BEAM COMMISSIONING PROGRAM OF THE 704 MHz SRF GUN*

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Abstract

A 704 MHz superconducting RF photoemission electron gun for the R&D ERL project is under commissioning at BNL. Without a cathode insert, the SRF gun achieved its design goal: an accelerating voltage of 2 MV in CW mode. During commissioning with a copper cathode insert, it reached 1.9 MV with 18% duty factor, which is limited by multipacting in a choke-joint cathode stalk. A new cathode stalk has been designed to eliminate multipacting in the choke-joint. At the same time, a first beam test was carried out in May this year, and dark current from the photocathode was measured in the faraday cup. The SRF cavity was tested after the beam commissioning and shows no-degradation of the performance. This paper presents recent commissioning setup, results and plans for the future beam tests.

INTRODUCTION

The R&D ERL [1] at BNL is an accelerator with high average current, up to 500 mA. It serves as test bed for future RHIC projects: eRHIC [2], Coherent-Electron-Cooling [3], and Low Energy RHIC Electron Cooler [4]. The 704 MHz half-cell SRF gun is designed to provide 0.5 A, 2 MeV electron beam. Commissioning of the SRF gun is carried out in stages: without a cathode stalk (finished in early 2013), with a copper cathode stalk (finished in fall of 2013), and beam commissioning (started in mid-2014). The SRF gun without a cathode stalk reached the design voltage of 2 MV in CW mode. During commissioning with a copper cathode stalk, strong multipacting in the quarter-wavelength choke-joint was observed and it was understood with simulation. A multipacting-free choke-joint has been designed and an order was placed its fabrication. In the meantime, first beam commissioning with the existing cathode stalk coated with alkali antimonide photoemission layer took place in May of 2014. Dark current was observed, measured and conditioned. This paper describes the SRF gun commissioning results and plans. A multipacting-free choke-joint design is addressed as well.

PERFORMANCE OF THE SRF GUN

The SRF gun cryomodule is shown in Figure 1. It is built around the 704 MHz half-cell SRF cavity, including a quarter-wavelength choke-joint cathode insert, a pair of opposing fundamental power coupler (FPC) to deliver 1 MW of RF power, a high temperature superconducting solenoid (HTSS) to compensate space charge and a room-temperature ferrite HOM damper. The gun was successfully commissioned and reached the design goal (2 MV in CW mode) without a cathode stalk insert [5]. However, multipacting occured during commissioning with a copper cathode stalk. The main reason for multipacting was caused by distortion of grooves due to BCP and high SEY in the stainless steel area. After spending some time on mutipacting conditioning, the gun was able to operate at 1.9 MV with 18% duty factor. One important parameter for the cavity operation is its field stability. The amplitude stability of 2.3E-4 (rms) and the phase stability of 0.035 degree (rms) was demonstrated.

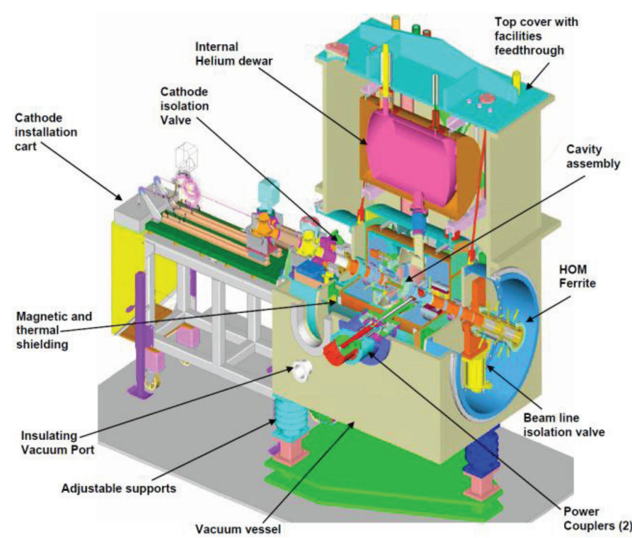

Figure 1: SRF gun cryomodule.

