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FIRST TEST RESULTS FROM SRF PHOTOINJECTOR FOR THE R&D ERL AT BNL*

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Abstract

An ampere class 20 MeV superconducting Energy Recovery Linac (ERL) is presently under commissioning at Brookhaven National Laboratory (BNL) [1]. This facility enables testing of concepts relevant for high-energy coherent electron cooling, electron-ion colliders, and high repetition rate Free-Electron Lasers. The ERL will be capable of providing electron beams with sufficient quality to produce high repetition rate THz and X-ray radiation. When completed the SRF photoinjector will provide 2 MeV energy and 300 mA average beam current. The injector for the R&D ERL was installed in 2012; this includes a 704MHz SRF gun with multi-alkali photocathode, cryo-system upgrade and a novel emittance preservation zigzag-like low energy merger system. We describe the design and major components of the R&D ERL injector then report the first experimental results and experiences learned in the first stage of beam commissioning of the BNL R&D ERL.

INTRODUCTION

The R&D ERL facility at BNL aims to demonstrate CW operation of ERL with average beam current upto 0.3 ampere, combined with very high efficiency of energy recovery. The ERL is being installed in one of the spacious bays in Bldg. 912 of the RHIC/AGS complex. The intensive R&D program geared towards the construction of the prototype ERL is under way [2]: from development of high efficiency photo-cathodes [3], design, construction and commissioning SRF gun [4], to the development of new merging system compatible with emittance compensation technic [5]. The R&D ERL will test many generic issues relevant with ultra-high current continuously operation ERLs: 1) SRF photo-injector (704 MHz SRF Gun, photocathode, laser) capable of 300 mA; 2) preservation of low emittance for high-charge, bunches in ERL merger; 3) high current 5-cell SRF linac with efficient HOM absorbers [6]; 4) BBU studies using flexible optics; 5) stability criteria of amp class CW beams.

BNL ERL design has one turn: electrons are generated in the superconducting half-cell gun and injected into the main superconductive linac 5cell SRF cavity. Linac accelerates electrons to 15-20 MeV, which then traverse a one turn re-circulating loop with achromatic flexible optics [7].

Two operating modes will be investigated, namely the high current mode and the high charge mode. In the high current (0.3 A) mode ERL will operate electron bunches with lower emittance 0.5 nC bunches with 703 MHz rep-rate. In this case the full energy of electrons at gun exit is limited to 2.5 MeV by the available RF of 1 MW. In a high charge mode, ERL will have electron beam with 5nC per bunch and 10 MHz repetition rate, i.e. it will produce 50 mA average current. In this mode, the electrons energy at the gun exit could be pushed higher. The maximum voltage at the gun is 2.5 MV limited by power coupling design and available RF power.

SRF COMPONENTS

The most important element of BNL ERL is SRF photo-injector. BNL 704 MHz SRF gun has been designed with a short 8.5 cm cell. The short length was chosen to provide high electric field at the cathode at low accelerating voltage. In order to provide effective damping of high order mode (HOM) this gun has rather large iris radius of 5 cm. Ferrate dumpers are installed around ceramic break at the exit of the gun. Gun has been installed at ERL in 2012. SRF gun now routinely operates CW without the cathode at 2 MV accelerating voltage [4]. With cathode stalk installed the gun operated at 1.8 MV voltage pulses 120 msec every second. After most recent additional conditioning the gun demonstrates CW operation at 1.2 MV voltages (as shown in Fig. 1).

The heart of the ERL facility is 5-cell 704MHz SRF linac, which is designed for operating with ampere-class CW beam current [8]. The cavity was designed as a “single-mode” cavity, in which all Higher Order Modes (HOMs) propagate to HOM ferrite absorbers

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through the large beam pipe. This design provides for very low Q's for HOMs and hence very high ERL stability. Measurements of the damped Q and R/Q of the HOMs and simulations show that in nominal operation regime the cavity is stable to over 20 amperes in a one pass ERL and over 2 amperes for two passes ERL. The 5cell cavity has been commissioned in 2010. In cold emission tests high gradients are achieved for short period of time (as shown in Fig. 2).

