SUB-MICROMETER RESOLUTION TRANSVERSE ELECTRON BEAM SIZE MEASUREMENT SYSTEM BASED ON OPTICAL TRANSITION RADIATION

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Abstract

Optical Transition Radiation (OTR) appearing when a charged particle crosses a boundary between two media with different dielectric properties has widely been used as a tool for transverse profile measurements of charged particle beams in numerous facilities worldwide. The resolution of the conventional monitors is defined by so-called Point Spread Function (PSF) dimension - the source distribution generated by a single electron and projected by an optical system onto a screen. In our experiment we managed to create a system which can practically measure the PSF distribution. We demonstrated that it is non-uniform. In this paper we represent the development of a novel sub-micrometer electron beam profile monitor based on the measurements of the PSF structure which visibility is sensitive to micrometer electron beam dimensions. In this report the recent experimental results and the future plans on the optimization of the monitor are presented.

INTRODUCTION

Resent results [1] have clearly demonstrated that the method based on the analysis of the PSF structure visibility gives an opportunity to measure the beam size with a micrometer resolution. In [2] a similar method based on measurements of vertical polarization component of synchrotron radiation (SR) PSF was applied at Swiss Light Source. The difficulty related to the SR measurements is that it is difficult to put the optical system close enough to the emission point. As a result the diffraction effect significantly increases the PSF and, therefore, degrades the resolution for beam size measurement. In the case of OTR submicrometer resolution might be achieved.

It was demonstrated in [3] the chromatic and spherical aberrations result in significant broadening of the OTR PSF leading to the degradation of potential resolution. In order to improve the beam size measurement technique additional efforts toward optimization of the optical system, a better understanding of the beam size effect and an increase of the signal-to-noise ratio of the detecting system were done. We also reduced the magnification factor to increase the light density at the CCD camera. We have installed a few more optical filters covering the wavelength range from 350 to 800nm to be able to investigate the spectral characteristics of the OTR PSF in details.

EXPERIMENTAL SETUP

The accelerator, vacuum manipulator, OTR target, timing system, DAQ system as well as the laser alignment system and calibration scheme have been described in [1]. In this paper we shall represent the upgrades we implemented recently.

In order to reduce the background contribution in acquired data and to be able to install a motorized polarizer, the entire optical line was modified (see Fig.1). The second turning mirror, rotation stage containing a polarizer and CCD camera with attached filter wheel with 5 filters were mounted onto vertical rail and placed into the light protected enclosure. We have installed a new lens of 30 mm in diameter to reduce the spherical and chromatic aberration effects as they are more significant near the edges of the lens. In fact we should have increased the effect of diffraction. Nevertheless, we assume the aberrations are stronger and surpass the diffraction broadening.

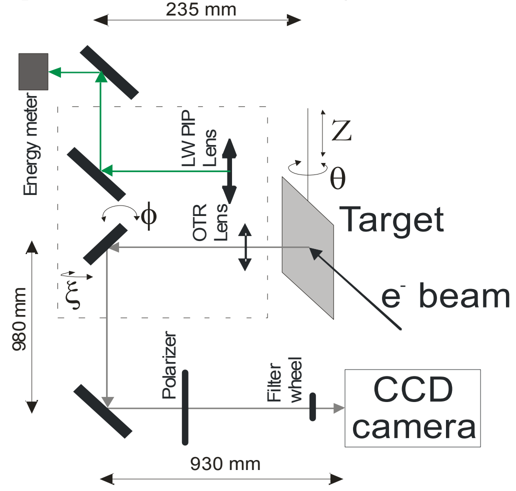

Figure 1: Experimental layout.

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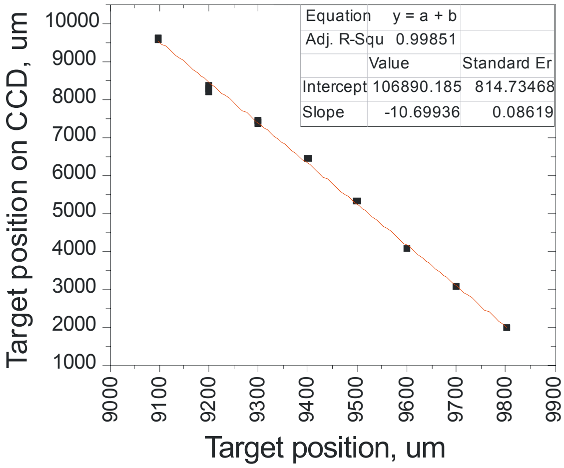

Figure 2: Calibration curve with the linear fit

LW – OTR selector

The main purpose of this OTR monitor is to measure transverse electron beam size for comparison with the ATF-II extraction line laser-wire (LW) monitor [4].