MULTIPACTING-FREE CATHODE STALK DESIGN

Figure 2 shows the cathode stalk to be inserted into the SRF cavity. There are two folded half-wavelength chokes or four quarter-wavelength chokes, so the stalk has four gaps. The copper cathode substrate and an inner Nb cylinder compose the first gap. The second gap (end of the first half-wavelength choke) is formed by two Nb cylinders. The third gap is composed of the outer Nb cylinder and an inner stainless steel cylinder. Two stainless steel cylinders constitute the forth gap. The Nb cylinders are part of the

Nb cavity, which stays inside the cryomodule. The copper substrate and stainless steel cylinders form the cathode stalk, which stays with a cathode transport cart.

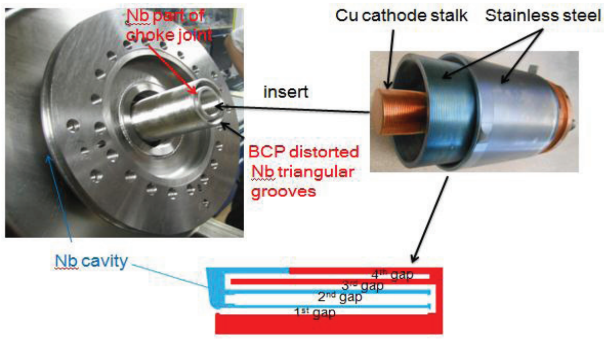

Figure 2: Quarter-wavelength cathode stalk insertion.

To run the gun in CW mode, a new multipacting-free photocathode choke joint has been designed, as shown in Figure 3. The main features of the new design are: 1) To suppress multipacting in the 1st gap, the ratio of the groove's depth over period is increased from 1 to 2; 2) To suppress multipacting in the 3rd and 4th gaps, the ratio of the groove's depth over period is increased from 1 to 1.2; 3) To suppress multipacting in the 2nd gap (Nb part), the cathode radius is reduced from 1.25 to 0.9 cm, which pushes the field higher. The results of multipacting simulations in the choke joint are shown in the Figure 4.

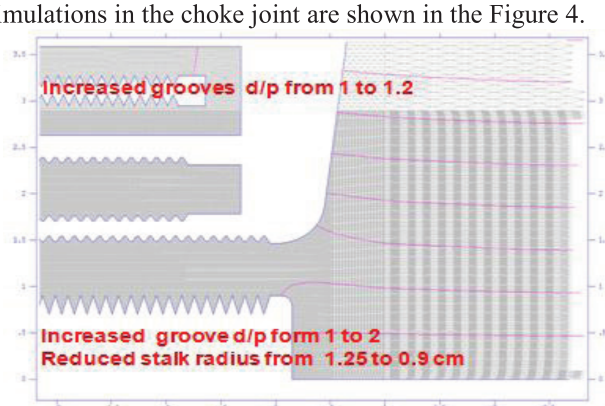

Figure 3: New design of a multipacting-free cathode stalk.

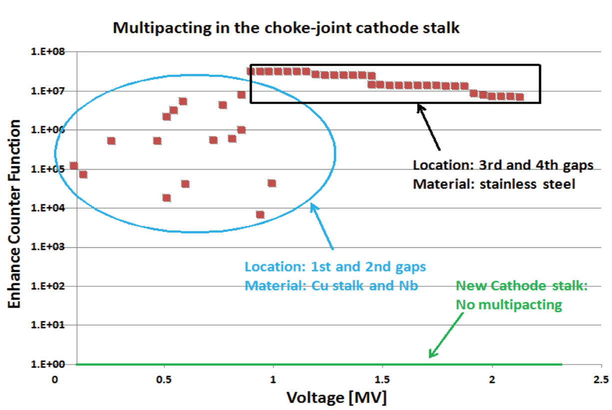

Figure 4: Multipacting simulation results in the quarter-wavelength choke joint.

