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EMITTANCE MEASUREMENTS AND SIMULATIONS FROM SRF GUN IN CEC ACCELERATOR

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Abstract

In this paper, we report on extremely good performance of 113 MHz SRF CW gun. This gun is a part of the system built to test coherent electron cooling concept and was aimed to generate trains of 78 kHz pulses with large 1 nC to 5 nC charge per bunch. While it was not built for attaining record low emittances, the machine can achieve very low normalized emittances ~ 0.3 mm mrad with 0.5 nC charge per bunch using CsK2Sb photocathode. In addition to ex-cellent performance, this gun provides for very long lifetime of these high QE photocathodes, with a typical using time of 2 months.

INTRODUCTION

Coherent electron Cooling (CeC) is a novel technique promising high cooling rates for high energy hadron beams [1], BNL's future electron-ion collider, eRHIC especially concerns its feasibility [2]. We found CeC efficiency to outperform other cooling methods such as electron cooling or stochastic cooling by orders of magnitude. Since CeC is untested method, it will need to be tested by cooling a single bunch of gold ions circulating in RHIC [1]. The proof-of-principle experiment is conducted at BNL to demonstrate this technique. The dedicated accelerator, shown in Fig.1, comprising of 113 MHz SRF electron gun, two 500 MHz room-temperature bunching cavities and 704 MHz SRF linac built for this purpose has been commissioned and now is fully operational [3].

Since CeC SRF accelerator uses cryogenic system supplied by RHIC, it is able to operate only during RHIC runs. The SRF electron gun with CsK2Sb photo-cathode is operating for third season and generates electron beams with kinetic energy of 1.05-1.15 MeV and to 3.9 nC charge per bunch. In this paper, we pre-sent selected simulation and experimental results focused on the transverse beam emittance.

SRF GUN AND PARMELA SIMULATIONS

The electrons in the SRF gun are generated from CsK2Sb photocathode by illumination from green 532 nm laser generating pulses with 0.25-nsec to 0.5-nsec duration. After accelerating to kinetic energy of 1.05 MeV (total energy 1.56 MeV), the beam propagates through the gun solenoid (located z = 0.65 m from the cathode, further in the text all distances are from the cathode surface), the bunching cavities (turned off for this measurements) and first transport solenoid (LEBT1, at z = 3.65 m) before it can be observed at YAG profile monitor (z = 4.28 m). The arrangement of this beamline is shown in Fig. 2. Being a low energy beam, its beam dynamics is strongly influenced by space charge starting from charge per bunch of few hundreds of pC. The particle tracking code PARMELA [4] has been used to simulate the beam dynamics.

We simulated the evolution of projected emittance and attempt to optimize strength of the gun and LEBT1 solenoids as well as the laser spot size on the cathode. Table 1 summarizes the parameters used in this optimization and result is summarized in Fig. 3. Cathode is located without recession in this simulation.

Table 1: Parameters Used for Optimization

Laser spot [mm]	Pulse length [ps]	Bunch charge [nC]	Energy gain [MeV]
1.25 ~ 2.5	300	0.1~0.5	1.05

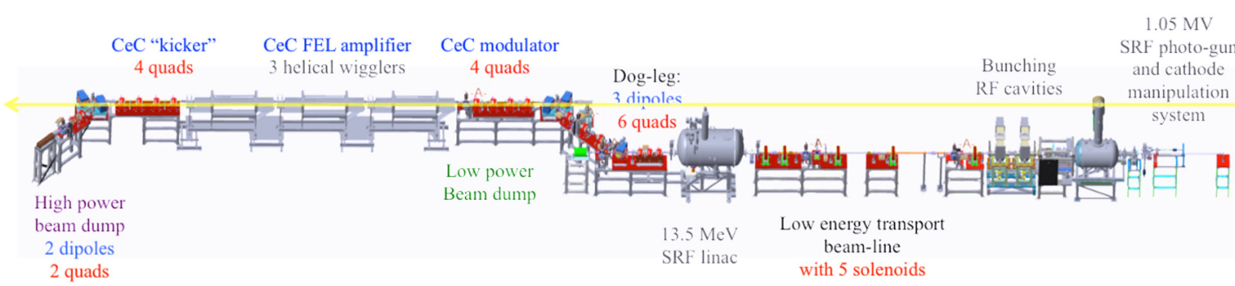

Figure 1: The layout of CeC experiment.

