INFLUENCE OF MAIN BEAM PARAMETERS STABILITY ON BEAM SIZE MEASUREMENTS AT PITZ *

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The photo injector test facility in Zeuthen (PITZ) is used to develop and characterize electron sources which produce a nominal bunch charge of 1 nC with the lowest possible transverse emittance. Measurements of the beam size provide us with knowledge on important beam characteristics. For example the measurement of the emittance is based on beam size measurements. Therefore, the control of uncertainties of beam size measurements is very important to validate the experimental results. The statistical uncertainty of transverse beam size measurements due to the beam energy and bunch charge jitters is considered in this paper.

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1. INTRODUCTION

The main goal of the Photo Injector Test facility at DESY in Zeuthen (PITZ) is to develop and to characterize electron sources which satisfy the requirements of SASE FEL. The PITZ facility has the laser system to extract electrons from the photocathode, an RF gun and a booster acceleration section, two solenoids for a space charge compensation and diagnostics installed along the vacuum pipe. The whole beam line is about 13 meters long but PITZ facility is still under development and the beam line will be extended during the next period with two high energy dispersive arms [1], the deflecting cavity [2] and the tomography module [3].

The nominal bunch charge during the operation is 1 nC. Mean beam energy after the gun reaches 5 MeV and after the booster - about 13 MeV. Up to 40 MeV mean energy is planed for the next stages of the facility upgrade. Transverse beam emittance is one of the major parameters included in the requirements for the SASE FEL. The normalized emittance should be below 1 mm mrad. Typically measured beam or beamlet RMS sizes during the emittance measurements are in the range from 0.1 mm to 1 mm [4].

The stability of the main beam parameters such as the mean energy and the bunch charge are very important for the FEL operation as well as for the beam characterization. The influence of the beam parameters stability on statistical uncertainty in the beam size measurements are presented.

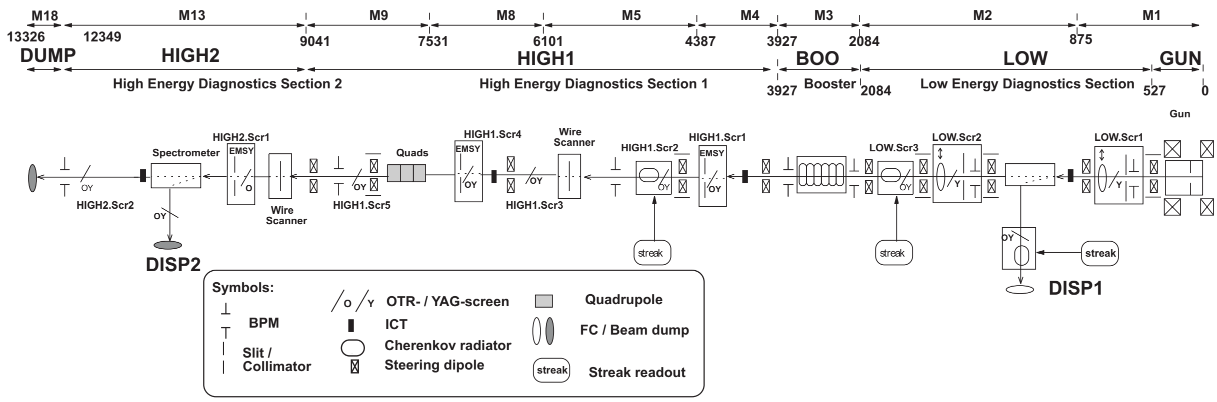

Fig.1. *PITZ setup scheme. Summer 2006*

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2. PHOTO INJECTOR SETUP

The whole scheme of the PITZ setup is shown in Fig.1. Integrating current transformer (ICT) monitors are used for charge measurements in both the low and the high energy sections. An ICT measures the bunch charge without beam destruction but it is not sensitive for bunch charges below 100 pC at PITZ. The Faraday cups are used for charge measurements in the low energetic section. One can measure the mean beam momentum and momentum spread after the gun in the low energy dispersive arm (DISP1) and after the booster in the high energy dispersive arm (DISP2) [5]. Ten screen stations and two wire scanners are installed for the beam size measurements. Three of the screen stations are the Emittance Measurement SYstems (EMSYs) [6]. The high energy section has one additional quadrupole triplet that focuses the beam after the booster. There are ten steering magnets to correct the orbit of the electron beam along the beam pipe. Beam position monitors are mounted along the beam pipe to control the orbit of the beam.

All of the screen stations at PITZ are equipped with a scintillation (YAG) screens and EMSY stations have both, the scintillation screen and the optical transition radiation (OTR) screen. Both screen types emit a light in the visible area which passes through the same optical system and is collected with a CCD camera. The OTR screen stations have one order of magnitude less light emission than the YAG screen stations because of low beam energy (13 MeV) during the operation. The OTR screens will be used at higher beam energies for the next stage of the PITZ setup development.