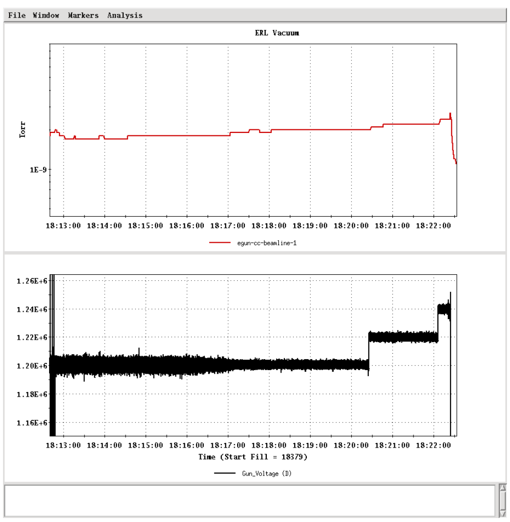

Figure 1: Beam-line vacuum (red) and gun voltage (black) during 1.2 MV CW operation of 704 MHZ SRF gun at BNL.

A thermal problem has been discovered during commissioning SRF 5-cell cavity, which prevents CW operation at gradients above ~12 MV/m. However, the prototype program can still be pursued if the cavity can be operated in a pulsed "quasi-cw' mode up to 20 MV/m, in which the cavity is on, with stable gradient, for a time long compared with the transit time through the ERL loop (10 nsec).

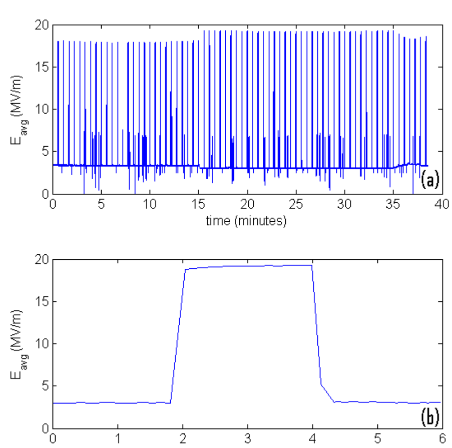

Figure 2: 5 cell cavity performance during horizontal test. Pulses are 2 seconds long with a 30 second interval.

SRF PHOTOINJECTOR FIRST BEAM TEST SETUP

The beam commissioning has been started on June 2014. The first beam test schematic setup shown in Fig. 3. For the first beam test, a Cs3Sb cathode was fabricated and QE has been measured 2E-3 in deposition chamber [3]. The ERL injection dipole is off during first beam test. The current coming from the gun goes straight to the faraday cup and can be measured. Steering magnet is installed next to the laser cross. The beam profile monitor (YAG crystal) can be inserted before the faraday cup to measure beam size.

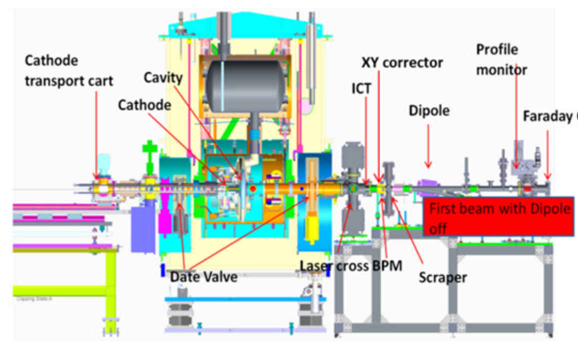

Figure 3: Schematic layout of the SRF injector at BNL R&D ERL.

RESULTS

During initial start of RF power to the gun with cathode inserted several vacuum spikes has been observed at very low gun voltage 8 KV (as shown in Fig. 4). Such vacuum degradation might significantly reduce QE of the cathode. If QE drops below 1e-5 it will be almost impossible to measure.