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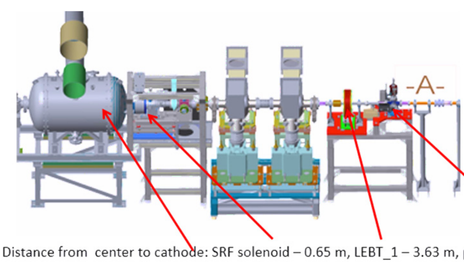

Distance from center to cathode: SRF solenoid – 0.65 m, LEBT_1 – 3.63 m, profile monitors - 4.28 m

Gun Solenoid

Parameter	Value
Maximal current	13.4 A
Peak axial field	0.693 kGs
Integral B_z dz	12.63 kGs cm
Linear magnetic length	18.2 cm
Integral B_z^2dz	6.14 kGs^2 cm
Quadratic magnetic length	12.8 cm
Resistance	1.12 Ohm

Beam Line Solenoids

Parameter	Value
Maximal current	8.4 A
Peak axial field	1 kGs
Integral B_z dz	12.24 kGs cm
Linear magnetic length	12.2 cm
Integral B_z^2dz	8.47 kGs^2 cm
Quadratic magnetic length	16.7 cm
Resistance	1.6 Ohm

Figure 2: The SRF electron gun, the gun and LEBT1 solenoids and the YAG profile monitor.

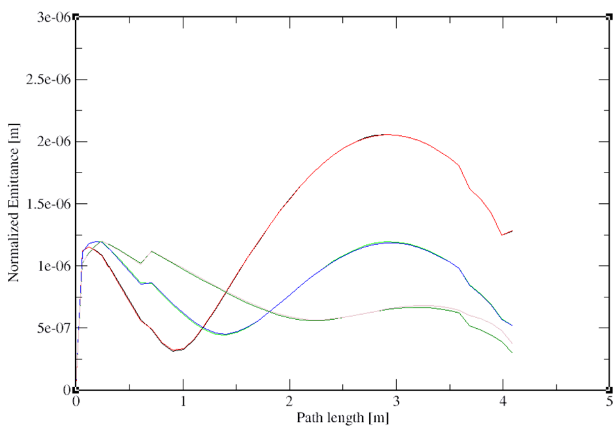

Figure 3: Evolution of the beam normalized emittance for various laser spot sizes: red curve is 1.25 mm, blue curve is 1.8 mm, and green curve is 2.5 mm.

Oscillations of normalized emittance along the beam line, known as emittance compensation, are shown in Fig. 3. Using PARMELA, emittance compensation was simulated to indicate the numerically feasible normalized emittance after the Gun solenoid for different charges.

Optimization has been done by scanning the Gun solenoid or LEBT1 solenoid aiming of minimizing the projected emittance by aligning all the phase space slices as much as possible. We used flat top and beer can-like distribution for the laser pulse and shape [5]. Simulations summarized in Fig. 4 showed that in the beam normalized emittance can be manipulated under one mm-mrad by proper choice of solenoid strength by help of emittance compensation.

Also, the 1.5-mm laser spot size showed relatively better emittance compensation outcome than the 1.0-mm spot size. Therefore, it is found that larger spot size prevents emittance growth in the gun.

