TRANSVERSE EMITTANCE MEASUREMENTS AT THE PHOTO INJECTOR TEST FACILITY AT DESY ZEUTHEN (PITZ)

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Abstract

The components and functionality of the emittance measurement system at PITZ are introduced. In brief some design considerations are reviewed as well. The influence of the noise due to dark current and electronic noise in beam size measurements is discussed and estimated. Results from recent transverse emittance measurements are presented and compared with simulations. Examples of a strongly distorted trace space are also considered where the application of a single slit scanning technique is a successful alternative of the multi-slit method.

INTRODUCTION

The main research goal of the Photo Injector Test Facility at DESY Zeuthen (PITZ) is the development of electron sources with minimized transverse emittance like they are required for the successful operation of Free Electron Lasers and future linear colliders [1]. The process of electron beam optimization requires characterization of the transverse emittance at a wide range of operation parameters. A slit/pepper-pot emittance diagnostic is designed and commissioned in order to characterize the trace space of the space charge dominated electron beam produced by PITZ.

EMITTANCE MEASUREMENT SYSTEM (EMSY)

EMSY (Figure 1) consists of two sets of masks for sampling the trace space distribution in both transverse directions. Each set is mounted on a separate carrier (actuator). In general EMSY has four degrees of freedom: rectilinear vertical and horizontal motion and rotation around both transverse axes. All motions are remote controllable. The masks are made out of 1-mm thick tungsten* plates. The slits have an opening of 50 µm, the diameter of the pepper pot mask holes is of the same size. There are two variations of multi slit masks installed in EMSY: with 1mm and 0.5 mm slit to slit separation. The design of the masks meets some general requirements introduced in [2], [3]:

-The beamlets produced by a slit mask must be emittance dominated

-The distance between the slits is a compromise between obtaining a good representation of the phase space and avoiding overlapping of the beamlets

-The contribution of the initial beamlet size to the beamlet size at the observation screen should be as small as possible

-The thickness of the mask is a compromise between the need to scatter electrons to form a uniform background and the desire to minimize the slit-edge scattering.

The masks are installed on the two actuators in the following arrangement: on the vertical actuator a multi-slit mask, a pepper-pot mask and a single slit mask are mounted. On the horizontal one: multi-slit mask, single-slit mask and YAG screen for direct observation of the electron beam.

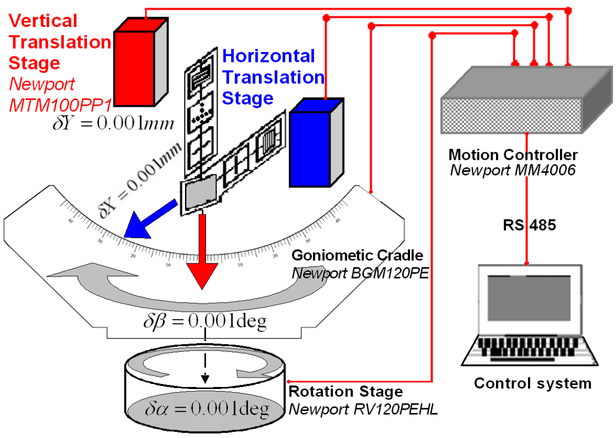

Figure 1: The emittance measurement system.

BEAM SIZE AND TRANSVERSE EMITTANCE MEASUREMENTS

The beam position and RMS size measurements are performed by calculating first and second central moments of intensity distributions of images obtained by CCD cameras:

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$$\bar{x} = S \cdot \frac{\sum_{i,j} i \cdot C(i,j)}{\sum_{i,j} C(i,j)}$$

$$\sigma^2 = \frac{\sum_{i,j} (S \cdot i - \bar{x})^2 - C(i,j)}{\sum_{i,j} C(i,j)}$$

Where the summation is over the rows and columns of the image matrix *C* and *S* is a scaling factor. In order to minimize the influence of the noise due to dark current and electronic noise a background subtraction is applied prior to the calculation of beam positions and RMS sizes. Since the background subtraction is never perfect the remaining noise still contributes significantly to the RMS size. An estimation $\boldsymbol{\delta\sigma}$ of this influence could be given by comparison between the RMS-size results $\boldsymbol{\sigma}avr$ and $\boldsymbol{\sigma}env$ obtained after subtracting an average and an envelope background image respectively:

$$\boldsymbol{\delta\sigma} = \frac{\boldsymbol{\sigma}avr - \boldsymbol{\sigma}env}{2}$$

