

OPTIMAL PARAMETERS OF THE PHOTOCATHODE GUN SPACE CHARGE TO IMPROVE BEAM QUALITY

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Abstract

Accelerator Test Facility at Brookhaven National Laboratory (BNL ATF) operates with 5 MeV photocathode gun and 70 MeV linac for different range of experiments with a few picoseconds and a few micrometers emittance electron bunch. Many conducted experiments require beam with good spatial resolution and short length as well. NdYAG laser pulse turns to the electron bunch in the gun with space charge affecting on the own bunch length and transverse profile. Optimal beam parameters of the space charge in the photocathode RF gun could be found and used to improve bunch length and emittance. Simple model and experimental results on the Accelerator Test Facility at Brookhaven national Laboratory will be described.

INTRODUCTION

On present BNL ATF operates copper cathode 1.5 cell photocathode RF gun. Laser cleaning used to enhance cathode surface properties improving Quantum Efficiency (QE) of electron emission. In the past cathode cleaning was enhanced by certain level of RF power. Now it is only laser high intensity focused beam. In this paper these two methods will be modelled and compared.

LASER CLEANING

Laser cleaning procedure was developed at BNL ATF to improve electron emission from the cathode surface after gun RF conditioning [1]. When vacuum of the gun reaches ultra high level ($\leq 8E-10$ Torr), several cleaning cycles applied to the cathode. After first scan QE was measured at different locations. On the cathode after irradiation and was found at 10^{-5} level.

Laser beam was focused on spot size $\sigma \sim 0.1$ mm, to reach intensity $80-500$ mJ/cm², laser fire 3 consecutive shots at one step. The cathode was then slowly scanned with the laser on area covered operation laser spot. At each scan site, the laser energy was adjusted. After scan cycles, the QE increased to 2×10^{-4}

THIN LAYER MODEL

Schottky effect of electron photoemission described by equation [2]:

$$\frac{d}{dt}\sigma(t) := J(t) \cdot A \cdot \left(h\nu - \phi_0 + \alpha \cdot \sqrt{\beta \cdot E_{\text{eff}}} \right)^2$$

Where $\sigma(t)$ – current density, $J(t)$ – laser intensity, A – material dependent coefficient, $h\nu$ – photon energy, ϕ_0 – material work function, α – constant, β – surface quality factor, E_{eff} – effective electric field at cathode surface.

$E_{\text{eff}} = E_{\text{RF}} + E_{\text{SC}}$ is effective electric field at cathode surface is sum of RF field $E_{\text{RF}} = E_0 \sin(\omega t + \varphi)$ and E_{SC} is field from space charge induced by emitted electrons.

In our simple model we slice time in dt steps and at every step electrons emitted from surface represented as thin layer with same diameter as laser beam, S . Typical laser pulse has length of 7 psec. Taking an account distance which layer travel from cathode in this time range and size of the laser spot $S = 2.3$ mm we can assume that electric field from thin layer with homogenously distributed charge Q could be presented as field $Q/2S\epsilon_0$ but in our case with image field this value double and equal $E = Q/S\epsilon_0$. So electric field at cathode from emitted electrons at time t can be expressed as sum of all charged layers emitted before time t . Every next emitted layer will add to this sum.

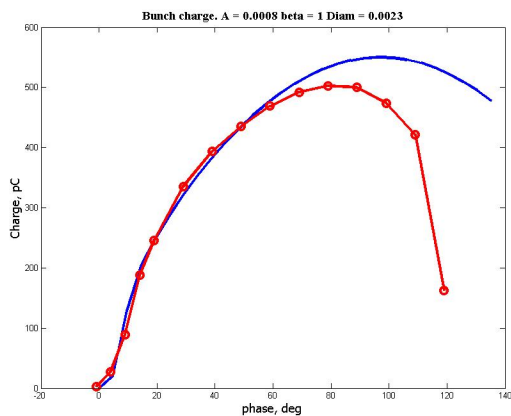


Figure 1: Bunch charge vs gun phase. Red line measured data and model (blue) matched with coefficients $A=8E-4$, $\beta=1$, $S=2.3$ mm. Data taken June, 2011

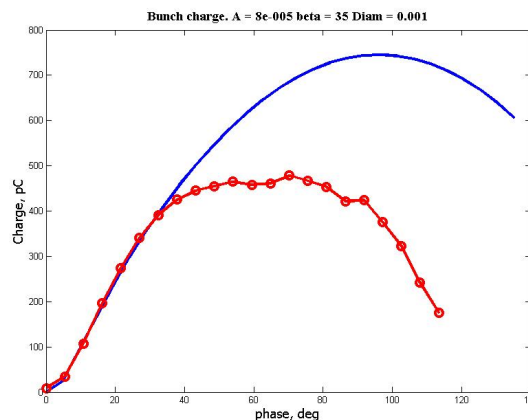


Figure 2: Bunch charge vs gun phase. Red line measured data and model (blue) matched with coefficients $A=8E-5$, $\beta=35$, $S=1$ mm. Data taken December, 1996.

