CHALLENGES OF OPERATING A PHOTOCATHODE RF GUN INJECTOR*

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Abstract

The major challenges in operating a photocathode RF gun based injector are its stability and reliability. This report discuss two important subjects which affect the performance of photocathode RF gun, high efficiency photocathode and experimental technique characterizing the RF gun injector. A Mg cathode was manufactured and routinely operated at 100 MV/m field with quantum efficiency on the order of 10^{-3}. By measuring the photoelectron charge as function of RF gun phase, we can monitor the RF gun driving laser pulse length variation, and measuring the laser arrive time variation on the cathode with Pico-second accuracy.

1 INTRODUCTION

The superior performance of photocathode RF gun based injectors have been experimentally demonstrated in many laboratories [1-3], all proposed fourth generation light source, such as X-ray and UV free electron lasers are based on the photocathode RF gun injector [4-6]. The performance of those future light sources will be determined by the photocathode RF gun injector. One of most challenging area in photocathode RF gun research is to improve the stability and reliability of its operation.

Brookhaven Accelerator Test Facility (ATF) is a facility dedicated to the beam physics and advanced accelerator physics research. It is one of few user facilities based on photocathode RF gun injector. It has a unique opportunity to address those challenges, demonstrate the feasibility of photocathode RF gun based user facility. The reliability and stability of the photoinjector are determined by the RF gun and its driving laser. The procedure developed in manufacture and operating RF gun reach in such stage that, it is mainly determined by the photocathode. The stability and reliability of the laser system for photocathode RF gun is the area much improvement is needed. Develop high efficiency, reliable photocathode, and laser diagnostic techniques, specially the longitudinal profile measurement, are critical to improve the stability and reliability of the photoinjector. We will first present experimental results of Mg cathode measurements at the ATF. Then we discuss a simple technique to study the laser longitudinal profile and laser intensity front variations on the cathode.

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2 MAGNESIUM PHOTOCATHODE

As we pointed out earlier, photocathode is one of the critical links to improve the RF gun operation for both metal and semiconductor materials. The life time and quantum efficiency (QE) stability of the cathode is the major concern for a user facility. We choose metal cathode at the ATF mainly due to its robustness. Magnesium (Mg) has demonstrated relative high QE under modest vacuum condition [7,8]; the challenge is to find reliable way to attach Mg cathode to the Copper. Many techniques were tested, such as press fitting and sputtering, to attach the Mg cathode to the Copper. The Mg cathode made of press fitting suspect to the temperature variation due to vacuum bake out, while sputtered Mg can be damaged by RF break down. We were able to work with NCT Inc of Connecticut to develop a frictional welding technique to attach the Mg to the Copper with reliable vacuum seal. The Mg cathode was prepared according to the procedure we have developed [9], the cathode surface was polished using three different sizes diamond polishing compound, as polish progressing, the diamond in the polishing compounds were reduced from 9 µm, to 6 µm, then to 1 µm. The polished surface was rinsed with Hexane before immersed in the Hexane bath for 20 minutes ultra-sound cleaning. After the cathode surface was blowed dry with dry nitrogen, it was placed inside a UHV vacuum chamber for 200 °C bake out. It was installed on the RF gun under dry nitrogen (Fig.1).

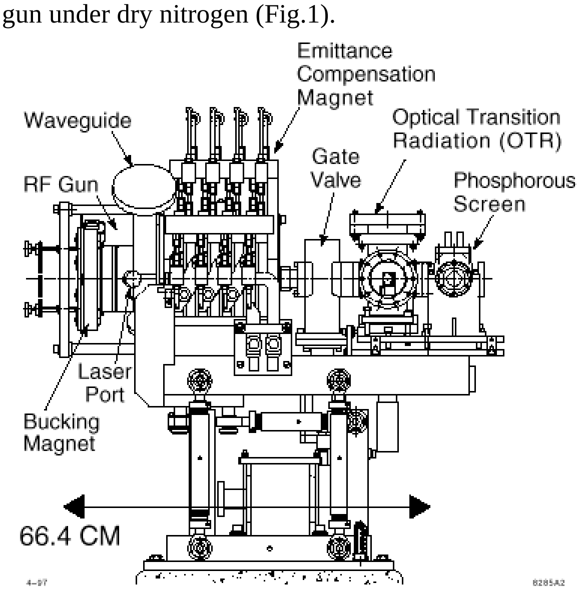

Figure 1: Layout of the ATF photoinjector.

Fig.1 shows the ATF photocathode RF gun injector. The RF gun was mounted directly on the emittance compensation solenoid magnet. There is a Electron beam diagnostic station, which is a multi-function device can be used as a beam profile monitor (BPM) and Faraday cup for photoelectron charge measurement. Fig. 2 is the measurement of photoelectron charge as function of the laser polarization and QE improvement after laser cleaning. The laser energy density used for the cleaning is about 7 mJ/cm^2. One of the most important improvement with frictional welding Mg cathode is its stability comparing to the sputtered Mg cathode [8], which decays by an order of magnitude after couple days operation. The QE measured is on the order of 10^{-3} for a peak field of 100 MV/m after laser cleaning.