Figure 5 shows thermal analysis of the new photocathode stalk. One important concern is RF heating of the choke-joint. With a fin style LN2 cooling channel, the cooling capacity is 736 W, which is bigger than the heat load of 656 W. RF heat load to 2 K is only 5.22 W, as compared with 7 W in the current design without the fin style cooling channel. The maximum temperature on the cathode stalk is 83.1 K. In addition to multipacting suppression, the tip of the cathode stalk will be coated with tantalum to increase quantum efficiency (QE) of the photocathode.

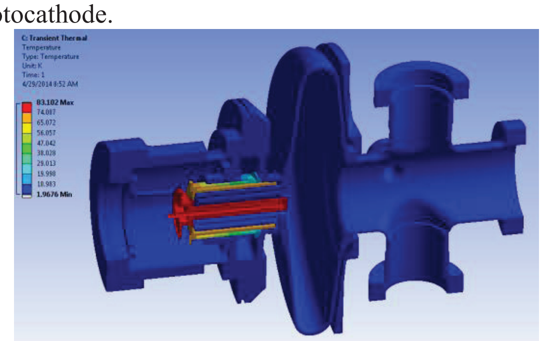

Figure 5: Thermal analysis of the new cathode stalk.

BEAM COMMISSIONING LAYOUT

The first beam commissioning of the SRF gun is done with a straight beam line ending up at a faraday cup, instead of going through a Zig-Zag injection line. The beam line configuration is shown in Figure 6. The Cs_3Sb photocathode [6] was deposited on the cathode stalk with copper substrate (a new cathode stalk will use Ta substrate) in the cathode deposition system located outside the ERL blockhouse. Then, the cathode stalk was moved to the ERL blockhouse inside the cathode transport cart and inserted into the SRF gun. A load-lock system is used for the connection between the SRF gun and cathode transport cart. Following the 704 MHz half-cell SRF cavity, there is a high temperature solenoid (HTSS), a room-temperature HOM absorber, a laser cross, an Integrated Current Transformer (ICT), a Beam Position Monitor (BPM), a vertical and horizontal beam corrector, a beam halo monitor, a pepper pot beam emittance measurement device, a beam profile monitor and a Faraday cup. The dipole magnet for bending electron beams to Zig-Zag is locked out for the first beam tests [7].

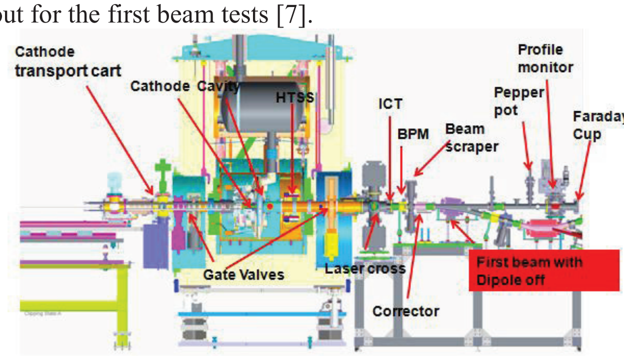

Figure 6: First beam commissioning configuration.

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BEAM TEST RESULTS

Because the substrate of the cathode stalk is copper, the QE is relatively low, 0.25% as measured in the cathode preparation chamber. After the cathode was inserted, we spent a little bit of time on setting up the field parameters in the cavity: 1.2 MV, 40% duty cycle. During the cathode insertion, there were a few minutes with vacuum worse than 1e-9. Also, the vacuum gauge (located 0.5 m away from the cathode in the downstream of the beam line) read vacuum level in order of 1e-8 for about 20 seconds. These made the QE to degrade dramatically. As a result, no photoemission was measured during the experiment, even when relatively high laser power was used. However, a dark current was observed by a beam profile monitor (YAG screen) and measured by the faraday cup. A typical dark current signal is shown in Figure 7.

