DESIGN OPTIMIZATION OF AN EMITTANCE MEASUREMENT SYSTEM AT PITZ *

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Abstract

The photo injector test facility at DESY Zeuthen (PITZ) has been built to test and to optimize electron sources for Free Electron Lasers (FEL's). In order to study the emittance conservation principle, further acceleration is required. To increase the electron beam energy up to 30 MeV, a booster accelerating cavity is under commisioning [1]. With this upgrade, the projected normalized transverse emittance less than 1 mm mrad is expected from beam dynamics simulations. To measure such small emittance, an upgrade of the existing Emittance Measurement SYstem (EMSY) is required. EMSY uses the slit mask technique to determine the beam emittance. In this paper, considerations on the physics of the system as well as results from GEANT4 simulations are given. The expected signal to noise ratio, the resolution of the system, and the energy deposition in the slit-mask are presented. EMSY is under construction at INRNE Sofia. Installation and first results are expected by the end of this year.

INTRODUCTION

The careful optimization of the electron source at PITZ has shown that it is possible to achieve small emittance for 1 nC bunch charge. Upgrade on the facility including installation of accelerating booster cavity will increase the energy of the electron beam to about 30 MeV. This requires upgrade of the present Emittance Measurement SYstem (EMSY) Fig. 1. The layout of PITZ is shown on Fig. 2. The electrons are extracted from a photo cathode based RF gun. The minimum beam emittance of $\sim 0.84\ \pi$.mm.mrad expected from the simulations could be achieved by further beam acceleration.

The setup of the emittance measurement system used at PITZ (Fig. 1) is typical for slit measurements. The system consists of two orthogonal actuators which can be inserted separately to penetrate the beam in order to take images or to cut beamlets in the beam transverse planes. The beamlets are observed at some distance L downstream and the normalized emittance ε_n is calculated using the standard formula (Eq. 1).

$$\varepsilon_n = \beta\gamma \cdot \sqrt{\langle x^2\rangle \cdot \langle x'^2\rangle - \langle x \cdot x'\rangle^2}. \qquad (1)$$

Here $\langle x^2\rangle$ and $\langle x'^2\rangle$ are the rms dimensions of the beam in the so called trace phase space where $x' = \sqrt{\langle p_x^2/p_z^2\rangle}$ represents the rms divergence of the beam. The rms beam size is measured on an OTR or YAG screen at the position of the slits along the beam axis. The divergence is obtained by analyzing the profiles of the beamlets produced from the slits which drift some distance L downstream where the spatial distribution of the beamlets corresponds to the local divergence, x' can be derived from the size of the beamlet using the formula in Eq. 2.

$$x' = \sqrt{\frac{\langle x_b^2\rangle}{L^2}}. \qquad (2)$$

Here x_b is the rms size of the beamlet on the screen after distance L. The $\beta\gamma$ is measured using a dispersive arm after EMSY.

EMSY LAYOUT

In general EMSY consists of two orthogonal actuators perpendicular to the beam axis which are holding the components which are inserted in the beam line. Stepper motors are provided to move separately each one of the four axes which give the precise spatial positioning and orientation of the components. On each of the actuators, either an YAG or OTR screen is mounted to observe the beam distribution. A single and a multi slit masks are mounted consecutive to take samples from the transverse phase space of the electron beam. A CCD camera is placed to observe the screens. EMSY was designed and manufactured jointly of Sofia Institute for Nuclear Research and Nuclear Energy and DESY Zeuthen in the period 2000-2001.

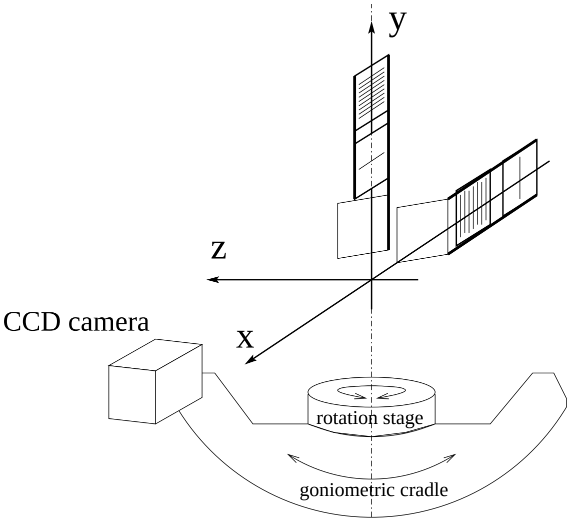

Figure 1: Layout of EMSY.

