SRF PHOTOEMISSION ELECTRON GUNS AT BNL: FIRST COMMISSIONING RESULTS*

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Abstract

Two SRF photoemission electron guns are under development at BNL. The first gun operates at 704 MHz and is design to deliver high bunch charge and high average current beams for the R&D ERL facility. Its cavity is of an elliptical geometry. The gun cryomodule has been commission without a cathode up to the design voltage of 2 MV. The experiments with a copper cathode are underway. The second gun utilizes a quarter wave resonator geometry with a coaxial cathode insert and beam tube RF power coupler. It will be used to produce high bunch charges, but low average beam currents for the Coherent electron Cooling Proof-of-Principle experiment. This 112 MHz SRF gun was first tested two years ago. Since then it was rebuilt in a new cryomodule and cryogenically re-tested in late 2012 / early 2013, reaching the accelerating gap voltage of 0.9 MV. This paper describes main design features of the two SRF guns, presents test results and discusses future plans.

INTRODUCTION

Two SRF photoemission electron guns are in commissioning/installation stages at BNL. A 704 MHz ½-cell elliptical gun [1, 2] will deliver high bunch charge and high average current beams for the R&D ERL facility [3]. A 112 MHz quarter wave resonator (QWR) gun [4] will produce high bunch charges, but low average beam currents for the Coherent electron Cooling Proof-of-Principle experiment (CeC PoP) [5].

DESIGN AND COMMISIONING OF THE 704 MHz SRF GUN FOR R&D ERL

The R&D ERL at BNL is a facility dedicated to develop accelerator technologies for future energy recovery linac applications [3]. The project will be commissioned in several stages. While the gun is capable to deliver the beam current as high as 500 mA, our eventual goal is to demonstrate average beam current of 300 mA, which will be required for a future electron-hadron collider eRHIC [6]. A 704 MHz elliptical half-cell SRF gun cavity was designed by BNL [1, 2] and fabricated by AES, Inc. The cryomodule was designed and fabricated by AES. Its layout is shown in Figure 1. The gun's main parameters are listed in Table 1.

A copper cathode stalk with a multi-alkali photoemission layer is connected to the cavity via a specially designed quarter-wave choke joint. All surfaces

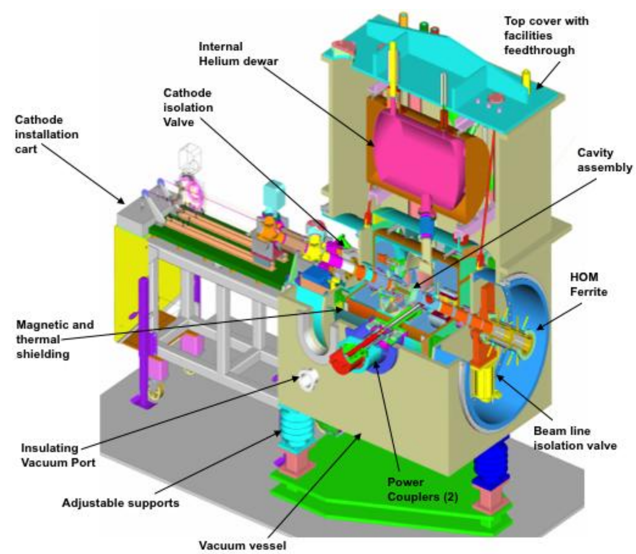

Figure 1: Layout of the 704 MHz ERL gun cryomodule.

Table 1: Parameters of the 704 MHz SRF Gun

RF frequency	703.5 MHz
Cavity active length	8.5 cm (0.4 cell)
Maximum energy gain	2.5 MeV
Maximum field at the cathode	33.4 MV/m
E_{acc} at 2.5 MV	29.4 MV/m
e^- emission RF phase at 2.5 MV	33.4°
Energy gain at 500 mA	2.0 MeV
e^- emission RF phase at 2.0 MV	29.9°
Beam power at 500 mA	1 MW
R/Q	96.2 Ohm
Cavity geometry factor	112.7 Ohm
Cavity Q_0 at 2 K	3×10^{10}
Cavity operating temperature	2 K
Cavity RF losses (2 K) at 2.0 MV	1.4 W
Cathode operating temperature	80 K
Copper cathode RF losses (80 K) at 2.0 MV	226 W

of the choke joint are grooved to prevent multipacting [7]. The gun has two fundamental RF power couplers (FPCs) allowing delivery of 1 MW to a 500 mA electron beam. The couplers were manufactured by CPI/Beverly. FPCs

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were conditioned with maximum RF power of 250 kW pulsed and 125 kW CW in a full standing-wave mode [8]. A beamline ferrite load with a ceramic break separating the ferrite tiles from beam vacuum provides strong HOM damping [9, 10]. A high temperature superconducting (HTS) solenoid is located inside the cryomodule near the beam exit.

