MEASUREMENT AND SIMULATION STUDIES OF EMITTANCE FOR SHORT GAUSSIAN PULSES AT PITZ

M. Khojoyan[†‡], G. Asova[§], J. Bähr, H. J. Grabosch, L. Hakobyan[‡], M. Hänel, Y. Ivanisenko, G. Klemz, M. Krasilnikov, M. Mahgoub, B. O'Shea[$], M. Otevrel, B. Petrosyan, S. Rimjaem, A. Shapovalov[#], R. Spesyvtsev[¶], L. Staykov[§], F. Stephan, G. Vashchenko, DESY, Zeuthen, Germany
S. Lederer, 22603, DESY, Hamburg, Germany
D. Richter, HZB, BESSY II, 12489, Berlin, Germany
J. Rönsch-Schulenburg, University of Hamburg, Germany

Abstract

The Photo Injector Test facility at DESY, Zeuthen site (PITZ), develops and optimizes electron sources for Free Electron Lasers (FEL's) such as FLASH and the European XFEL. The electrons are generated by the photo effect using a cesium telluride (Cs_2Te) cathode and are accelerated in a 1.6-cell L-band RF-gun cavity with about 60 MV/m maximum accelerating field at the cathode. The upgraded laser system at PITZ produces flat-top and Gaussian laser pulses of different time durations. Emittance measurements have been done for short Gaussian laser temporal profile ~2 ps FWHM and for 6.6 MeV electron beam energy. The transverse projected emittance was measured for various transverse laser spot sizes at the cathode and different low bunch charges to find an optimum condition for thermal emittance measurements. ASTRA simulations were performed for various measurement conditions to estimate the space charge contribution to the emittance. The comparison of emittance measurement results and simulations is presented and discussed in this contribution.

INTRODUCTION

The main goal of PITZ, is the production of electron beams with very small transverse emittances at 1nC bunch charge. The new upgraded laser system at PITZ which was developed by Max-Born institute [1] can also produce very short Gaussian laser pulses with a length of about 0.85 ps rms. Transverse projected emittance measurements at PITZ are performed with emittance measurement systems – EMSYs, applying the single slit scan technique [2]. PITZ has already measured transverse projected emittance below 1 mm mrad for 1 nC bunch charge with flat-top longitudinal laser profile [3]. In such a case it is very important to estimate the main part of the emittance, which is generated during the emission process, i.e. the thermal emittance. At PITZ it is not possible to measure the thermal emittance directly at the photocathode, but in the position of the first emittance measurement system - EMSY1, located at 5.74 m downstream the photocathode for the current PITZ setup (PITZ1.7). A simplified overview of the PITZ setup for the thermal emittance measurements is shown in Fig.1.

† martin.khojoyan@desy.de
‡ on leave from YerPhI, Yerevan, Armenia
§ on leave from INRNE, Sofia, Bulgaria
$ on leave from UCLA, California, USA
# on leave from MEPHI, Moscow, Russia
¶ Currently at UCL, London, UK

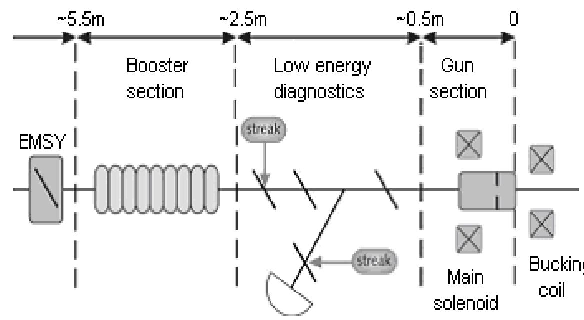

Figure 1: A simplified overview of PITZ beamline for thermal emittance measurements (from right to left).

To estimate the thermal emittance, PITZ measures normalized beam emittance for various laser spot sizes on the cathode at very low bunch charges and very short laser pulses in order to reduce the space charge and RF influences on the measured emittance values [4, 5]. The average kinetic energy of the electrons is then calculated by fitting linearly the measured data points of emittance depending on the laser transverse rms spot size at the cathode [6]. In this paper the results of emittance measurements performed for short Gaussian pulses and 3 different measurement conditions are presented. ASTRA [7] simulations have been performed to estimate the influence of different effects on the measured emittance.

