

DC PHOTOEMISSION GUN UPGRADE AT THE COMPACT ERL

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Abstract

We have developed a DC photoemission gun at the compact ERL (cERL) at KEK for future energy recovery linac light sources and high repetition rate X-ray FELs. The cERL gun has stably provided beam for ERL commissioning and laser Compton scattering experiments since April 2013. The operational voltage has however been limited to 390 kV due to failures of two segments out of the full ten segmented ceramics. In order to recover 500 kV operation, we installed an additional two segmented ceramics on the existing ceramics during summer shutdown in 2015. We performed high voltage conditioning up to 548 kV and holding test at 500 kV for more than four hours. With the upgraded gun we demonstrated high current operation up to 1 mA at 390 kV as well as high voltage operation at 450 kV at the cERL.

INTRODUCTION

DC gun-based photoinjectors have been developed worldwide for a high repetition rate X-ray free electron laser (XFEL) such as LCLS-II and a high power FEL based on energy recovery linac (ERL) for EUV lithography [1,2]. Recently cathode thermal emittance dominated high bunch charge beams satisfying LCLS-II injector specifications were successfully generated at the Cornell photoinjector with a 400 kV photoemission gun [3]. A record high average current of 75 mA was also generated at the Cornell photoinjector [4,5]. The average current is three orders of magnitudes greater than LCLS-II specification and high enough for high power EUV FEL.

Development of a photoemission DC gun with voltage higher than 400 kV is important to reduce space charge induced emittance growth especially for FELs driven by high bunch charge. Employment of a segmented insulator is a key to reach higher voltage [6]. This technique led to the first demonstration of 500 keV beam from a photoemission DC gun at Japan Atomic Energy Agency (JAEA) [7]. The gun has been used for commissioning of the compact ERL (cERL) at KEK since April 2013 [8]. The gun operational voltage at the cERL is however limited to 390 kV, because the insulator is operated with eight segments due to the failures of two segments out of the full ten. Recently a new two segmented insulator was installed on the top of the existing insulator. The insulator with 2+8 segments was successfully conditioned up to 548 kV with the cathode electrode in place. Generations of high current beam up to 1 mA and high energy beam up to 450 keV were demonstrated at the cERL. In this paper, we describe status of the cERL gun upgrade.

HIGH VOLTAGE GUN AT THE CERL

As demonstrated at the Cornell photoinjector, it is feasible to generate cathode emittance dominated beam using a photoemission DC gun. Development of higher voltage and higher gradient gun will help further improve the performance of the DC gun-based photoinjector. The photoemission DC gun at the cERL was mainly developed at JAEA. The details of the gun system are described in Refs. [6,7,9]. A segmented insulator with guard rings is a key to reach high voltage without giving fatal damage to the insulator. The high voltage conditioning up to 550 kV with the central stalk was achieved in 2009 [6], and generation of 500 keV beam with current up to 1.8 mA was demonstrated in 2012 [7]. The gun was shipped and installed at the cERL and has stably delivered beam for commissioning of the cERL as well as laser Compton scattering (LCS) experiments since April 2013 [8]. The gun operational voltage has been limited to 390 kV because of failures of two segments of the ten segmented insulator, which was found at KEK after the gun shipment from JAEA. Short bars have been connected between the electrodes of the failed segments. The gun has been operated with eight segments until summer shutdown in 2015.

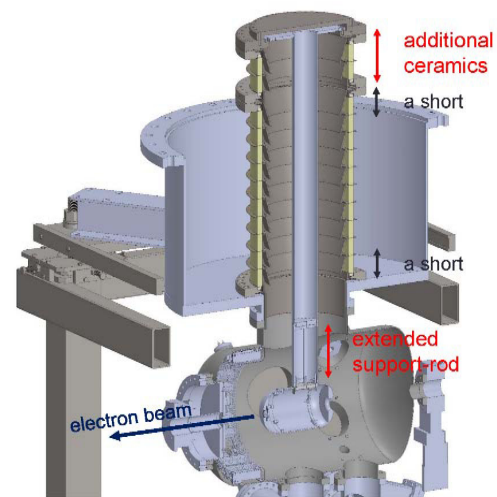


Figure 1: The cERL gun configuration with additional two segmented ceramics in place.

