EMISSION STUDIES OF PHOTOCATHODE RF GUN AT PITZ

J. Li*+, G. Asova‡, I.V. Isaev, M. Groß, L. Hakobyan, Y. Ivanisenko, M. Khojoyan‡+,G. Klemz,
G. Kourkafas, M. Krasilnikov, K. Kusoljariyakul‡‡, M. Mahgoub, D. Malyutin, B. Marchetti,
A.Oppelt, B. Petrosyan, S. Rimjaem‡‡, A. Shapovalov, F. Stephan, G. Vashchenko,
DESY, 15738 Zeuthen, Germany
G. Feng, DESY, 22607 Hamburg, Germany
L. Shang, University of Science and Technology of China, 230029 Hefei, China
D. Richter, HZB, 12489 Berlin, Germany

Abstract

The Photo Injector Test facility at DESY, Zeuthen site (PITZ), was built to develop and optimize electron sources for linac based Free Electron Lasers (FELs) like FLASH and the European XFEL. For the value of the bunch charge extracted from a photocathode, discrepancy has been observed between the data measured at PITZ and simulation results from the ASTRA code. As a factor which could explain the discrepancy, a Schottky-like effect is considered. Meanwhile, the PARMELA code was applied to the emission studies on the PITZ gun as benchmark. Since PARMELA cannot be used to simulate Schottky-like effects with its own modules, MATLAB scripts have been developed to implement this feature of the photoemission in an RF gun.

INTRODUCTION

With the aim to produce beams with high density, low transverse emittance and short bunch length, the PITZ characterizes the RF photocathode electron sources for FLASH and the European XFEL. Considering it is one of the most sensitive components for high quality beams in an XFEL facility, detailed research should be done on the electron gun.

Measurement of the accelerated charge downstream of the gun as a function of the beam launch phase, which is called phase scan or Schottky scan, is a basic experiment to study the emission properties of the PITZ gun. A Space Charge Tracking Algorithm (ASTRA) [1], originally developed at DESY and extensively used in photo injector design and benchmarking of experimental data [2], has been used to simulate the phase scans. The measured extracted charge is not consistent with the simulation results. One of the possible reasons is a Schottky-like effect. In order to justify this hypothesis, Phase and Radial Motion in Electron Linear Accelerators (PARMELA) [3], which is widely applied to linac design and dynamic analysis, has been used to simulate the emission process of the PITZ gun. Simulations have been done considering Schottky-like effects with ASTRA and PARMELA, respectively.

BACKGROUND AND MOTIVATION

PITZ Gun

The electron gun is a 1.6-cell copper cavity with resonance frequency of 1.3 GHz. The Cs_2Te photocathode is inserted into the backplane of the cavity by a load-lock system. The cavity is surrounded by a pair of solenoids: the main solenoid, used to focus the beam, counteracting its expansion due to the space charge force, and the bucking one, used to compensate the field of the main solenoid on the photocathode surface to ensure that the electron bunch leaves the magnetic focusing region without any remaining average angular momentum [4].

Discrepancy for Higher Charge

When specific machine settings were directly used in ASTRA, it was not possible to produce 1 nC at the gun operation phase, whereas 1 nC and even higher charge is experimentally detected. ASTRA phase scans have different shapes as compared to the experimentally measured data in Fig. 1, in which zero phases are the Maximum Mean Momentum Gain (MMMG) phases. Initial parameters are shown in Tab. 1.

As a factor which could explain this discrepancy, field enhancement was considered, such as Schottky-like effect.

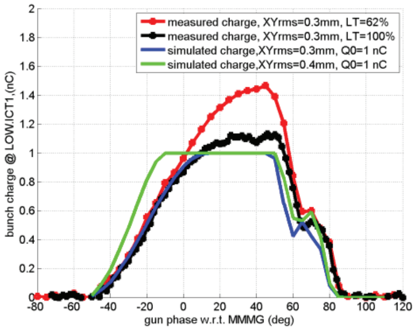

Figure 1: Measured and simulated (ASTRA) phase scans.

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* ji.li@desy.de

\+ On leave from USTC/NSRL, Hefei, China

‡ On leave from INRNE, Sofia, Bulgaria

‡+ On leave from ANSL, Yerevan, Armenia

‡‡ Currently at Chiang Mai University, Chiang Mai, Thailand.