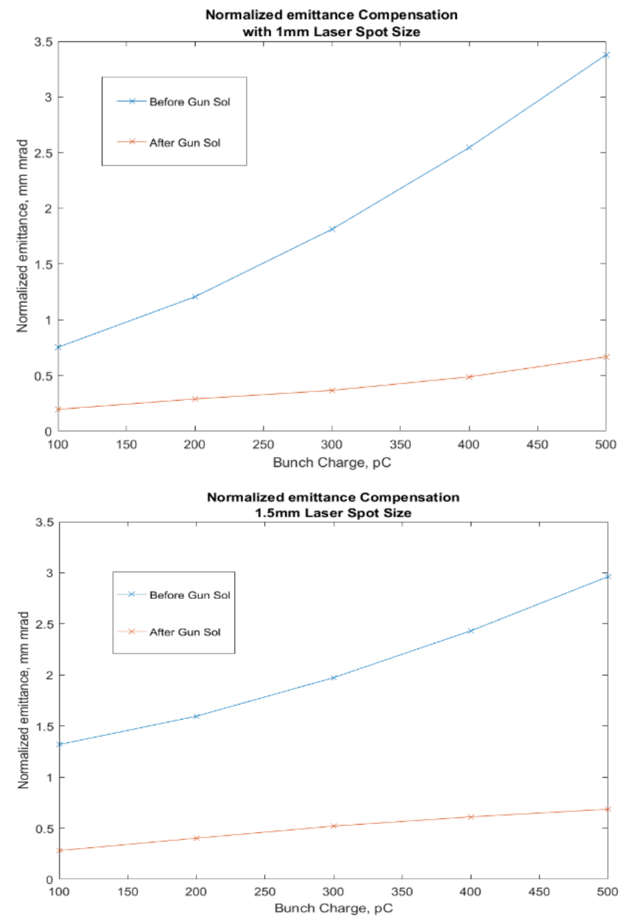

Figure 4: Relationship between emittance-compensation effect by Gun solenoid and bunch charge for 1.0-mm laser spot size (top), 1.5-mm (bottom): blue curve - normalized emittance before the Gun solenoid, red curve - normalized emittance after the Gun solenoid.

The emittance growth due to the nonlinear force inside of the gun is inevitable effect for our system. The different location of the cathode was simulated to test the relationship between the recessed cathode and achievable normalized emittance. The results are shown in Fig. 5. Here, the cathode position, mm, indicates the amount of cathode recession from the cathode nose.

The result showed that the focusing effect inside of the Gun depends on the cathode position. Hence, for certain cathode positions, beam radius at the Gun solenoid gets so tiny that solenoidal focusing becomes less effective compared with the beam of other cathode positions. This would be useful giving us a good estimation of cathode position because fine cathode position adjustment is necessary to have better emittance as shown in Fig. 5.

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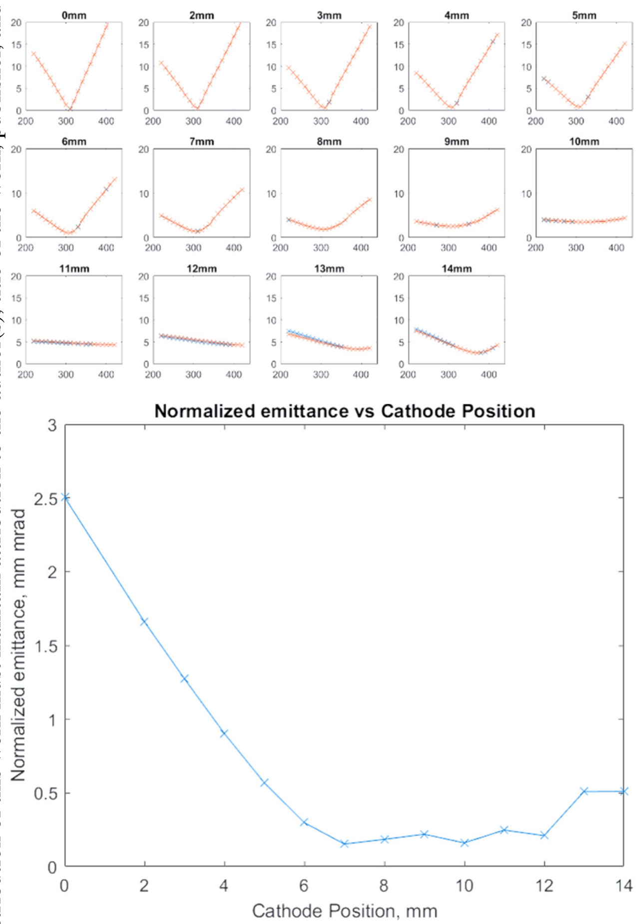


Figure 5: The result of Gun solenoid scan on YAG profile monitor1for different cathode positions (top) and achievable compensated normalized emittance at YAG profile monitor 1 for each cathode position.

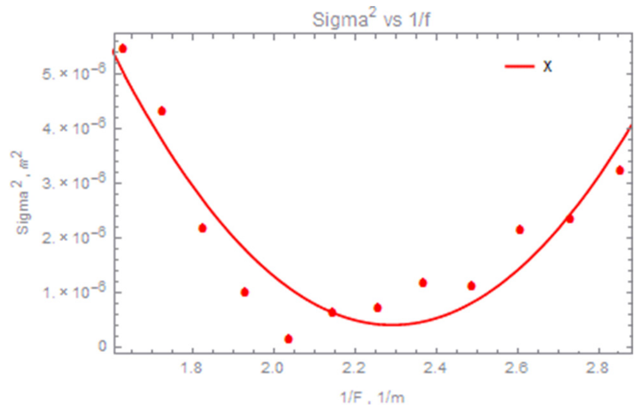
EXPERIMENTAL RESULTS

Experimentally beam emittances were measured using system and script detailed in Fig. 5.