OPERATION CONDITIONS AND DIFFICULTIES

The reference screen for the thermal emittance measurements for PITZ1.7 setup is relative far located in comparison to the previous PITZ setup. That causes the intensity problems for electron beams having very low bunch charge and relatively small momentum. For that purpose emittance measurements were performed for 60 MV/m accelerating gradient at the cathode and for relatively high bunch charges. During the measurements the RF phase of the gun has been adjusted to the phase of maximum mean momentum gain. The electron beam measurements have been done for each laser transverse diameter and the emittance has been measured for a main solenoid current corresponding to a beam focus at

EMSY1. Horizontal and vertical slits at EMSY1 with 50 um width have been used for obtaining the transverse phase space distributions. Five measurements have been taken for the emittance at each plane. The beamlet intensity has been kept at some constant high level in order to use the full dynamic range of the 12 bit CCD camera [4]. The transverse emittance has been measured for different laser spot sizes on the cathode and for 3 different measurement setups:

a) 15 pC fixed charge, number of laser pulses tuned to have the required beamlet intensity on the screen

b) 100 fixed laser pulses, charge tuned to have the required beamlet intensity on the screen

c) 4 different fixed charge densities at cathode, number of laser pulses tuned to have the required beamlet intensity on the screen

ASTRA simulations were performed to estimate the space charge contribution to the measured emittance. The emittance has been simulated as a function of rms spot size including the experimental conditions, i.e. the laser pulse length, laser rms spot size, mean momentum at gun on-crest phase etc..

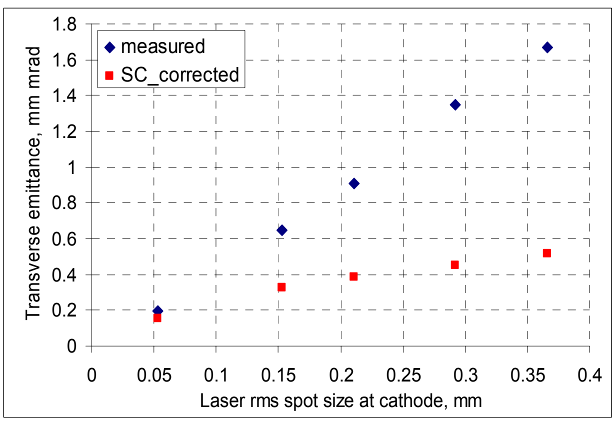

Figure 2: Emittance as a function of laser spot size (originally measured and space charge corrected values).

The space charge (SC) influence on the emittance is calculated by comparing the simulated emittance including the space charge and the theoretical thermal emittance [8]. Then, the SC contribution is subtracted from the measured emittance.

$$\varepsilon_{SC\_sim} = \sqrt{\varepsilon_{sim}^2 - \varepsilon_{generator}^2} \Rightarrow B = \frac{\varepsilon_{SC\_sim}}{\varepsilon_{sim}} \qquad (1)$$

$$\varepsilon_{SC\_meas} = B \cdot \varepsilon_{meas} \Rightarrow \varepsilon_{corr} = \sqrt{\varepsilon_{meas}^2 - \varepsilon_{SC\_meas}^2} \qquad (2)$$

where ε_{meas} is the measured emittance, ε_{sim} is the simulated emittance including measurement conditions, $\varepsilon_{generator}$ is the thermal emittance - a kinetic energy of the electrons of 0.55 eV is assumed for all calculations, ε_{corr} is the measured emittance value where the space charge contribution is subtracted according to simulation predictions. In Fig.2 the originally measured and the space charge corrected emittances are shown as a function of the laser rms spot size for b) measurement case, i.e. 100 fixed laser pulses. It is crucial to mention the existing difference between measured and simulated beam size values as visual in Fig. 3.

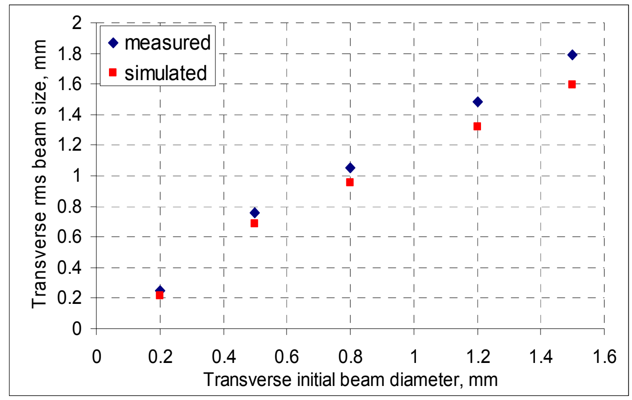

Figure 3: Measured and simulated rms beam sizes at EMSY1 for different initial beam diameters at the cathode.

During the run period fluctuations of the gun phase were observed [9, 10]. The reason of the fluctuations was the absence of low level rf regulation in the gun system. More detailed description of the gun cavity structure and RF system at PITZ can be found in [11]. Investigations have been carried out to estimate the impact of the phase fluctuations on the measured emittance. For the statistical estimations the histogram of the gun phase was obtained by exporting the phase data from the data acquisition system for 10 measurements.

