PEPPER-POT BASED EMITTANCE MEASUREMENTS OF THE AWA PHOTOINJECTOR#

J. G. Power*, M. E. Conde, W. Gai, F. Gao, R. Konecny W. Liu, and Z. Yusof ANL, Argonne, IL 60439, U.S.A.
Ph. Piot and M. Rihaoui NIU, DeKalb, IL 60115, U.S.A.

Abstract

The Argonne Wakefield Accelerator (AWA) RF photocathode gun is a 1.5 cell, L-band, RF photocathode gun operating at 77 MV/m, with emittance compensating solenoids, a magnesium photocathode, and generates an 8 MeV, 1 nC – 100 nC beam. In this paper, we report on a parametric set of measurements to characterize the transverse trace space of the 1 nC electron beam directly out of the gun. We emphasize details of the experimental setup, image analysis, and end with a comparison of the measuremetns to PARMELA simulations.

INTRODUCTION

An ideal transverse emittance measurement would completely characterize the transverse phase space of a beam on a single-shot basis. Traditional emittance measurement methods based on the evolution of the beam in a drift (e.g. 'quad scans' and '3 screen measurements') are poorly suited for use with RF photoinjectors since these methods do not account for space charge [1, 2]. The fact that these beams are space charge dominated can be seen by considering that the typical photoelectron bunch has high charge (1 nC), low transverse emittance (a few μm) and low energy (a few MeV). Attempts have been made to modify the traditional methods to include space charge [2, 3], but these methods are still not single shot. Methods based on averaging over many shots (e.g. 'scanning slits', 'quad scans with space-charge', and '3 screen measurements with space charge') are better, but are still not ideally suited for photoinjectors since the shot-to-shot variation of the laser system means that fine details of the phase space will be averaged out. Lastly, transition radiation based diagnostics [4] over come the above limitations, but suffer from the fact that the yield only moment (R.M.S.) information. The method that comes closest to the stated ideal is the pepper pot (PP).

PP based emittance measurements are well suited for the characterization of the beam produced directly by an RF photoinjector. Potentially, it can characterize the 4D transverse phase space of the beam directly out of an RF photoinjector on a single shot basis with relatively fine sampling of the phase space. In the remainder of the paper we present the results of measurement of the 2D transverse phase space of a 1 nC, 8 MeV beam produced by the AWA photoinjector: 1.5 cell, 1.3 GHz, Ez = 77MV/m, driven by a laser pulse: 2mm radius transverse flattop and 3.5 psec rms longitudinal.

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*jp@anl.gov

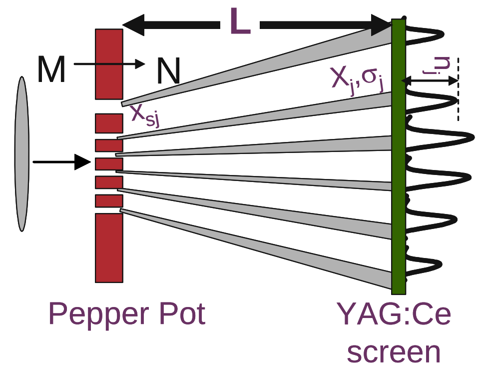

Figure 1: Block diagram of pepper-pot system.

THE PEPPER POT METHOD

The PP is thoroughly described elsewhere [5] and only a brief recap of how it works is given here. The PP is a beam mask made by drilling a pattern of holes in a dense plate. It serves to stop most of the incident beam while permitting a series of low-charge beamlets to pass through holes and drift to a downstream screen. The purpose of the mask is twofold: (i) to lower the charge of the beamlets so that they are emittance dominated and (ii) to sample the phase space of the beam. The rms emittance $\varepsilon_{rms}^2 = \langle x^2\rangle\langle x'^2\rangle - \langle x'x\rangle^2$ of the incident beam can be retrieved from the experimentally obtained image via [5]

$$\varepsilon_{rms}^2 \approx \frac{1}{N^2}\left\{\left[\sum_{j=1}^{p} n_j\left(x_{sj}-\bar{x}\right)^2\right]\left[\sum_{j=1}^{p}\left[n_j\left(\frac{\sigma_j}{L}\right)^2 + n_j\left(\bar{x}'_j-\bar{x}'\right)^2\right]\right] - \left[\sum_{j=1}^{p} n_j x_{sj}\bar{x}'_j - N\bar{x}\bar{x}'\right]^2\right\} \quad (1)$$

where x_{sj} is the j-th slit's position; p is the total number of slits; n_j is the number of particles passing through j-th slit and hitting the screen; $\bar{x}$ is the mean position of all beamlets; $\bar{x}'_j$ is the mean divergence of j-th beamlet; $\bar{x}'$ is the mean divergence of all beamlets; $\sigma_{x'_j}$ is the r.m.s. divergence of j-th beamlet.