Since OTR system placed in the LW post interaction point (PIP) region where the high power laser beam (green line at Fig.1.) is re-collimated and dumped into the energy meter [5], the small sliding optical table was introduced (dashed rectangle in Fig.1.) in order to switch the optical paths between LW PIP and OTR line.

RESULTS

Previously the optical system had a large magnification factor [1]. Since the observed PSF distribution was large, to increase the light density at the CCD camera and improve the signal-to-noise ratio the distance between CCD camera and the target was reduced in order to decrease the magnification factor. After that the standard calibration technique [1] was applied. The resulting dependence of the target position measured at the CCD camera versus manipulator readout was measured to calibrate the monitor (see Fig.2.). The magnification factor extracted from the linear fit was $10.69 \pm 0.08\ \mu m$.

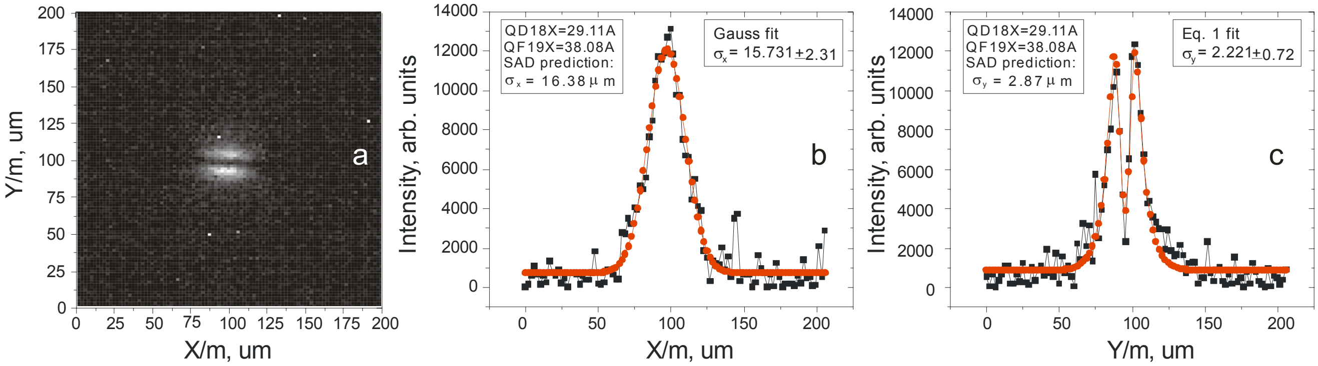

Figure 3: CCD image of the OTR taken with linear polarizer and 500 nm optical filter (a) and two image projections: horizontal (b) and vertical (c).

Figure 3a shows the CCD image of the OTR taken with linear polarizer set to transmit the vertical polarization component and 500 nm optical filter. Figures 3b and 3c represent two image projections: horizontal (Fig. 3b) and vertical (Fig. 3c) derived from summation of the pixels intensities within the horizontal and vertical broad corridors.

Lens Focus tuning using OTR

Initial lens longitudinal position was adjusted to provide a clear target edge image using 632 nm alignment laser. The lens height position and the angular corrections were applied in order to have no image position shifts while changing longitudinal lens position.

As soon as the OTR spot was found, the electron beam size was minimised by reducing the horizontal projection corresponding to the horizontal beam size and (see Fig.3b) and maximizing the visibility of the vertical projection corresponding to the smallest vertical beam size. Afterwards the longitudinal lens position was re-adjusted to minimize the OTR spot on the CCD camera.

To demonstrate the new method application to the beam size measurements, two independent quadrupole scans were performed. At first the QF19X quadrupole magnet was used to change the horizontal beam size. The horizontal image projections were fit with a Gaussian distribution, and the resulting horizontal RMS beam size as a function of the QF19X strength is represented in Fig.4a. The discrepancy between the experimental results and SAD expectations are due to the fact that the emittance and dispersion conditions, which significantly depend on the tuning procedure applied, were different.