In the optimization process the components of the existing EMSY were modeled using GEANT4 [2] for the in-

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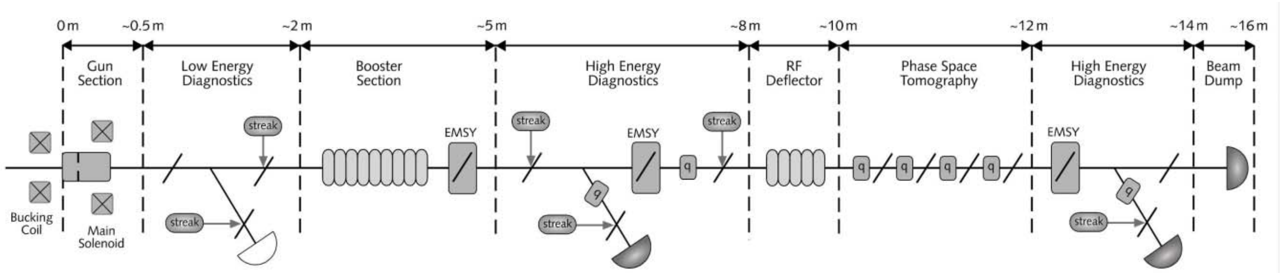

Figure 2: Layout of PITZ.

teractions of the beam with the material of the masks, and ASTRA [3] for detailed beam dynamics simulations.

OPTIMIZATION OF EMSY

Requirements for the system

During the optimization of the system, the following requirements were taken into account [4]:

- The beamlets produced by the slit mask must be emittance and not space charge dominated.
- The contribution of the initial beamlet size to the one measured at the observational screen must be as small as possible.
- The distance betwen the slit mask and the screen must be big enough to resolve small beam divergence.
- The mask thickness must be enough to scatter the residual electrons from the beam in order to produce an uniform background for the beamlets measurements and still it must provide sufficient acceptance angle.

Beam Dynamics considerations

The first requirement can be summarized taking into account formula 3 which is the ratio of the emittance and space charge terms in the envelope equation of a Gaussian beam [5].

$$R_b = \sqrt{\frac{2}{3\pi}} \cdot \frac{I}{\gamma I_0} \cdot \frac{d^2}{\varepsilon_n^2}. \qquad (3)$$

Here I is the beam current, I_0 is the so called Alfvent current and d is the slit width.This ratio must be smaller than 1 when we require emittance dominated evolution of the beamlets after the slit mask. In order to minimize the uncertainty brought by the influence of the space charge forces we set this ratio to be smaller than 0.1 for the design optimization. Since R_b is scaled with $1/\gamma$ it is obvious that for higher energies this is not a dominating parameter. Where the second requirement can be described using Eq. 4 assuming that the beam is at waist.

$$d \leq \sqrt{12} \cdot \frac{L\varepsilon_n}{\gamma\langle x\rangle} \qquad (4)$$

Taking this into account for the wide range of parameters expected in PITZ one ends up with slit width which must be $\leq$ 10 μm. The result is illustrated on Fig. 3 where a nominal beam is tracked using Astra. The influence from the finite slit size is clearly visible in the case of 50 and 25 μm in comparison with the 10 μm slit width.

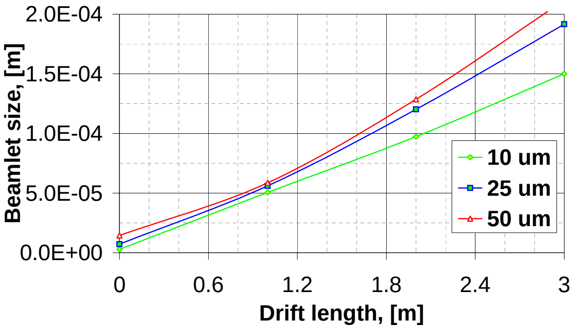

Figure 3: Beamlet evolution along the drift space

GEANT4 simulations

The energy deposition and the signal to noise ratio (S_2N) were estimated using GEANT4. A simplified geometry shown on Fig. 4 was used for the simulations.