Table 1: Parameters for Simulation

Parameters	Units	Value
Laser temporal profile (r.t/FWHM\f.t)	ps	2.2/21.46\2.2
RMS lase spot size (XYrms)	mm	0.3
Initial kinetic energy	eV	0.55
Maximum gradient on the cathode	MV/m	-60.58
Maximum B_z in the gun	T	0.2333
Laser transmission (LT)		62%, 100%

Schottky Effect

The Schottky effect describes the lowering of the work function or the potential barrier of a metal by an external electric field, which leads to an increased electron emission from the metal. As the Schottky effect is originally defined for a metal cathode, a similar phenomenon observed in an electron gun with semiconductor cathode is called Schottky-like effect. For a photocathode RF gun, this effect can be significant due to the strong field.

If a Schottky-like effect is considered in ASTRA, the charge of a bunch is determined at the time of its emission as [1]:

$$Q = Q_0 + SRT\_Q\_Schottky \cdot \sqrt{E} + Q\_Schottky \cdot E\,, \qquad (1)$$

where E is the combined (external and space-charge) longitudinal electric field in the centre of the cathode. The charge Q_0, is the charge of the macro particles as defined in the input distribution (eventually rescaled according to the parameter Q_{bunch}), *SRT_Q_Schottky* and *Q_Schottky* describe the field dependent emission process [1].

Motivation

When XYrms=0.3 mm is used in the ASTRA simulation with Schottky-like effect, it is not possible to produce the measured charge for any combination of Q_0, *SRT_Q_Schottky* and *Q_Schottky* [6]. If the laser spot size was slightly increased to 0.32 mm, the simulated results fit to the measurement well as shown in Fig. 2.

Considering this discrepancy between measured data and ASTRA results, we would like to use other codes to verify the data, like PARMELA. Since PARMELA could not be used to simulate the Schottky-like effect by itself, MATLAB scripts have been developed to add this feature.

An arbitrary temporal shape of the bunch can be generated by varying the number of macro particles in each separated short pulse in PARMELA. A code was written by MATLAB to obtain the longitudinal distribution considering the Schottky-like effect and run phase scans. Through Eq. 1, the emitted electron bunch can be composed by several short bunches, which are uniform in longitudinal direction and transverse direction with various heights according to different RF phases.

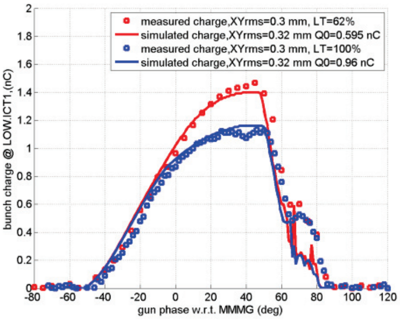

Figure 2: Phase scans with optimized parameters.

PARMELA SIMULATIONS

MATLAB Scripts

In the PARMELA input file, the charge is set by defining the length of the bunch and the average current during an RF cycle. The scripts divide the bunch into slices and calculate the increase of charge induced by Schottky-like effect in each slice separately. An increased electron emission is achieved by the increased number of macro particles, which finally leads to the increase of average current.

When Eq.1 was used in the ASTRA, only Q_0 was changed for different LT if proper *SRT_Q_Schottky* and *Q_Schottky* were set. But when it was used for PARMELA, results could not fit the measured data if just Q_0 was changed for different LT with constant *SRT_Q_Schottky* and *Q_Schottky*. A modified equation was applied in the scripts, which reads:

$$Q = Q_0 (1 + \alpha \cdot \sqrt{E} + \beta \cdot E) \quad , \qquad (2)$$

where E is the combined (RF force and space charge force) longitudinal electric field in the centre of the cathode. The Q_0 is the charge produced by the laser, α and β describe the field dependent emission process which are related to the material properties [5].

The flow chart is shown in Fig. 3, where *E(i)* is the strength of the RF field on centre of the bunch slice ; *N* means the total number of macro particles in the bunch; *x(i)* is the number of macro particles of each slice. *X(i)* is the number of macro particles in each slice considering the Schottky-like effect; *N'* is the total number of the macro particles in PARMELA considering the Schottky-like effect.