In a similar manner a second quadrupole (QD18X) scan was done. To analyze the vertical projection, especially OTR spot minimum behavior, a special empirically chosen fit function had been introduced (see, for instance, [1]):

$$f(x) = a + \frac{b}{1+\left[c(x-\Delta x)\right]^4}\left[1 - e^{-2c^2\sigma^2}\cos\left[c(x-\Delta x)\right]\right] \qquad (1)$$

where a, b, c, σ, and Δx are free parameters of the fit function, namely: a is the vertical offset of the distribution with respect to zero which included a constant background; b is the amplitude of the distribution; c is the distribution width; σ is the smoothing parameter dominantly defined by the beam size; and Δx is the horizontal offset of the distribution with respect to zero

Figure 4b shows the dependence of the smoothing parameter σ divided by a factor of 2 as a function of QD18X quadrupole magnet strength (black dots) along with SAD predictions of the vertical beam size for the same magnet strengths (red dots). One can see a clear correlation between SAD predictions and [5] and the smoothing parameter. However, the data are still under analysis, and a new method for extracting the electron beam size from the PSF is being tested.

CONCLUSION

In this paper we present the experimental results which clearly demonstrate that the method based on the analysis of the PSF structure visibility gives an opportunity to measure the beam size with a micrometer resolution. In order to improve the beam size measurement technique additional efforts toward the optimization of the optical system, and better understanding of the beam size effect is required. The horizontal projection still gives the horizontal beam size profile as it is much larger than the vertical one.

To be able to achieve our goals and demonstrate sub-micrometer resolution we intend to employ an achromat lens to minimize the chromatic aberrations in the optical system. What will be a significant step forward as this monitor will be used for cross calibration of the LW and also be essential for LW optimization.

Also a few more optical filters covering the wavelength range from 350 to 800nm with 50nm step will be used in the future experiment to investigate the spectral characteristics of the OTR PSF in details.

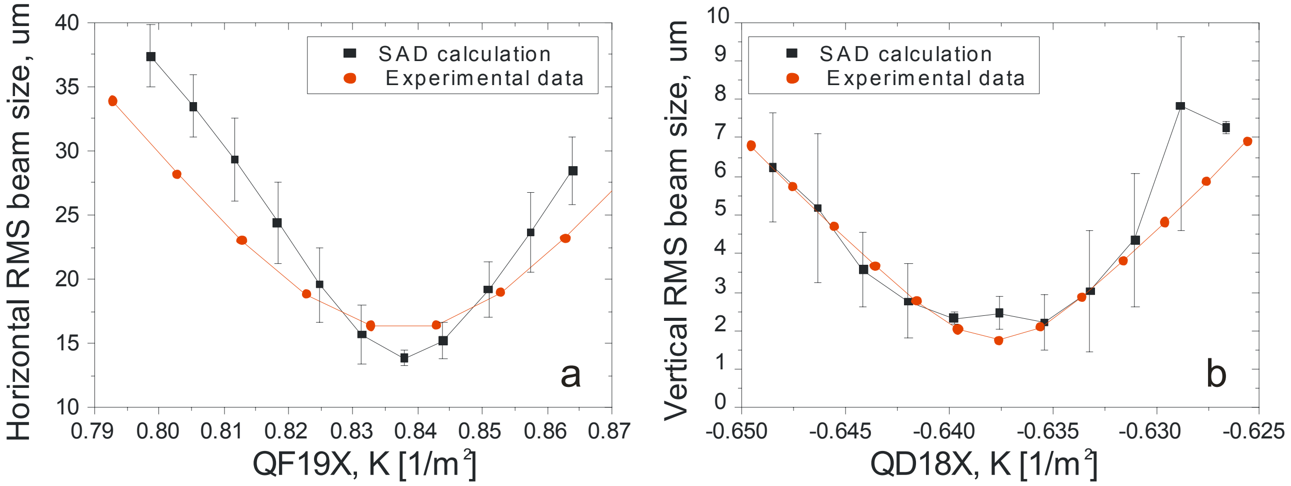

Figure 4: Horizontal RMS beam size as a function of the QF19X strength (a) and the dependence of the smoothing parameter σ (Eq. 1) versus QD18X quadrupole magnet strength. SAD predictions of the vertical beam size for the same magnet strengths are also shown in the picture.

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