BNL PHOTO-INJECTOR PERFORMANCE OPTIMIZATION*

X.Y. Chang[†], X.J. Wang, I. Ben-Zvi, ATF, BNL, Upton, NY 11973, USA

Abstract

Extensive simulation studies of the BNL 1.6 cell photo-injector were carried out at the Accelerator Test Facility (ATF) using computer program PARMELA. The transverse emittance of photo-injector was optimized at much lower RF gun phase than earlier studies, which agrees with the longitudinal emittance compensation predictions [1,2]. The Schottky effect on the emittance and pulse length of photoelectron beam was investigated. Instead of flat longitudinal distribution, simple laser and electron beam longitudinal profile control techniques, such a laser pulse truncation by saturable absorber, or electron beam longitudinal beam profile truncation using energy slit, were used to achieve transverse emittance 1 mm-mrad for a charge of 1 nC.

1 INTRODUCTION

The Brookhaven Accelerator Test Facility (ATF) is an only multi-user facility based on the photo-cathode RF gun injection system. ATF photo-injector has been in operation for almost a decade, its record performance [3] is critical for success of many ATF experiments, such as HGHG, VISA and Stella.

ATF photo-injector consists of a 1.6 cell S-band RF gun, emittance compensation solenoid magnet, and electron and laser beam diagnostics cubes. About one meter down-stream of RF gun there are two sections of SLAC-type traveling wave linac. It has been found in experiments that the optimized laser launch phase ϕ_0 (initial phase) is around 30° for a longitudinal Gaussian distribution of the driving laser pulse with total charge of 0.5 nc [3]. According to theory [4], the best launch phase should follow the following formula: $(p/2 - f_0) \sin f_0 = 1/2 a$. Where $a = eE_0/(2mc^2k)$ is the dimensionless parameter representing the strength of the accelerating field in RF gun. For BNL ATF case, E_0 = 100Mv/m, f = 2856MHz. So, $a = 1.64$. The optimized launch phase is 71°. Also In the old simulations for BNL gun, the optimized launch phase is around 50° ~ 60° [7]. They all differ significantly from the experiments results.

The LANL computer program PARMELA was used for our studies. We developed both pre-processor and post-processor for PARMELA to allow us to modify the laser distribution arbitrarily in both longitudinal and transverse directions. Post-processor make it possible not only to study slice emittance, but also to select emittance and beam distribution during its transportation.

* Supported by US DOE contract Number DE-AC02-98CH10886.
[†]xychang@bnl.gov

After numerical error studies, we first investigated BNL existing photo-injector. Our simulation shows the best performance is at lower RF gun phase, generally agreed with ATF experiment results and longitudinal emittance compensation [1,2]. We then studied the Schottky effect and slice emittance along the beam. Finally we explored various other techniques for optimizing the emittance.

2 SIMULATION

Following parameters were assumed for our studies: $E_{cathode}$=100Mv/m, charge/bunch=1nc, transverse uniform laser distribution with R=1.1mm. We used fixed linac phase (close to crest) to reduce computing time since it is not critical for our studies.

2.1 Simulation accuracy

Our simulation covered from cathode to the exit of the linac (8 meters), carefully selection of mesh size and time step are important. If mesh size and time step too rough, numerical truncation errors and space charge effect may cause large error. On the other hand, too fine mesh may not only cause more accumulation errors, but also longer computing time.

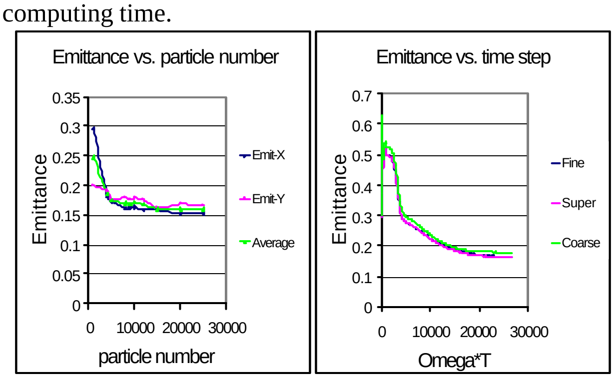

Figure 1: Emittance vs. particle number and time step

Table 1: Time step settings for Fig. 1

	Cathode	**In gun**	**Drift**	**Linac**
coarse	1ps/step	1ps/step	4ps/step	8ps/step
fine	0.2ps/step	1ps/step	2ps/step	4ps/step
Super	0.2ps/step	1ps/step	1ps/step	1ps/step

Both Fig. 1 and table 1 show that, the particle number should exceed 10k, and time step setting should be 'fine' for reasonable numerical error. In our simulations, we will use 15k particles and 'fine' time steps, and use the average of Emittance-X and Emittance-Y as our Emittance. This will limit the numerical error within 2%.