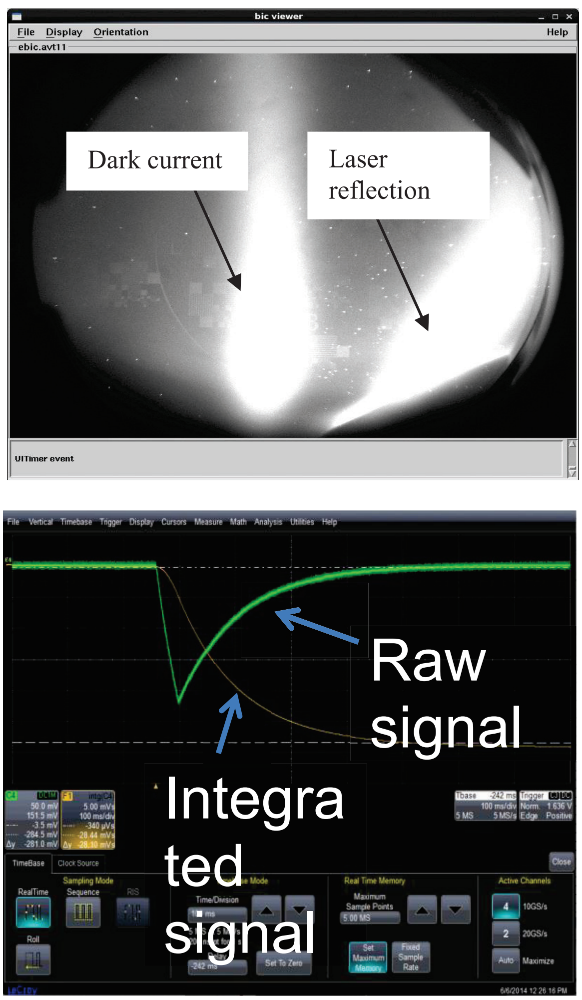

Figure 7: Dark current image on YAG screen (above) and dark current measured by faraday cup (bottom).

After spending a few hours on conditioning field emission, the dark current reduced by about 25 times. Figure 8 compares the dark current before and after conditioning. After conditioning, we were able to run the gun at 1.2 MV in CW mode. The duty cycle at other field levels increased as well. The cavity was tested again after the cathode stalk was removed from the gun. There was no measurable dark current and little radiation at the field levels relevant for beam commissioning, the same as was measured before the cathode stalk insertion.

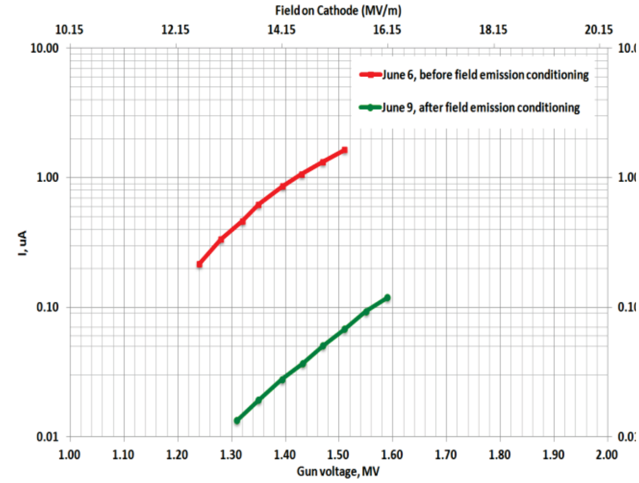

Figure 8: Dark current measured before and after conditioning.

SUMMARY

The SRF gun for the R&D ERL is at the beam commissioning stage. So far, only one photocathode was made and tested. All subsystems function well. This is a milestone, even though only dark current but not photoemission was observed. Vacuum degradation during insertion of the photocathode is under investigation and will be improved in the next tests. There is no sign of the cavity performance degradation due to operating with photo-cathode.

A new cathode transport cart and multipacting-free photocathode stalk with Ta tip are in preparations. Also, the cathode stalk insertion procedure will be improved to avoid the vacuum spikes during the cathode insertion. An RGA will be added at the exit of the SRF gun cryomodule. With these improvements, we expect to observe photo-emission current.

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