Measurements had been done in three configurations:

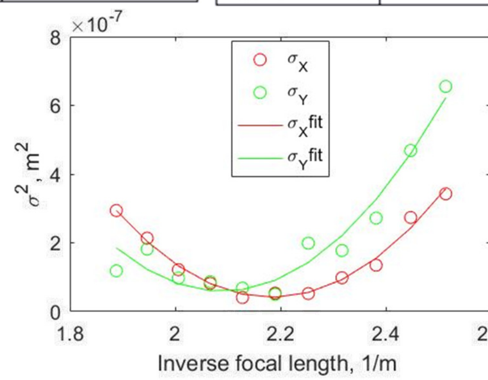
1) Gun solenoid scan and YAG1 profile monitor.
2) LEBT1 solenoid and YAG1 profile monitor.
3) LEBT3 solenoid and YAG2 profile monitor.

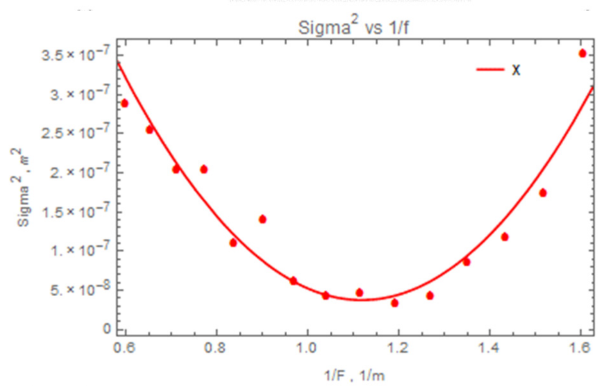
In all case, the SRF gun voltage was at 1.05 MV and the charge per bunch was larger than 100 pC. Some of experimental results of the emittance measurements by the above solenoid's scan are shown in Fig. 6. Measured normalized emittances in horizontal plane were 0.48, 0.95, 0.58 mm mrad for horizontally, correspondingly.



fit	ax^2+bx+c
a	0.0000104474
b	-0.0000478713
c	0.0000552547

β_x [m]	5.00816
α_x [rad]	-10.0929
ϵ_x [m rad]	1.58662×10^{-7}
ϵ_{xn} [m rad]	4.8468×10^{-7}





fit	ax^2+bx+c
a	1.05177×10^{-6}
b	-2.35158×10^{-6}
c	1.35199×10^{-6}

β_x [m]	5.29172
α_x [rad]	-0.752514
ϵ_x [m rad]	1.89218×10^{-7}
ϵ_{xn} [m rad]	5.77651×10^{-7}

Figure 6: Results of three emittance measurements performed using three different solenoid's scans: (a) the gun solenoid and YAG1 profile monitor with 500pC; (b) the LEBT1 solenoid and YAG1 profile monitor with 300pC; (c) LEBT3 solenoid and YAG2 profile monitor with 100pC.

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Possible explanation of larger value of the beam emittance measured using LEBT1 solenoid is its close proximity to the YAG 1 profile monitor and limited resolution of the later. We plan to continue detailed studies of the beam emittance from our unique SRF gun.

CONCLUSIONS

All the experimental results indicate that our SRF gun is generating electron bunches with normalized emittance at submicron scale for bunch charges ~0.5 nC. Therefore, the 113 MHz SRF gun is capable of generating CW beam (in our case 78 kHz rep-rate provided by the laser) with high charge per bunch and sub-micron normalized emittances. Our experimental results also reflect the simulation results done by PARMELA with good agreements, but we will pursue further verification and more detailed comparison. As PARMELA predicts, the fine adjustment of laser spot size is necessary to minimize the normalized emittance and its estimation can be done by Gun solenoid scan. In our low energy transport beamline, we have a “pepper pot” system located in front of the YAG2 profile monitor, which we plan to use for further measurements and analysis our beam.

ACKNOWLEDGMENTS

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