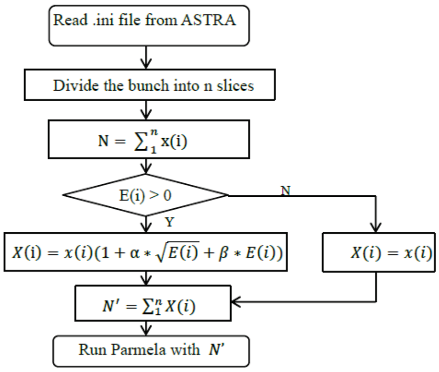

Figure 3: Flow chart of MATLAB scripts.

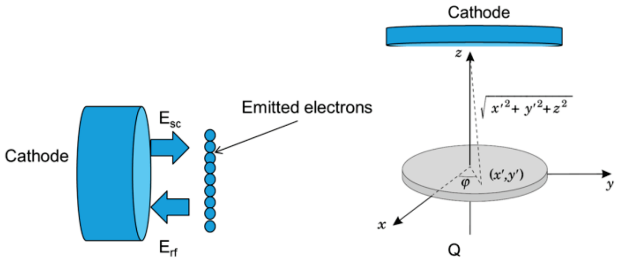

Figure 4: Space-charge force model.

For the space-charge field strength, an estimation model was used which is shown in Fig. 4. Considering that the emitted electrons exert a force on the cathode surface, each emitted slice was treated as a flat plate with uniform charge distribution. The force on the centre of the cathode from each slice was calculated using Eq. 2, 3 and 4, where Q is the charge of the flat plate and R is the radius of the flat plate.)

$$E_{sc} = \frac{Q}{2\pi\varepsilon_0 R^2}\left(1 - \frac{z}{\sqrt{R^2+z^2}}\right) \quad , \tag{3}$$

$$E = E_{rf} - E_{sc} = E_{cathode} \cdot \sin(\varphi_{launch}) - E_{sc} \quad . \tag{4}$$

Results

The simulated results and measured data were compared in Fig. 5. The values of charge were simulated at the position where a Faraday cup is located along the beam line, and the measured data were obtained in the year 2011. The initial conditions were set according to Tab. 1. In the PARMELA simulation, the Q_0 is 0.57 nC in the LT=62% case, while the Q_0 is 0.77 nC corresponding to the LT=100% case.

The experimental data in the year 2012 have been used to check the Schottky model for PARMELA. When XYrms is 0.3 mm and maximum voltage on the cathode is 45 MV/m, Q_0 is set to 0.326 nC for LT=14%. The simulated results are consistent with measurement, which are shown in Fig. 6.

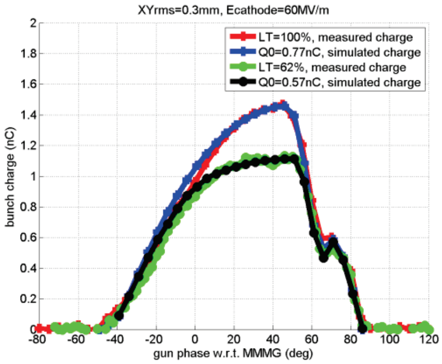

Figure 5: Measured and PARMELA phase scans (2011).

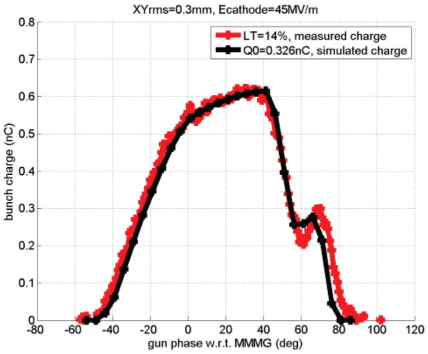

Figure 6: Measured and PARMELA phase scans (2012).

SUMMARY

Through simulations for different cases, the results from PARMELA considering Schottky-like effects fit the measurement data well. Eq. 2 can be used to explain the increase of the electron emission in the PITZ gun successfully.

In the simulations, the relationship between Q_0 and LT is not linear. Experiments should be done to check if the photocurrent is saturated at high laser transmission. Studies to accurately model the initial distribution and parameters optimization for Eq. 2 are to be done.

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