Two wire scanners were installed and tested at PITZ [7]. The wire scanner has two wires for both X and Y planes. The spacing between wires is 10 mm. The material of the wires can be tungsten or carbon 10 μm in diameter (in general diameter can be varied from 5 to 80 μm). The wire scanner technique does not destruct the beam that allows to use it further. The test beam size measurements with the wire scanners at PITZ have shown good results comparable with a screen measurements. Because of the mechanical properties wire scanners need significantly more time to scan the beam profile than the screen station. Therefore they are presently not very often used as beam profile monitors. This situation will change when the operation energy and the number of pulses in electron train will increase.

3. BEAM PARAMETERS STABILITY

Beam dynamics is sensitive to a number of photo injector parameters which in turn change the electron beam parameters. Two of the main beam parameters are the mean electron energy and the bunch charge. The mean energy of the beam depends mostly on the peak electric field in the gun and the RF phase. The bunch charge depends on the laser intensity, on the RF phase and peak field in the gun and on the quantum efficiency of the photocathode.

A beam RMS size is a function of the beam energy mainly due to the solenoid focusing. Besides, it depends from the bunch charge because of the space charge forces. Thus, a variation of the beam parameters can change a beam dynamics that influences on the uncertainty in the beam RMS size measurements. Simulations of the beam dynamics were done to find out the dependence of the beam RMS size standard deviation (STDEV) as a function of the charge and the energy fluctuations. ASTRA tracking algorithm [8] was used for the simulations. All simulation settings were close to the experimental values during the emittance measurements [4].

Beam parameters instability together with the laser position jitter and instability of power supply of the steering magnets can lead although to the beam position jitter. If the light from the screen is collected during one train (usual operation regime) a beam position jitter inside the train systematically increases measured beam size. One should measure the beam position jitter during the operation to take into account induced systematical uncertainty due to this effect.

4. ENERGY STABILITY

Beam energy E depends linearly from the maximum electric field in the cavity at constant RF phase and therefore it depends as a square root on the power P absorbed in the gun [9]

$$E = e \cdot \sqrt{r_s L P}\sqrt{1 - e^{-2\tau}} \cos\varphi_s, \tag{1}$$

where e is the electron charge, r_s the shunt impedance per unit length, L the length of the cavity, τ the attenuation factor and φ_s the synchronous phase. After the variation of Eq. (1) and dividing the result by the same equation to exclude the unknown coefficients we obtain an uncertainty relationship:

$$\frac{\delta E}{E} = \frac{1}{2}\frac{\delta P}{P}. \tag{2}$$

For the usual operating regime at PITZ, the power in the gun is $P = 3.3$ MW and beam energy after the gun is $E = 4.5$ MeV, thus Eq. (2) gives:

$$\delta E[keV] = \frac{2}{3} \cdot \delta P[kW]. \tag{3}$$

Fig.2.(right) shows the results from the ASTRA simulations for six different maximum electric fields in the gun that correspond to the different mean energies. Bunch charge was fixed to the nominal value 1 nC. The beam RMS size sensitivity to the energy fluctuation is shown in Fig.2.(left). The STDEV of the beam size depends on the distance from the cathode Z and can be represented as a linear function of the mean energy at a given position Z for small energy fluctuations. The maximum STDEV of the beam size is about 11% per 10 keV of the electron beam energy fluctuations. During the usual operation regime the gun absorbtion power has a 7 kW STDEV. The

7 kW power STDEV should lead to the 5 keV of the mean energy STDEV (Eq. (3)) which is in a good agreement with the energy measurements in DISP1. The 5 keV energy deviation gives $STDEV_E = 5.5\%$ maximum deviation for beam size measurements (see Fig.2).

5. CHARGE STABILITY

To determine the charge jitter effect on beam size measurements ASTRA simulations were done for five different initial charges (Fig.3(left)) around the nominal value 1 nC. The beam size STDEV is a function of the distance from the cathode Z and it can be represented as a linear function of the bunch charge at a given position Z for small charge fluctuations. The beam size STDEV reaches up to the 2.2% per 1% of charge fluctuation at 1 nC bunch charge (Fig.3.(right)). The sensitivity to the charge fluctuations is lower before the beam focusing point and reaches the maximum value after it. The charge measurements at the same number of the laser pulses for PITZ setup give about 20 pC charge STDEV at 1 nC bunch charge hence using ASTRA simulations results one can obtain a maximum beam RMS size deviation $STDEV_Q = 4.4\%$.