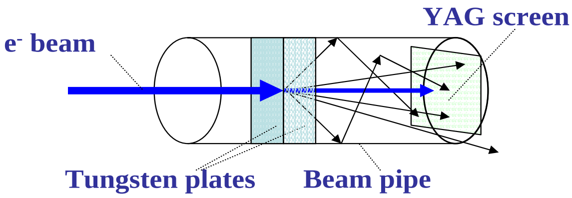

Figure 4: Model applied for the GEANT4 simulations

The mask material and thickens, and the distance between the mask and the observational screen were used as a variables in the optimization procedure. The signal to noise ratio S_2N (Eq. 5) was estimated using the area weighted light output from the YAG screen placed on 1, 2 and 3 meters downstream the slit mask. The signal density is expressed using $\rho_s = N_s^{ph}/A_b$ where N_s^{ph} is the number of photons produced from the beamlet and A_b is the area from the screen covered by the beamlet, $\rho_n = N_n^p/A_s$ is the noise density where N_n^{ph} is the number of photons produced from the scattered electrons, positrons and photons which are interacting with the screen of area A_s. The screen area is $4 \times 4\ cm^2$.

$$S_2N = \frac{\rho_s}{\rho_n} \tag{5}$$

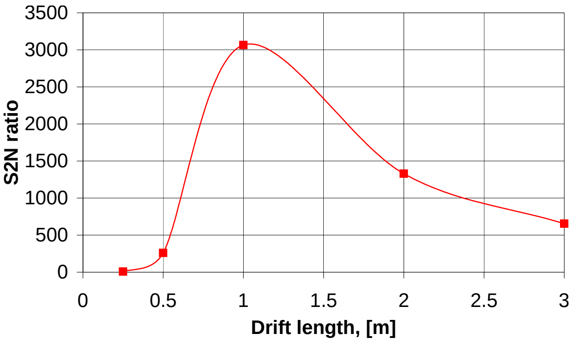

Figure 5: The signal to noise ratio for different drift lengths, mask thickness is 1 mm, slit opening 10 μm

On Fig. 5 one can see that a reasonable signal to noise ratio emerges still after 50 cm downstream from the slit mask and has maximum at $\sim$ 1 m. The image of the beamlet produced from the YAG screen can be seen on Fig. 6 no influence from the scattered radiation is visible.

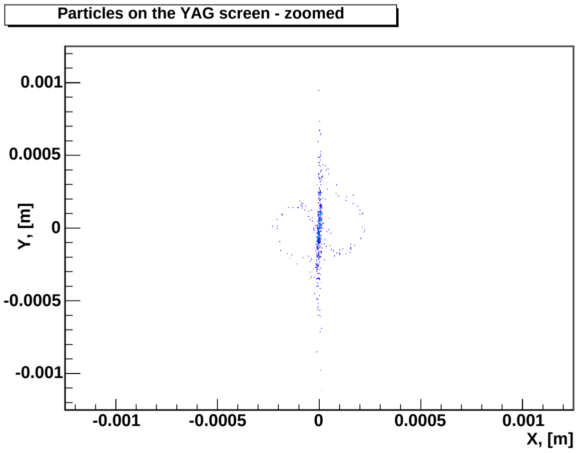

Figure 6: The beamlet image on the YAG screen 1 m downstream, mask thickness is 1 mm, slit opening 10 μm

Heat load of the slits

The energy deposited in the slits (Fig. 7) was used to estimate the heat load of the slits. A 2D numerical model was used to simulate the heat transport trough the tungsten piece. Assuming that no heat is transfered to the other components of the EMSY (which is the worst case scenario in vacuum conditions) we derived the maximum temperature to be reached by the slit components to be smaller than 727 °C.

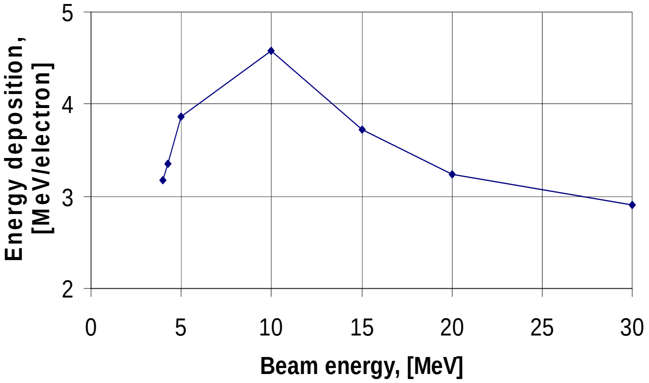

Figure 7: The energy deposition in the components of the mask, mask thickness is 1 mm

CONCLUSIONS

The parametersof the existing emittance measurement system at PITZ were optimized to decrease the uncertainty of the measured emittance smaller then 10 percent in the interval 5-30 MeV. It has been estimated that 1 mm thick tungsten with 10 μm opening for the slit mask must provide reasonable signal to noise ratio after 0.5 m downstream, still for better resolution larger distance from the screen and the slit mask is needed. Big drift length can also be a relief for the optical system of the camera which must resolve beamlet sizes in the interval 0.05 to 1.5 mm.

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