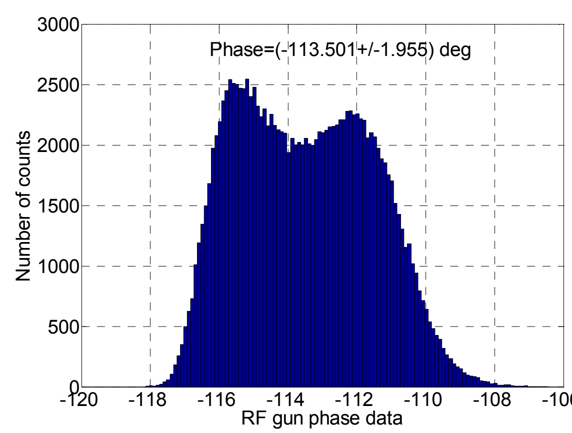

Figure 4: An example of the gun phase histogram.

100 fixed laser pulses, 1.2 mm laser beam diameter. Periods (5 measurements for each horizontal and vertical plane) including the phase values for all RF buckets where the laser pulses were injected - Fig. 4. A phase jitter contribution to the simulated emittance is afterwards estimated by overlapping the phase spaces of all phases shown in the histogram of gun phase. The ratio between

the emittance value obtained from overlapped phase spaces and the simulated emittance value for fixed on-crest phase has been considered to be the correction factor

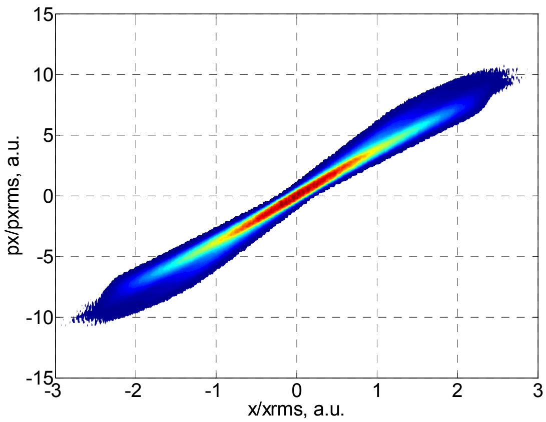

Figure 5: Overlapped phase spaces for all phases shown in the histogram of gun phases.

which was later on subtracted from the measured emittance - Fig. 6. For the case of 100 fixed pulses almost no influence of the phase jitter on the emittance is observed from the simulations.

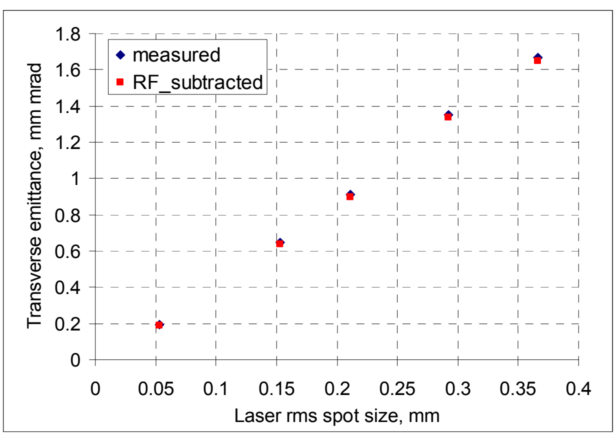

Figure 6: Emittance as a function of rms laser spot size for the measured and the phase jitter corrected values.

RESULTS AND DISCUSSION

In Table 1, measurement conditions for two cases, 15 pC fixed charge and 100 fixed laser pulses, are shown: The number of laser pulses used for the horizontal (X) and the vertical (Y) plane measurements for the first case and the bunch charges for the second case are given. The thermal emittance values are estimated by the subtraction of the space charge contribution deduced from simulations from the measured emittance values which have already been corrected for the phase jitter contribution. The original measured and the thermal emittances for different rms laser spot sizes at the cathode are shown in Fig. 7. It is important to mention that for the smallest laser rms spot size, which is about 0.05 mm, the maximum possible extracted charge was 10 pC. It shows that the space charge is still very strong for this small spot size and short laser pulse length.

Table 1: Measurement conditions for two cases (fixed 15pC and fixed 100 pulses).