Here the average background is determined by averaging the dark current profiles over a given number of RF pulses. The envelope background is determined by taking always the peak camera pixel values for a given number of dark current images. Since the envelope background subtraction cuts more of the tails of the intensity distribution one obtains $\boldsymbol{\sigma}avr \geq \boldsymbol{\sigma}env$. On the other hand the subtraction of an average background tends to underestimate the influence of the noise. Therefore one could evaluate the size $\boldsymbol{\sigma}$ as:

$$\boldsymbol{\sigma} = \frac{\boldsymbol{\sigma}avr + \boldsymbol{\sigma}env}{2} \pm \boldsymbol{\delta\sigma} \quad (1)$$

In this paper (1) is used for evaluating the beam size.

The goal of our emittance measurements is to obtain a value for the normalized RMS emittance defined as:

$$\varepsilon x = \beta\gamma \left[\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2 \right]^{\frac{1}{2}}$$

For practical use it is more convenient to apply an equivalent definition as derived in [4]:

$\varepsilon x = \beta\gamma \sqrt{\langle x^2 \rangle \langle \tilde{x}'^2 \rangle}$, where $\tilde{X}'$ is the uncorrelated divergence. The RMS size $\langle X^2 \rangle$ is measured directly at the position of the slit masks. $\langle \tilde{x}'^2 \rangle = \sum_i w_i \cdot \left(\frac{\sigma_i}{L} \right)^2$ is deduced by analyzing the beamlet profiles observed on a YAG screen downstream of EMSY (Figure 2), here $\boldsymbol{\sigma}_i$ denote the transverse size of the beamlets and $\mathbf{w}_i$ are the corresponding weights, which depend on their intensity. *L* is the distance between the slits and the screen of observation.

Often when measuring with a multi-slit mask the beamlet profiles partially overlap on the screen. In such cases the projected intensity is fitted to a sum of gaussian functions in order to estimate the size of the beamlets and their contribution to the overall intensity distribution. The applicability of this method is limited to the cases when the overlapping is not too strong and fits well to the above-mentioned assumption. The scanning with a single slit gives the possibility to analyze each profile separately without any assumption of the beam shape. This method was mainly used in the measurements presented below.

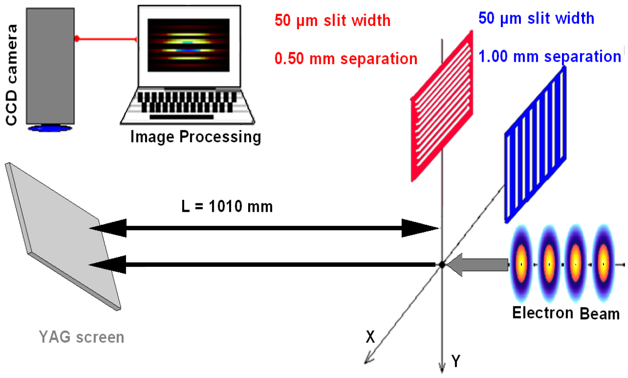

Figure 2: Measuring beam divergence

RESULTS

One example of scanning with a single slit through the horizontal cross section of the beam is shown in Figure 3. The scanning step is 0.300 mm the bunch charge is 0.66 nC. The mean momentum was measured to be 4.57 MeV/c. The current in the main solenoid was Imain=290 A. This current corresponds to a beam waist at the position of the slit. The X-RMS size of the beam at the position of the slit (1.62 m after photocathode) was measured directly to be 0.38 +/- 0.01 mm. The measured normalized X-RMS emittance is equal to 5.3 +/- 0.7 mm.mrad.

Analog an Y-RMS emittance of 4.7 +/- 0.5 mm.mrad is obtained

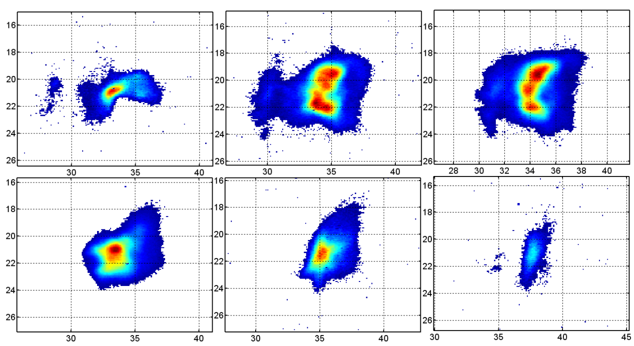

Figure 3: Single slit measurement in X-direction

The simulation results show values εx = 5.6 mm.mrad, εy = 4.5 mm.mrad. Figure 4 shows the simulated phase space, corresponding to the measurements shown in Figure3. The phase space distribution shown on this figure is typical for the case when the beam is focussed on the position of the emittance measurement system, which leads to extreme increase of the space charge forces acting on the beam particles.