2.2 Simulation for BNL ATF injector

The Gaussian longitudinal laser distribution used for the ATF injector simulation (Fig. 2).

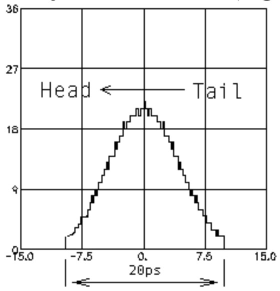

Figure 2. Laser distr.

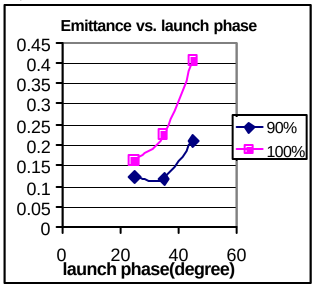

Figure 3. Emit. vs. ini. phase

Fig. 3 plotted emittance as a function of the laser arrives RF phase (90 deg corresponding to peak field on the cathode) for two cases. The first one, 100% case, indicates all particles were included for the emittance calculation. And another case (90%), indicates 90% of the particles long the electron beam longitudinally was selected by truncating the both edges. One of the most important features in Fig.3 is that, emittance optimized at much lower RF phase, which agreed with both experiment results and longitudinal emittance compensation.

Emittance as function of photo-electron beam charge was also studied (Fig. 4), it is easily observable that, emittance grows almost linearly with charge. Emittance dependency on both RF gun and linac field gradient were also investiagated (Fig. 5 and 6). To achieve good emittance, RF gun field should be around 100 MV/m.

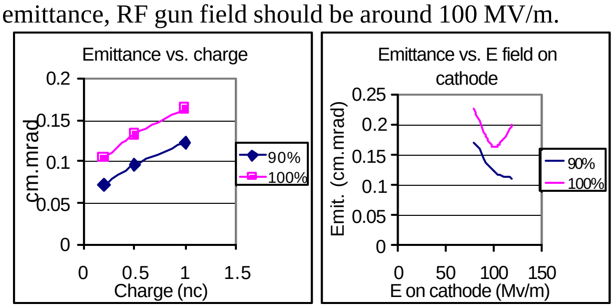

Figure 4. Emit. Vs. charge

Figure 5. Emit. vs. $E_{cathode}$

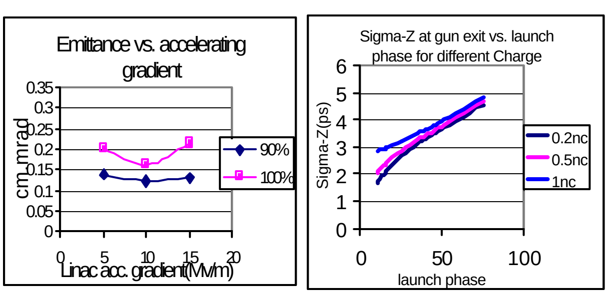

Figure 6. Emit. Vs. E_{linac}

Figure 7. σz vs. ϕ_0

Longitudinal beam size σ_z as a function of ϕ_0 is also studied (Fig. 7). It almost linearly decreases when decrease ϕ_0. This shorter σ_z at lower ϕ_0 leads reduction of emittance compare to that of higher ϕ_0 case.

The following figures (Fig. 8 and 9) show the beam profile and slice emittance along Z at optimized condition for charge=1nc.

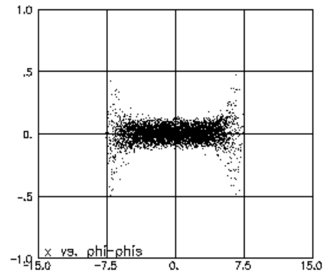

Figure 8. Beam profile

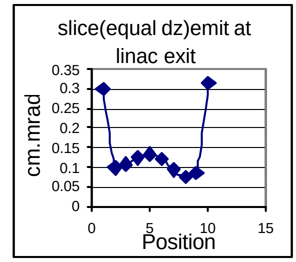

Figure 9. Slice emittance

2.3 Schottky effect

Here we only consider RF field Schottky effect. For a Gaussian distribution, this effect is small because the distribution taking this effect into account is very close to the original one, see Fig 9. The emittance increases only 2% by simulation. But for uniform longitudinal laser distribution, the effect will be much more significantly.