The cryomodule was assembled at BNL, including its hermetic string preparation in the clean room. It was installed in the ERL blockhouse where its commissioning without a cathode began in November of 2012 and was completed in March of 2013 [11]. Eventually, the gun cavity achieved 2 MV (the original design voltage) and 220 kW of RF power in CW mode. In pulsed mode, with a 0.7 ms pulse duration and 1 Hz repetition rate, the RF power was up to 400 kW. This allowed high-power RF processing (HPP) of field emission in the cavity, as illustrated in Figure 2.

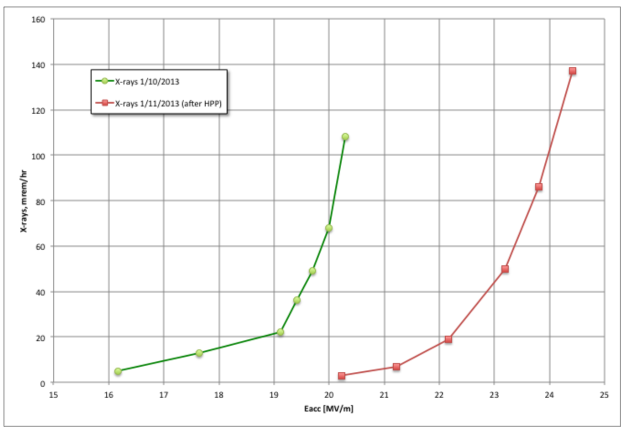

Figure 2: X-ray level near the SRF gun before and after high-power RF processing.

Digital LLRF was commissioned, demonstrating the cavity field amplitude stability of $2.3 \cdot 10^{-4}$ and phase stability of 0.035° (both rms). Measured Lorentz force detuning coefficient is -11.9 Hz/(MV/m)^2, the cavity frequency sensitivity to He bath pressure is 704 Hz/Torr.

Commissioning with a copper cathode has begun in August of 2013 [11]. So far, we have reached 1.8 MV with an RF pulse duration of 40 ms; and 2.2 MV with 0.5 ms. The pulse repetition frequency was 10 Hz in both cases. At low field levels there was multipatcing in the choke-joint, which was conditioned easily. At higher fields we have to re-condition FPCs. The conditioning will continue until we reach stable operation at 2 MV in CW. Testing with a multi-alkali cathode and first beam generation is tentatively scheduled for November of 2013.

112 MHz SRF GUN FOR COHERENT ELECTRON COOLING EXPERIMENT

A superconducting 112 MHz quarter-wave resonator type SRF gun will be used to produce high charge bunched at 78 kHz repetition rate for CeC PoP experiment [12]. The gun was developed by collaborative efforts of BNL and Niowave, Inc. [4]. The low frequency was chosen to take full advantage of QWR benefits. The long wavelength allows generating long bunches and thus reducing space charge effects. A short, with respect to the wavelength, accelerating gap makes transit time factor close to unity and the gap field practically constant.

The gun will operate at 4.5 K with liquid helium provided from a quiet helium source via the cryomodule cryogenic tower. Assuming a residual surface resistivity of 10 nOhm and a residual magnetic field of 60 mG, we expect to achieve the cavity quality factor of 1.8×10^9.

The QWR's center conductor geometry naturally accommodates a half-wavelength choke joint and allows mechanical decoupling of the cathode assembly from the niobium cavity [13]. A low RF loss photocathode stalk operates at room temperature. It is hollow, allowing inserting a small photocathode pack via a load lock system. The gun's cryomodule layout is shown in Figure 3 and the gun parameters are listed in Table 2.