EXPERIMENTAL SETUP

The *Bucking* and *Focusing* solenoids are placed symmetrically around the Mg photocathode and the *Matching* solenoid is located slightly after the gun exit. The photoelectron beam exits the gun at approximately

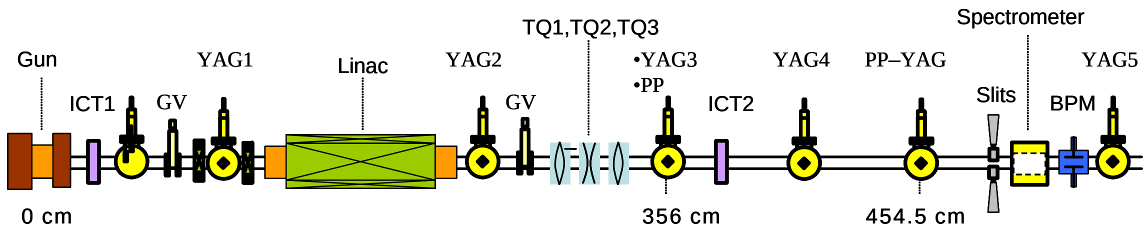

Figure 2: Block Diagram of the AWA beamline. The photocathode is located at z=0cm, a pepper pot (PP) and a YAG screen (YAG3) are installed at z=356cm and a YAG screen (PP–YAG) for viewing the beamlets is installed at z=454.5cm.

8 MeV and drifts to PP, located 356 cm from the photocathode. *Note PP was not installed at the location of the ideal emittance minimum.* During the experiment the following were held fixed: the linac was off (since the goal was to measure the emittance directly out of the gun); the quads (TQ1-3) were set to zero gradient; *Bucking* = -*Focusing* = 1.4 kG; laser rms transverse radius = 1 mm; and rms longitudinal pulse length = 3.5 psec. Only two parameters were varied during the experiment: (i) *gun phase* (ϕ_0) from approximately 10^0 to 60^0 degrees (sine convention); and (ii) *Matching* solenoid to obtain a minimum spot size on PP, with a typical value near 4.5 kG. The beamlets emerging from PP then drift 98.5 cm to a normal incidence YAG:Ce (PP–YAG).

Pepper Pot Geometry & Dynamic Range

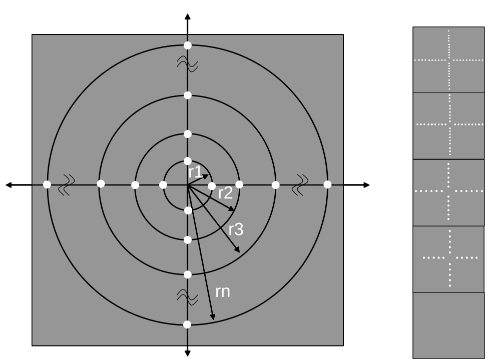

Figure 3: Pepper pot geometry. (left) 50 μm holes on circles of ri. (right) Rail with the four PP of different hole spacing and one blank plate for background.

Only a limited range of emittance values can be measured with a given PP system due to the spacing of the holes and the drift distance between the PP and the screen. To deal with this limitation, a series of 4 PP (tungsten plates: 1" square x 500 μm thick) were installed onto a rail mounted to an 8 inch stroke MDC motorized actuator. All holes on the PP have radius = 50 μm but different spacing Δr = {700, 800, 900, 1000} μm, thus increasing the dynamic range of the in situ setup.

Imaging System

A 100 μm thick YAG:Ce screen (Fig. 2, PP–YAG) was mounted on a motorized actuator at normal incidence to insure that all beamlets drift the same distance and to minimize the depth of focus problem. The screen was viewed at a working distance of 173 mm using a 16-bit ICCD camera [PIMAX-1k] using a 105 mm F-mount Nikon zoom lens. An in situ resolution target (USAF-1951) was also installed on the same actuator as PP-YAG but proved difficult to use due to uneven illumination. Therefore, the resolution and depth of focus (d.o.f.) were measured offline using a scanning pinhole (dia = 15 μm) technique (Fig. 4). Final results: calibration = 20 μm per pixel, resolution = 30 μm, and d.o.f. = 4 mm.

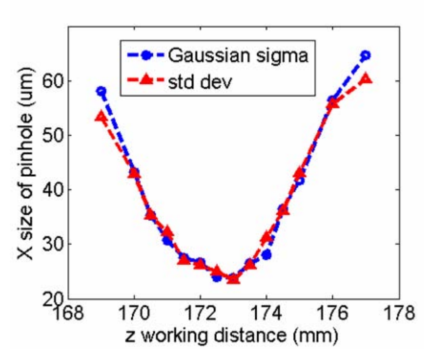

Figure 4: Resolution and depth of focus measurement.

