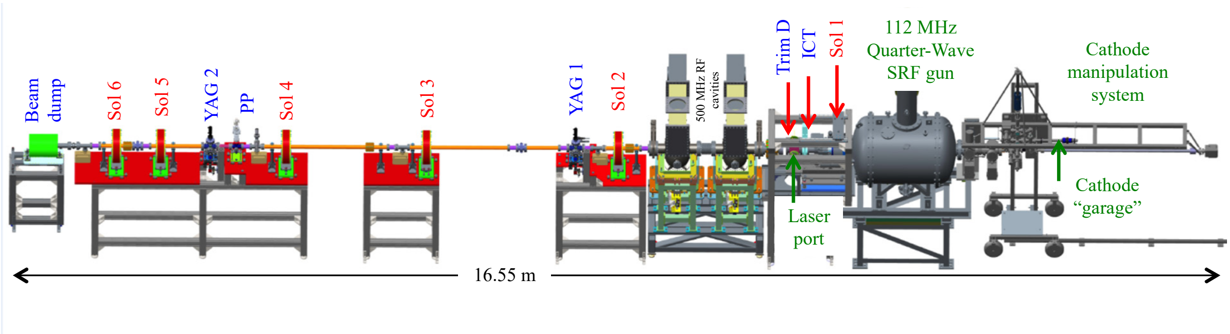


Figure 2: Rendering of the low energy beamline. The overall length is about 16 meters. The gun on the right hast cathode launch mechanism attached. Presently on the place of the beam dump we have installed 704 MHz accelerating cavity and beam dump is shifted down.

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.

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.

The transverse beam profile can be viewed with two 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.

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

The beamline was terminated with low power (uncooled) beam dump, which also can serve as Faraday cup.

BEAM TESTS

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

During summer shutdown all equipment was installed and we started operations after start of Run 16. 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. We were able to test diagnostics 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 (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.

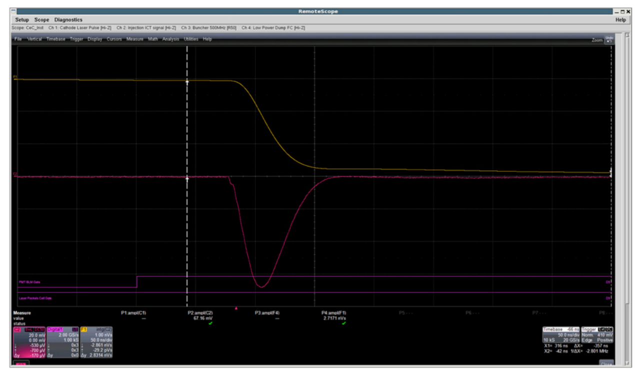


Figure 3: Oscilloscope trace (magenta) of the record charge extracted from the gun as well as its integral. The integral is 2.7 nVs, which corresponds to 2.1 nC charge.

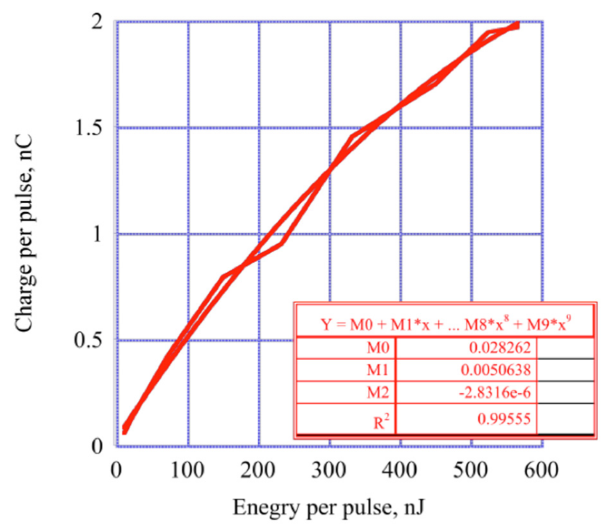


Figure 4: Dependence of the extracted charge vs. laser pulse energy. At high charge we observe drop of the quantum efficiency due to the space charge effects.

On the second day of the tests cathode was delivering 1 nC of charge and we measured beam emittance. The beam transverse profile on the screen is shown in Fig. 5. Figure 6 shows distribution of beam intensity after insertion of the horizontal slits for measuring of the vertical emittance. From the divergence and beam size we can estimate beam emittance of 0.5 mm mrad for the horizintal plane and 1.5 mm mrad for the vertical plane.

Later we needed to switch off RF due to access to the RHIC tunnel. During come back we developed multipacting and the cathode quantum efficiency dropped significantly and we were getting only 100 pC of charge. At this level cathode was operating stably for a few days.