Beam shaping aperture (BSA), mm	Laser rms spot size, mm	Fixed 15 pC Number of pulses used for X / Y	Fixed 100 pulses Charge pC
0.2	0.053	7 / 7	1.4
0.5	0.153	75 / 87	11.8
0.8	0.211	125 / 155	20
1.2	0.292	175 / 200	36
1.5	0.366	287 / 200	47

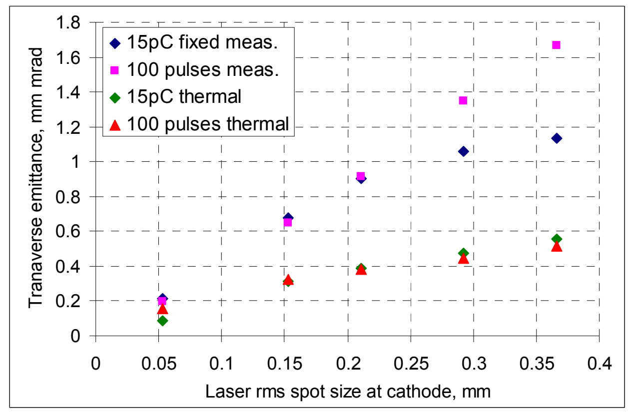

Figure 7: Emittance as a function of laser rms spot size at the cathode for fixed 15 pC and for fixed 100 pulses.

One of the important criteria for thermal emittance measurements is actually not the small charges but small charge densities at the cathode, i.e. the amount of charge per square (or cubic) millimetre at certain spot size. Emittance measurement conditions - Tab.2 in the case of 4 different fixed charge densities at the cathode and results - Fig.8 for different laser rms spot sizes are shown below. The emittances for 4 different charge densities at the cathode obtained from the same correction procedure. The phase jitter and the space charge correction, as described before, are shown in Fig. 9.

Table2: Conditions for the emittance measurements in the case of 4 fixed charge densities at the cathode.

Surface charge density at cathode pC/mm^2	Charge, pC				
	BSA 0.2mm	BSA 0.5mm	BSA 0.8mm	BSA 1.2mm	BSA 1.5mm
112	0.32	2.9	5	10	15
372	1.05	9.7	17	32	50
745	2.11	19.5	33	64	100
1490	4.21	39	65	126	200

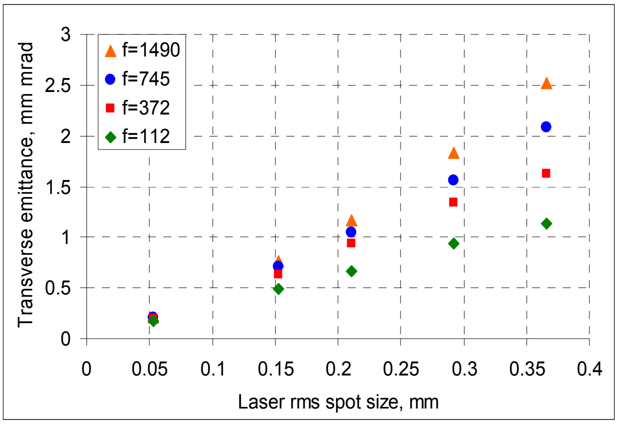

Figure 8: Measured transverse emittance as a function of the rms spot size at the cathode for 4 fixed charge densities at the cathode.

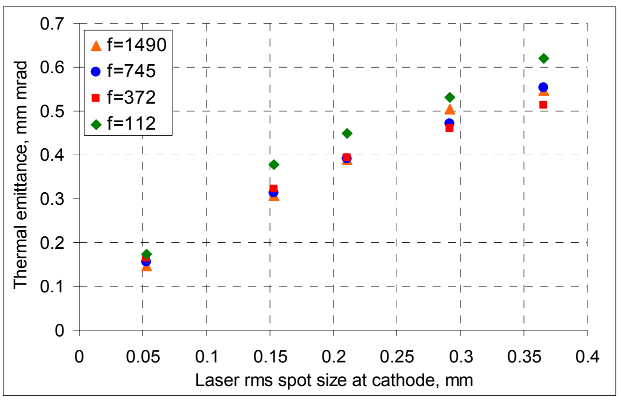

Figure 9: 'Thermal' emittance as a function of the laser rms spot size for 4 fixed charge densities at the cathode.

The surface charge density of $745\, pC/mm^2$ corresponds to the same volume charge density value in the case of PITZ nominal measurement settings - 1 nC bunch charge, 1.5 mm transverse laser beam diameter and longitudinal flat-top profile, optimized to measure the smallest projected emittance [4]. For that case the estimated value for the thermal emittance (Fig. 9) is about 1.5 times higher than the thermal emittance value expected from the theory.

SUMMARY

Emittance measurements done for short Gaussian laser profile, different laser rms spot sizes at the cathode and different bunch charges are presented for three different measurement conditions. Almost no phase jitter influence on the emittance is observed by the simulations for all measurement cases. For the case of short Gaussian laser profile - more pronounced space charge forces within the bunch, the charge density factor is a very important issue and has to be carefully set during the measurements.

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