DATA ACQUISITION AND IMAGE ANALYSIS

Before taking data, the gun phase (ϕ_0) is first determined by performing a charge scan and then ϕ_0 is set to the desired value. With ϕ_0 set, the laser energy delivered to the photocathode is adjusted by varying the final laser amplifier until the charge is equal to 1 nC. Finally, with YAG3 inserted, the *Matching* solenoid was

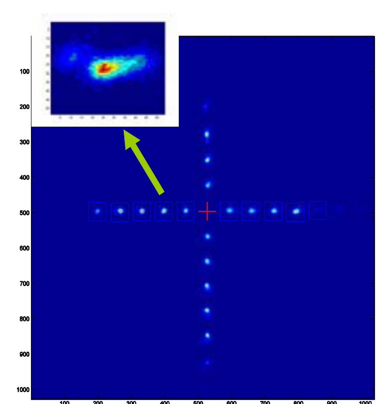

Figure 5: Pepper pot beamlets on PP–YAG.

used to minimize the spot size on YAG3 (also the location of the pepper pot). The spot size measured directly from the YAG3 image (typical $\sigma_{x,y}$ = ~3 mm) was in good agreement with the spot size calculated indirectly from PP-YAG via the first sum in Equation 1. After the images were captured on YAG3, the screen was withdrawn and PP was inserted. With the ICCD gate set to 50 nsec, to minimize dark current contributions to the image, a MATLAB based routine was used to capture 20 images of the beamlets at PP-YAG plus 1 background image, where the laser was blocked.

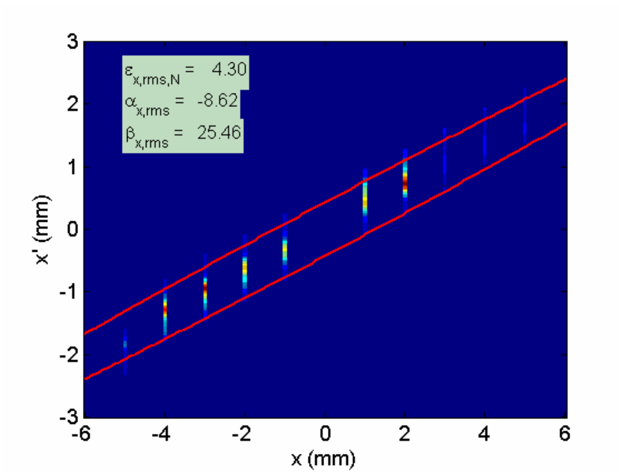

Figure 6: Example of a measured phase space and fit.

The rms Twiss parameters (α_{rms}, β_{rms}, ε_{rms}) were extracted from each single-shot signal (background subtracted) image using a MATLAB based routine. The current routine requires the user to click on the approximate center of each individual beamlet but future version may 'find' the beamlets. The routine then crops a region around each beamlet, as indicated by the boxes in figure 5. After finding the intensity and the centroid of the beamlet, the standard deviation is calculated from the 2-sigma core (95%) of the beam (inset Fig. 5). Using these beamlet quantities and the PP geometry the Twiss parameters were calculated (Eq. 1) and an ellipse was fitted to the phase space (Fig. 6). Note that the ellipse displayed in Figure 6 is 4 times larger than the fitted rms ellipse and thus encloses 95% of the beam.

RESULTS

A comparison between the measured values of the emittance and PARMELA simulations is shown in Figure 7. The measured values are the mean of the 20 signal images and the error bars are the standard deviation of the same points. The PARMELA predictions are shown as stars; x-data in blue; y-data in red. In general, the agreement with simulation is good, with most predictions falling within the error range of the data.

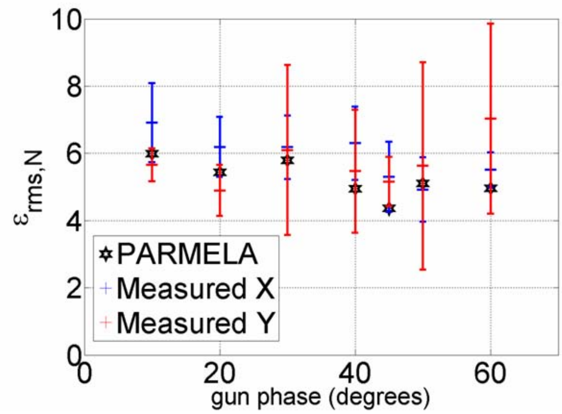

Figure 7: Comparison of PARMELA to data.

Limitations & Future Improvements

Due to the long distance from the photocathode that PP was installed, only a limited parameter scan was achieved. For example, the *Matching* solenoid current had to be adjusted for each different value of ϕ_0 to keep a reasonable spot on YAG3 and PP–YAG. If solenoid current was set too high some of the beamlets would fall outside of the field of view of the PIMAX. However, the field of view could not be increased without sacrificing resolution. A solution to this would be to use a scientific-grade camera with an array greater than 1K x 1K to increase the field of view yet maintain the resolution.

CONCLUSION

A Pepper pot measurement system was installed in the AWA beamline and used to measure the transverse phase space directly out of the 1.3 GHz photoinjector. During these measurements the beam energy was 8 MeV and the charge was 1 nC. We reported on the experimental setup, gave details of the emittance measurement system and a description of the image analysis. Comparisons between PARMELA and data showed good agreement.

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