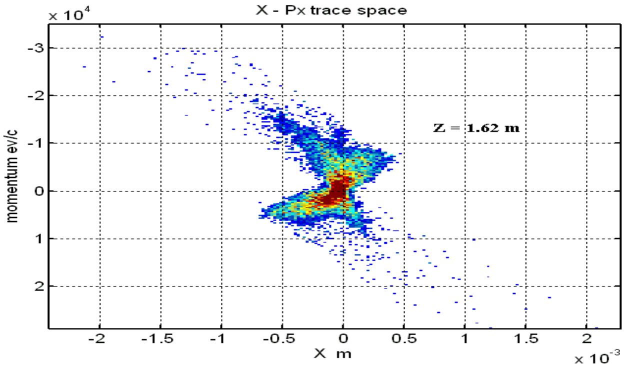

Figure 4: Simulated phase space

The transverse emittance was measured as a function of the current of the main solenoid (Figure 5). The measurements were done at the following conditions:
Gun gradient = 40.0 MV/m, bunch charge = 0.66 nC
Mean momentum = 4.58 MeV/c.

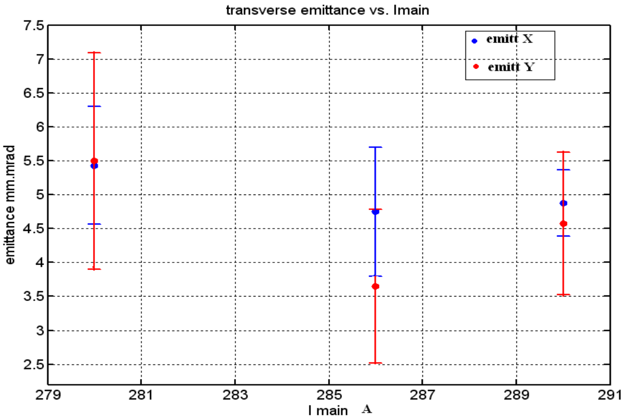

Figure 5: Transverse emittance vs. solenoid current

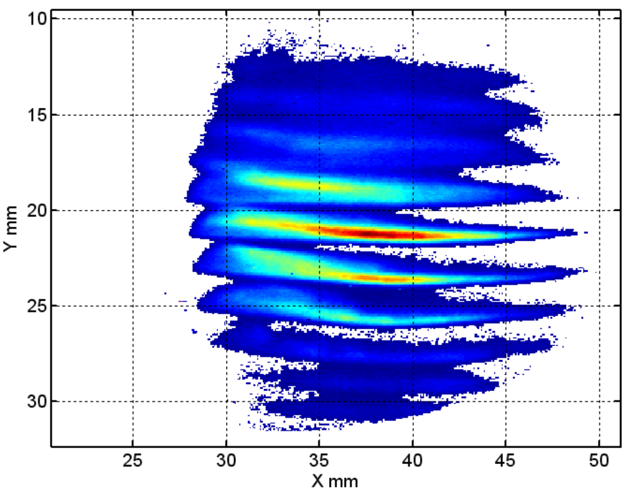

Figure 6: Beamlet profiles measured by the vertical multi-slit mask

Emittance εy= 5.8 ± 0.6 mm.mrad was measured with the vertical multi-slit mask as shown in Figure 6 at the following conditions: gun gradient = 40.5 Mv/m, Imain=300A, charge=0.49nC, Pmean = 4.56 MeV/c, Beam rms size at slits = 1.05 mm.

CONCLUSIONS AND OUTLOOK

The emittance measurement system at PITZ is fully commissioned. Measurements of the transverse beam emittance were done in a wide range of machine parameters. The transverse emittance numbers presented in this paper are not the optimum values that are possible with the RF gun at PITZ. The main reason for this is that the current laser system produces very short pulses of 7 ps FWHM, which lead to strong space charge forces at the cathode. The short laser pulse profile is done in preparation of installing a flat top longitudinal laser profile in 2 months. Also the current longitudinal position of the main solenoid is optimised for the future flat top laser shape. All this means that better experimental results are expected in near future

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