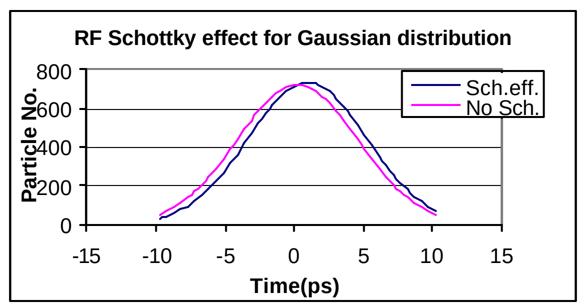

Figure 10. RF Schottky effect

2.4 Emittance Optimization Studies

A. Modifying laser longitudinal distribution to a truncated Gaussian distribution in both ends.

From Fig. 8 and Fig. 9 we see that the small part of the particles in both ends contribute the great proportion of the emittance. Truncating the laser longitudinal distribution can improve the beam performance. The emittance is improved from 1.63mm.mr to 1.32mm.mr (20 % down) by simulation. Fig. 11 and Fig. 12 are the beam profile and slice emittance for this case.

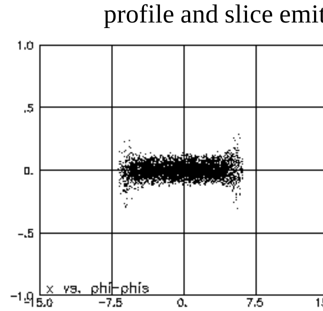

Figure 11. Beam profile

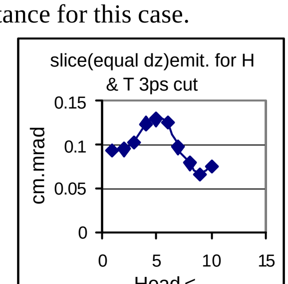

Figure 12. Slice emit.

B. Uniform longitudinal distribution.

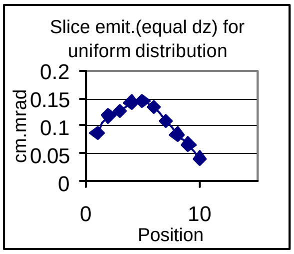

Figure 13. Slice emit.

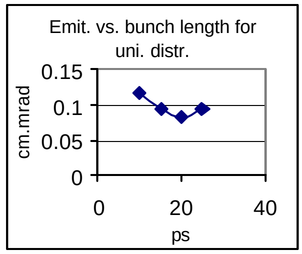

Figure 14. Emit. vs. σ_{laser}

A uniform laser distribution can reduce the unbalanced space charge effects created in a Gaussian distribution. This can greatly decrease emittance. It is reduced to 1.18mm.mr (28% down) by simulation. By optimizing laser bunch length, emittance can be reduced to 0.83mm.mr at laser length=20ps. Fig. 13 and Fig. 14 are slice emittance and emitance vs. laser bunch length for uniform laser distribution respectively.

C. Curving cathode.

Another possible way to improve emittance is modifying cathode shape illustrated in Fig. 15. The focusing force near cathode produced by this shape is very helpful to beam because it can compensate the strong space charge forces near cathode. The emittance is improved to 1.39mm.mr at α=15° by simulation.

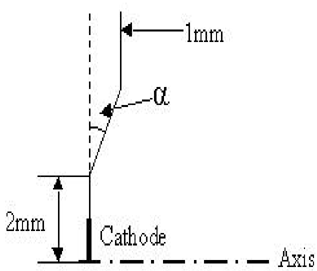

Figure 15. curved cathode

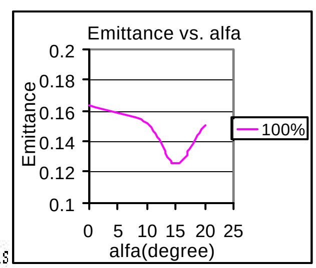

Figure 16. Emit. vs. α

3 SUMMARY AND CONCLUTION

By appropriately increasing particle samples and setting fine iteration steps, we achieved the required simulation accuracy. The simulation results are consistent with experimental results. The initial phase is around 30° for ATF system for optimized emittance. The optimized linac accelerating gradient is around 10Mv/m. The particles at bunch edges contribute greatly to emmitance for longitudinal Gaussian distribution laser pulse. Modifying laser shape to a truncated Gaussian distribution can reduce Emittance. This measure is equivalent to cutting beam bunch ends after linac. Emittance for truncated laser is 1.32mm.mr and for cutting beam after linac is 1.23mm-mr by simulation. This provides an alternate way to eliminate bad edge particle influence. Modifying cathode shape is also efficient to improve beam performance. For BNL gun, α should be about 15°.

4 ACKNOWLEDGEMENT

Authors would like to express our gratitude for the support we have received from NSLS and BNL director office.

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