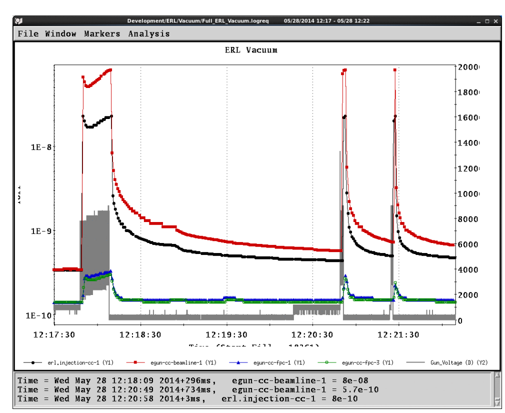

Figure 4: Vacuum spikes as observed during initial start of SRF gun operation with cathode inserted: gray color is gun voltage, other colors vacuum in different section of beam line.

Gun has been running with 40 msec pulses with 1 second interval during dark current measurements. Dark current has been observed at YAG crystal (Fig. 5) and measured by faraday cup (Fig. 6) 1.4μA at cathode field 15MV/m. The PARMELA simulation and energy

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measurements results agreed. After conditioning dark current is measured 25 times less (Fig. 7). The energy measurements cannot be carried out due to very weak signal at the YAG crystal.

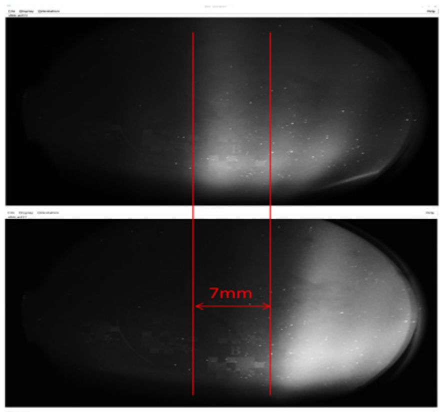

Figure 5: Dark current image taken at beam profile monitor during energy measurement at gun voltage settings 1.2 MV. Corrector current top 0.5 A, bottom 1 A. 7mm shift due to 0.5 A corrector change corresponds to beam energy of 1.2 MeV.

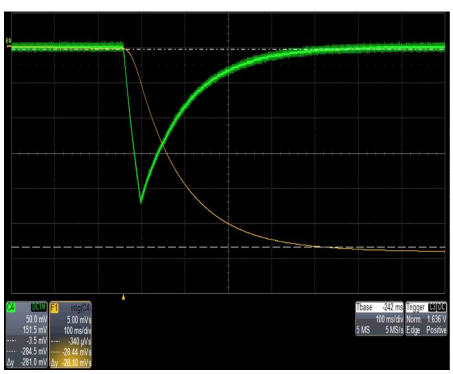

Figure 6: Faraday cup signal (green -225mV peak) due to dark current and its integral (yellow 28 mVsec).

STATUS AND PLANS

The 704 SRF gun with photocathode commissioning has been started at BNL R&D ERL. Gun operate CW at 1.2 MV voltage with cathode inserted.

During the first beam test we were able to set up beam diagnostics and carry out dark current measurements. After conditioning dark current reduced by 25 times. We will continue low power beam tests when new cathode is installed to the gun. We will avoid running gun at low voltage to reduce the risk of developing multipactoring and vacuum degradation. Next time we will have solenoid operational. We will be able to make a cathode image at the beam profile monitor.

The ERL 1MW beam dump is installed. Extraction line magnets vacuum components will be installed shortly. We plan to start gun to beam dump test this summer.

After the recirculation loop will be completed we will be able to demonstrate energy recovery with high charge per bunch and high beam current

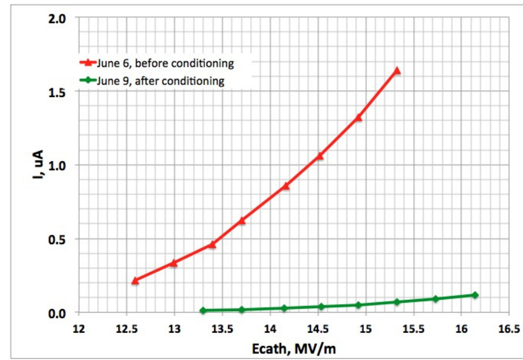

Figure 7: Dark current measured at faraday cup vs field at the cathode, before (red) and after (green) conditioning. Reduction is 25 times.

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