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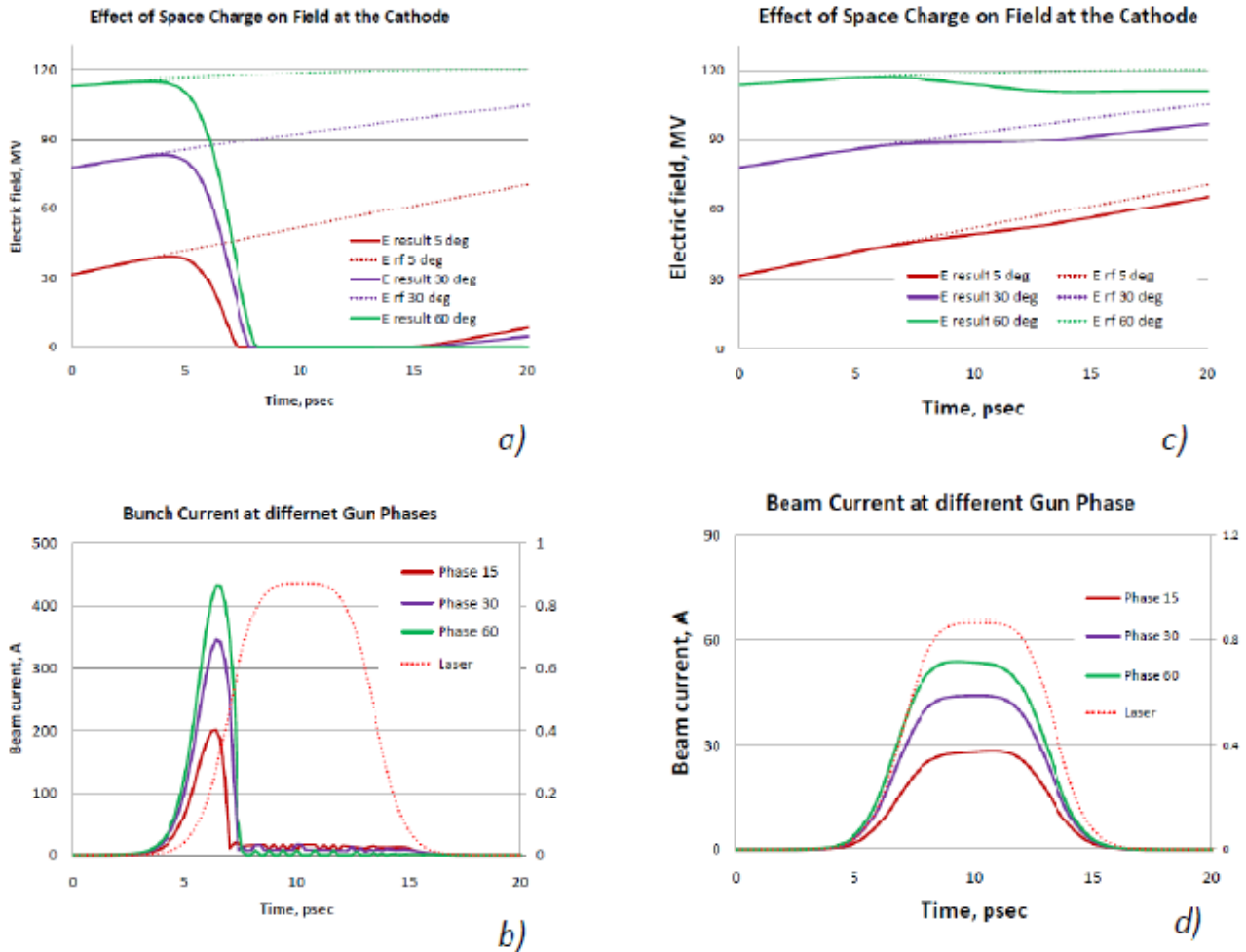


Figure 3: Effect of space charge on the bunch length. Intense laser beam (small spot area) together with high value of surface quality factor produce high intensity electron emission that in turn “lock” the emission and create short bunches. On the figure same duration of laser profile beam focused in spot sizes and on cathodes with different surface quality factors. (a,b): S=1 mm, A =8E-5, β=35; (c,d): S=2.3 mm, A=8E-4, β = 1

Effective field now can be written as:

$$E_{\text{eff}}(t) := E_0 \sin(\phi + \omega \cdot t) - \int \frac{\sigma(t)}{\epsilon_0} dt$$

And Quantum Efficiency expression with space charge effect will have a look:

$$QE := A \cdot \left[h\nu - \phi_0 + \alpha \cdot \beta \cdot \left(E_0 \sin(\phi + \omega \cdot t) - \int \frac{\sigma(t)}{\epsilon_0} dt \right) \right]^2$$

This model can be compared with observation of measured charge at different gun phases. On Figures 1 and 2 shown observed charge versus gun phase and model with coefficients A and β matched to measured data.

On these figures charge is saturated with increasing of gun phase. This effect can be explained as electron emission is “locked” by space charge. More detailed explanation shown on Figure 3.

Measured data has different cathode material, method of laser cleaning and laser beam spot sizes. As result high laser intensity together with material and surface quality factor produce high value quantum efficiency. Electric field from already emitted electrons reduced and turn to zero at some point (Fig.3,a). That stop pulling electrons from cathode surface and “lock” electron emission reducing charge output (saturation on Figure 2).

As sequence it is produce bunches with length shorter than laser pulse duration. Pictures a) and c) shows model of progression of effective electric field at different gun phases: 5, 30, 60 deg; a) and d) illustrates electron bunch

profiles at these gun phases with laser profile on background to visualize “locking” effect.

CONCLUSION

Effect of the space charge on photocathode emission was estimate by simple model on two different material and quality cathodes. Different laser cleaning techniques can be applied for photocathode enhancement but as result high surface enhancement value could change bunch structure and emitted bunch length cannot be controlled by laser pulse duration.

REFERENCES

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