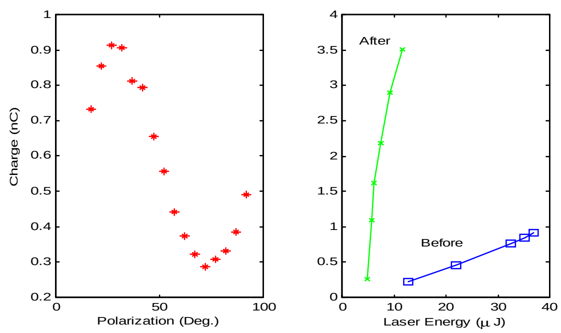

Figure 2: Photoelectron charge as function laser polarization (left) and laser cleaning (right).

3 LONGITUDINAL LASER PROFILE STUDIES

The photoinjector driving laser stability is determined by its energy fluctuation, point stability, timing jitter, transverse and longitudinal longitudinal profiles distribution. Develop experimental technique to characterize those laser properties are critical to improve laser performance. We have developed a technique to study laser longitudinal profile variation and timing jitter by measuring the photoelectron charge as function of the RF gun phase.

The photoelectron current density can be described by the following formula,

$$j = AI(t)(h\nu - \varphi + \alpha\sqrt{\beta E(t)})^2$$

Where I (t) is the time dependent laser intensity, hν is the photon energy, φ is the cathode work function, E(t) is RF field, and β is the field enhancement factor. Using frequency quadrupled Nd:Yag laser (266 nm), the first two terms in above equation is much smaller than the last term for Copper and Mg, so the photo-emission is dominated by the so called Schottky effect. The total photoelectron charge as function of the RF gun phase is,

$$Q(\phi) = \int_{-\infty}^{\infty} d\tau A I(\tau)(h\nu - \varphi + \alpha\sqrt{\beta E(\phi - \tau)})^2$$

The above equation shows that, the charge $Q(\phi)$ is the convolution of the laser intensity distribution $I(\tau)$ and RF field $E(\phi)$. So in principle, we could deduce the laser longitudinal distribution by measuring the photoelectron charge through deconvolution.

Measuring the photoelectron charge as function of the RF gun phase is one of the simplest, but most import measurement in photocathode RF gun operation. Fig.3 is the experimental measurement for both Copper and Mg cathodes. We could obtain following information from Fig.3,

- **Absolution RF gun phase:** both photoelectron beam transverse emittance and bunch length are the function of the RF gun phase [10], accurate measure of the absolute RF gun is essential any stable photoinjector operation. For Schottky effect dominated photoemission, the peak of $Q(\phi)$ corresponding to the RF field crest (90 deg).
- **Timing Jitter:** taking advantage of $Q(\phi)$ dependency on the RF gun phase, we can measure the timing jitter between the RF system and RF gun driving laser. Notice the asymmetry in Fig.3, the falling edge of the $Q(\phi)$ curve is much more sensitive to the laser timing jitter. For a maximum charge of 1.5 nC, the sensitivity of the measurement can be 35 pC/deg. For a S-band RF gun, one degree RF phase is almost equal to 1 ps, this easily allows us to measure femto-seconds timing jitter between the laser and RF system if laser energy fluctuation can be simultaneously take into consideration. To deduce the laser system timing jitter, the timing jitter dependency on the RF gun phase must be taken into consideration [11].

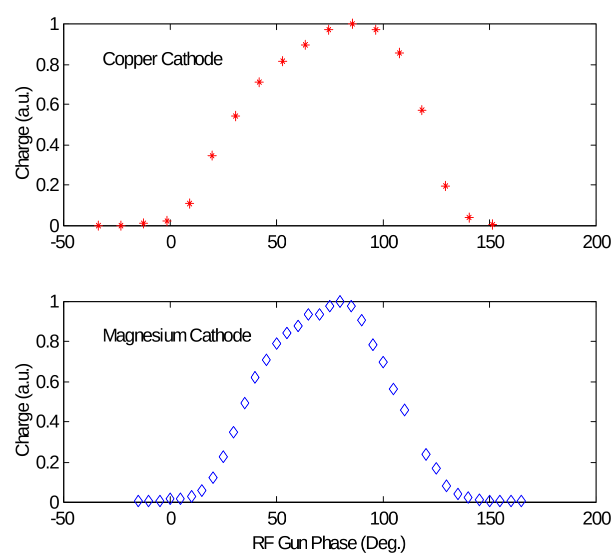

Figure 3: Photoelectron charge as function of RF gun phase for different cathode materials.