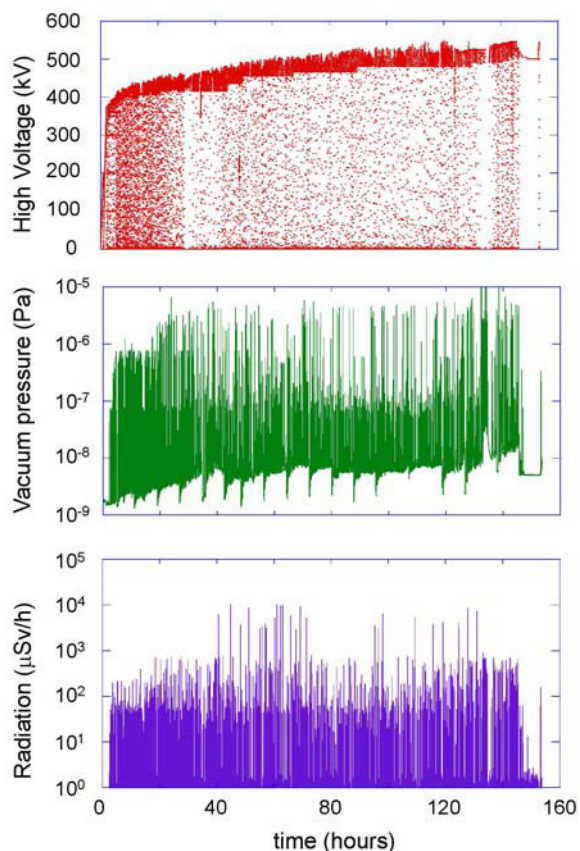


Figure 2: High voltage (top), vacuum pressure (middle) and radiation (bottom) as a function of time during HV conditioning of the cERL upgraded gun with cathode electrode in place.

THE CERL GUN UPGRADE

In order to recover 500 kV operation, we proposed to install an additional two segmented insulator on the existing ten segmented insulator (see Fig. 1) in the following reasons. The two segmented insulator is not as expensive as a new ten segmented insulator. Installation work of the two segmented insulator does not seem to affect the existing insulator. Thus gun operation at least 390 kV will be easily achieved.

After installation of the two segmented insulator, we performed high voltage conditioning without central stalk in July 2015. We reached 550 kV within an hour and performed holding test at 550 kV without any discharge activity for more than three hours [10]. This result clearly showed that installation work of the additional ceramics was successful.

We performed high voltage conditioning with central stalk and cathode electrode in place. We reached 548 kV in 150 hours and performed HV holding test at 500 kV for more than four hours, as shown in Fig. 2. Details of the conditioning result will be found elsewhere [11]. The HV power supply is interlocked when the vacuum pressure or radiation monitor exceeds the set points. The typical set

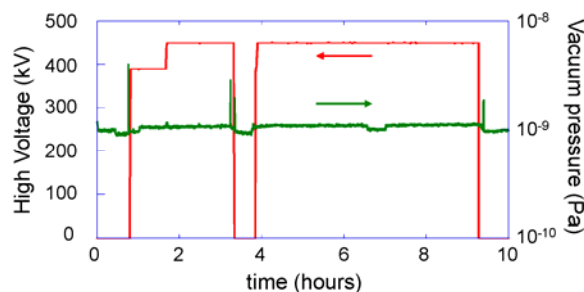


Figure 3: High voltage (red) and gun vacuum pressure (green) during beam generation test at 450 kV.

points were 1×10^{-7} Pa for vacuum and 1000 $\mu\text{Sv/h}$ for radiation.

The beam generation test from the upgraded gun was first performed at 390 kV. This is because 1 mA operation through the cERL recirculation loop by March 2016 was our first priority [12]. The average beam current delivered from 390 kV gun at the cERL has been increased 10 times every year starting from 1 μA , as they monitor the radiation level outside the accelerator hall. The average beam current from 0.8 to 0.9 mA was stably delivered for five hours in total during LCS experiments [12]. The beam frequency is 162.5 MHz and bunch charge is roughly 5 pC. The photocathode used in the present study was GaAs activated with cesium and oxygen. The QE degradation during 1 mA operation was negligibly small. The charge extracted during 1 mA operation is roughly 18C. The high voltage 390 kV is very stable and vacuum pressure is 1×10^{-9} Pa during 1 mA beam generation.

We also performed beam generation at 450 kV after the high current operation, as shown in Fig. 3. Because the cERL beam time was limited, we only had two days for 450 kV operation. We successfully circulated the beam delivered from 450 kV gun through the cERL loop.

SUMMARY

The cERL photoemission gun was successfully upgraded. The operational voltage was increased from 390 kV to 450 kV. High current operation up to 1 mA was also demonstrated. We plan to continue the high voltage conditioning of the gun to demonstrate generation of 500 keV beam at the cERL in the near future.

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