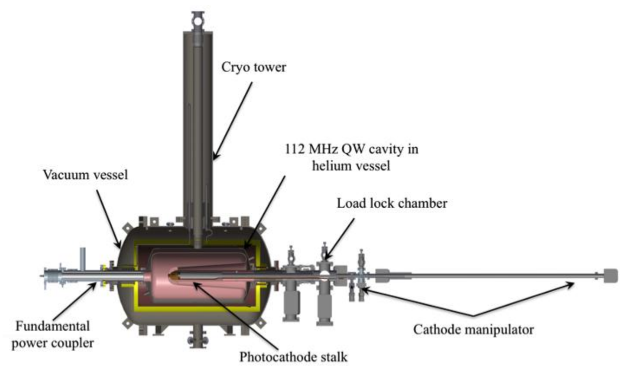

Figure 3: 112 MHz SRF gun cryomodule.

Table 2: Parameters of the 112 MHz QWR SRF Gun

RF frequency	112 MHz
Maximum energy gain	2.0 MeV
Bunch charge	1 to 5 nC
Bunch repetition frequency	78 kHz
R/Q	127.3 Ohm
Geometry factor	38.5 Ohm
Cavity Q_0 at 4.5 K	1.8×10^9
Cavity RF losses at 2.0 MV	17 W
RF losses in the cathode stalk at 2.0 MV	38 W
Frequency tuning range	78 kHz
Frequency tuning with FPC	3 kHz
Q_{ext} of FPC, min.	1.25×10^7
Available RF power	2 kW

The 112 MHz gun uses a dual-purpose fundamental RF power coupler/fine frequency tuning assembly [13]. The fine frequency tuning is achieved via adjusting the FPC position and has a range of 3 kHz. It will be controlled

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remotely. The fine tuner will complement a larger range (78 kHz) coarse mechanical tuner. The coarse tuning is achieved by deforming the cavity gap. It will be used only for an initial frequency set up. A focusing solenoid is placed on top of the FPC close to the cryomodule beam exit flange.

The cavity was designed and built originally as an SBIR project at Niowave, Inc. It was cold tested there and the results were reported previously [4]. Over the last two years, the gun was refurbished and modified to be compatible with installation into the RHIC tunnel. The modified gun was cold tested again at Niowave in December of 2012 and February of 2013 [14]. The gun reached an accelerating voltage of 0.92 MV, limited by an insufficient radiation shielding of the experimental set up. Figure 4 shows the gun cavity behavior during the cold test at Niowave.

After completion of the cold test, the gun cryomodule was shipped to BNL, where it is installed in the RHIC tunnel. The commissioning will begin as soon as cryogenic and other systems are ready, tentatively in January of 2014.

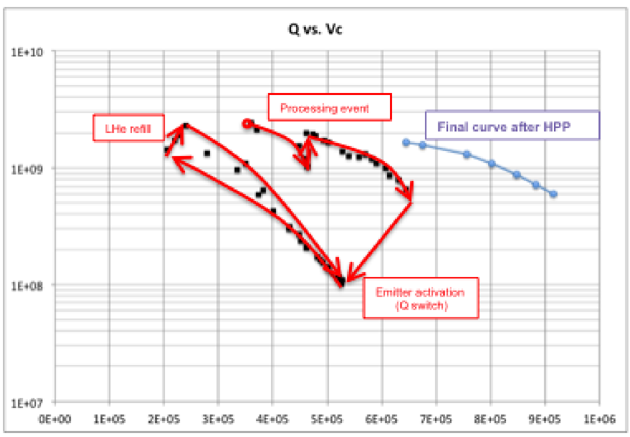

Figure 4: Q *vs.* V_c plot showing the gun cavity behavior during conditioning and the final curve.

SUMMARY

The superconducting RF photoemission electron guns promise to provide high-quality electron beams for a variety of accelerator applications. At BNL, we are pursuing several design options, two of which are in the installation or commissioning stages. The 704 MHz gun, manufactured by AES, Inc. for the R&D ERL, is assembled and is under commissioning with a copper cathode insert. As soon as this phase is complete, a multi-alkali photoemission layer will be deposited on the copper cathode to generate first electron beam. Eventually, it is expected to generate high intensity current beams to demonstrate parameters needed for the future ion-hadron collider eRHIC. The second gun, the 112 MHz QWR, is designed to produce high bunch charge, low average current beam for the CeC PoP experiment. The gun is manufactured, delivered to BNL and installed in the RHIC tunnel. Before shipping, it was cold tested at Niowave, Inc. It will be re-tested at BNL and conditioned to full voltage after the linac set up in the RHIC tunnel is complete in early 2014.

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