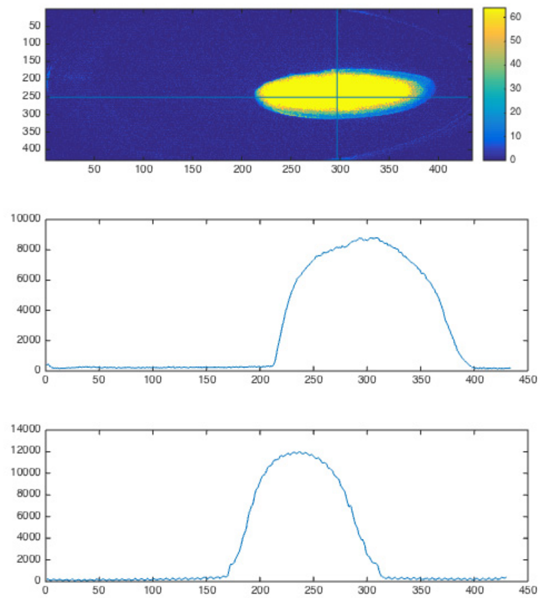


Figure 5: Beam distribution at the second profile monitor. Horizontal beam size is 9 mm FWHM, and vertical is 6 mm FWHM

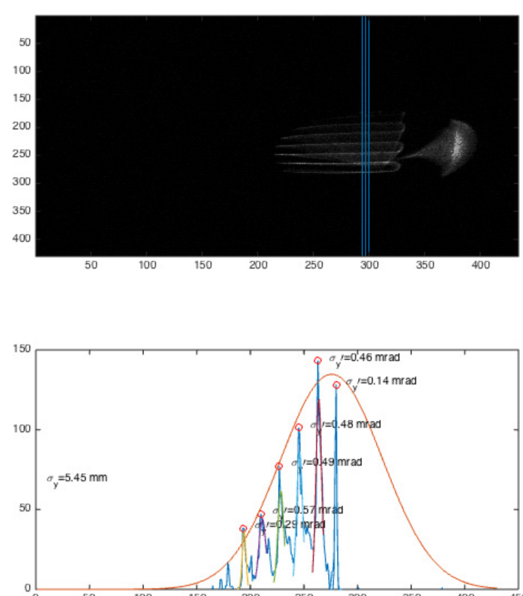
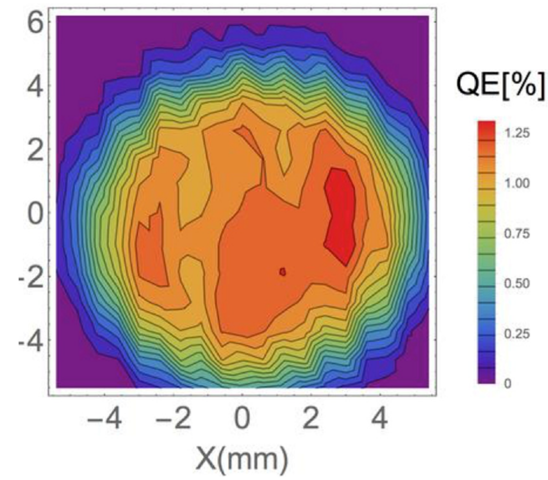
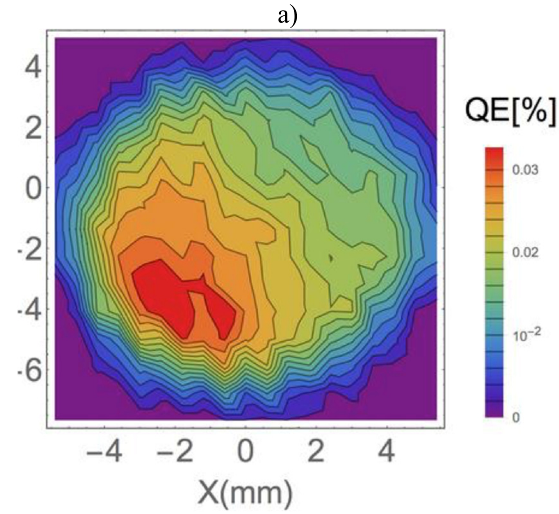


Figure 6: Beam distribution after insertion of the horizontal slits. The beam in the center has angular r.m.s diversion of 0.5 mrad.

We have measured quantum efficiency map of the fresh cathode as well as whet it was operating at 100 pC charge level. The results are shown in Fig. 7.



a)



b)

Figure 7: Quantum efficiency map of fresh (a) and damaged (b) cathode.

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. Beam parameters are with the requirements.

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