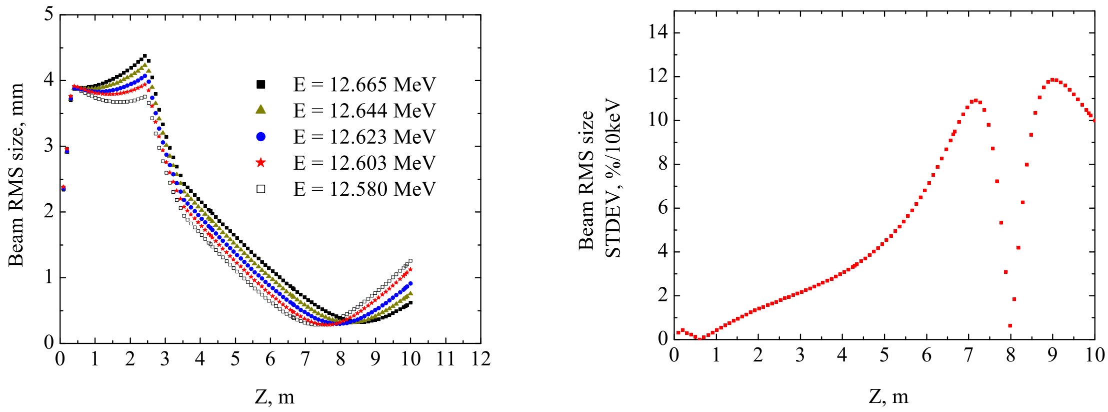

Fig.2. *Beam RMS size as a function of the distance from the cathode (left). Beam RMS size deviation in percent per 10 keV mean energy fluctuation for 1 nC electron bunch charge (right)*

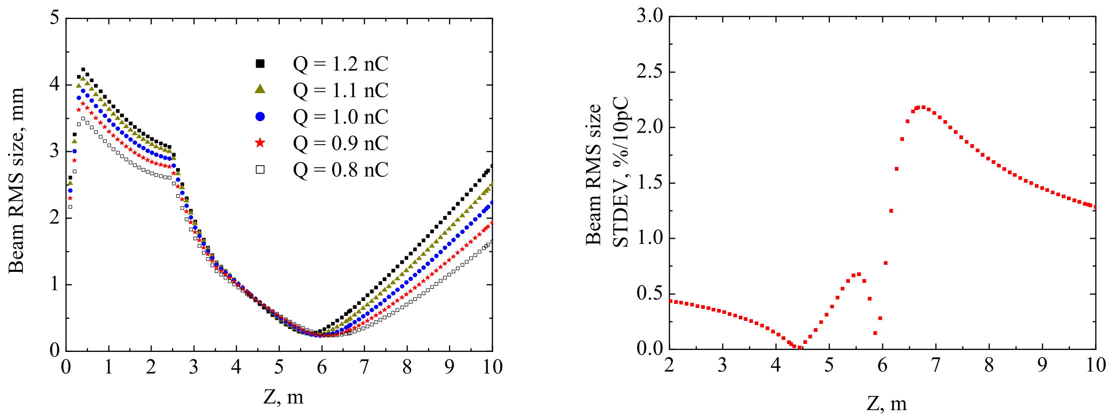

Fig.3. *Beam RMS size as a function of the distance from the cathode (left). Beam RMS size deviation in percent per 10 pC charge fluctuation for 1 nC electron bunch charge (right)*

6. RESULTS

Full beam size deviation including both effects the energy ($STDEV_E$) and the charge ($STDEV_Q$) jitters is a quadratical sum of the STDEVs

$$STDEV = \sqrt{STDEV_Q^2 + STDEV_E^2}. \qquad (4)$$

Using present simulations for both STDEVs one can obtain the maximum beam size STDEV with these effects

$$STDEV = \sqrt{4.4^2 + 5.5^2} = 7\%. \qquad (5)$$

The statistical uncertainty for the beam size measurements can be estimated as

$$u = STDEV/\sqrt{n}, \qquad (6)$$

where n is the number of the measurements for the one point.

7. CONCLUSIONS

Influence of the energy and charge jitter on transverse beam size measurements is considered. Simulations of the effect allow to predict the possible STDEV for the beam size measurements when the energy and charge jitters are known. Using Eq. (6) one can estimate the statistical uncertainty in the beam size measurements.

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ВЛИЯНИЕ СТАБИЛЬНОСТИ ОСНОВНЫХ ПАРАМЕТРОВ ПУЧКА НА ИЗМЕРЕНИЕ РАЗМЕРА ПУЧКА В PITZ

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Стенд испытания фотоинжекторов PITZ служит для разработки и характеризации источников электронов, которые способны производить пучки с номинальным зарядом в 1 нКл и малым поперечным эмиттансом. Одним из базисных измерений при характеризации фотоинжектора является измерение поперечного размера электронного пучка. В частности, измерение поперечного эмиттанса основано на измерениях размера пучка. Знание погрешности в измерении размера пучка является очень важным условием для определения достоверности экспериментальных результатов. В данной работе рассмотрена статистическая неопределенность в измерении поперечного размера электронного пучка, вызванная флуктуациями энергии и заряда пучка.

ВПЛИВ СТАБІЛЬНОСТІ ОСНОВНИХ ПАРАМЕТРІВ ПУЧКУ НА ВИМІР РОЗМІРУ ПУЧКУ В PITZ

Р.І. Спесівцев

Стенд випробувань фотоінжекторів PITZ використовується для розробки та вивчення характеристик джерел електронів, що випромінюють пучки з номінальним зарядом в 1 нКл та якомога меншим емітансом. Одним з базових вимірів є вимір поперечного розміру електронного пучку. Наприклад, вимірювання емітансу базується на вимірах розміру пучку. Таким чином, врахування невизначеності вимірів розміру пучку є важливим для визначення вірогідності експериментальних результатів. В даній роботі розглянута статистична невизначеність виміру поперечного розміру електронного пучку в PITZ.