The $Q(\phi)$ curve was extensively used at the ATF for photocathode RF gun injector stability studies. We have measured the effect of the frequency doubling crystal on the longitudinal profile distribution of the RF gun driving laser system (Fig.4). As we increase the laser energy to saturate the frequency doubling crystal, the laser profile change significantly, this is indicated by the variation of the rising edge of the $Q(\phi)$ curve, and broadening the range of the $Q(\phi)$ curve. From convolution theorem [12], the variance of the convolution equal to the sum of the individual function's, so laser pulse length increase will lead to the broadening of the $Q(\phi)$ curve.

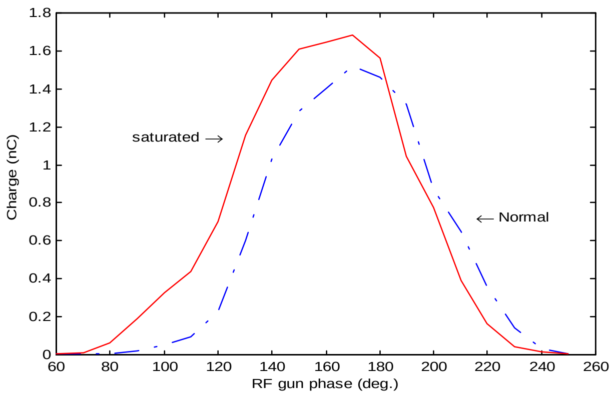

Figure 4: Photoelectron charge as function of RF gun phase for two different longitudinal laser profiles.

Fig. 5 shows variation of the $Q(\phi)$ curve FWHM from normal laser operation condition (80 deg) due to the laser pulse lengthening. We first confirmed this finding by measuring the electron beam bunch length, the laser pulse length inferred is 20 to 25 ps (FWHM). A streak camera with 2 ps resolution was employed to study the laser pulse length, and the laser pulse length obtained is 10 to 14 ps. tremendous efforts was devoted to investigate the inconsistency of those results. Since a grating was used to correct the laser intensity front tilt caused by the oblique laser incidence. We suspected that might cause the effective laser lengthening. We developed a technique of measuring the laser intensity front tilt on the cathode using $Q(\phi)$ curve. A $Q(\phi)$ curve was first obtained for normal laser spot on the cathode (2 mm diameter). Then a laser aperture was used to reduce the spot to 0.3 mm, the second $Q(\phi)$ curve for the smaller laser spot was compared with the first one. It was found that the RF gun phases corresponding to the maximum charge are different. This led us to believe that the laser arrives time varying with the position on the cathode. Further more, $Q(\phi)$ curves were measured as we move the small laser spot on the cathode. Comparing the RF phases for different positions we concluded that, the laser arrive time on the cathode vary as much as 10 ps with position.

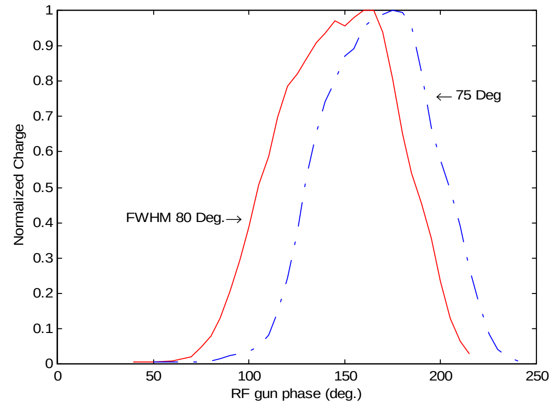

Figure 5: Q curve Width variation due to laser intensity front tilt leads to effective laser lengthening.

4 ACKNOWLEDGEMENT

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5 REFERENCES

[1] P.G. O'Shea *et al*, Nucl. Instr.and Mth. A331(1993) 62-68.

[2] X.J. Wang *et al*, Nucl. Instr. And Meth A375 (1996) 82-86.

[3] D.T. Palmer *et al*, to be published in the Proceeding of PAC 97, Vancouver, Canada May12-16, 1997.

[4] The Brookhaven National Laboratory DUV Free Electron Laser CDR, BNL-49713, Jan. 1994.

[5] LCLS Design Study Report, SLAC-R-521, April 1998.

[6] A VUV Free Electron Laser at the TESLA Test Facility at DESY, DESY TESLA-FEL 95-03, 1995.

[7] X.J. Wang et al, Nucl. Instr. And Meth A356 (1995) 159-166.

[8] X.J. Wang et al, to be published in Nucl. Instr. And Meth A, BNL – 65002 (1997).

[9] T. Srinivasan-Rao *et al*, Study on the Sensitivity of Quantum Efficiency of Copper Photocathodes on Sample Preparation, BNL-62626 (1996).

[10] X.J. Wang *et al*, Phys. Rev.E.54 R3121 (1996).

[11] P.G. O'Shea, Nucl. Instr. And Meth A 358 (1995) 36-39.

[12] Deconvolution of Images and Spectra, edited by P.A. Jansson, Academic Press.