ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPB10

GRATING SCANNER FOR MEASUREMENT OF MICRON-SIZE BEAM PROFILES*

L. G. Sukhikh†, A. P. Potylitsyn, S. A. Strokov, Tomsk Polytechnic University, 634050, Tomsk, Russia
G. Kube, K. Wittenburg, Deutsches Elektronen Synchrotron DESY, 22607, Hamburg, Germany

Abstract

Wire scanners are widely used for transverse beam size diagnostics. The minimum detectable beam size is affected by the diameter of a single wire that is of about 4 microns. Sub-micron beam sizes have to be resolved due to development of modern electron accelerators and future linear electron-positron colliders. In this report we propose to use a set of of gold stripes with varying period (gap) on a Si substrate. By moving this scanner across the beam one could measure the Bremsstrahlung yield vs. the coordinate, resulting in an oscillating dependence. The visibility of the resulting image allows defining the beam sizes in the range of 0.5–1.5 µm for the proposed scanner parameters.

INTRODUCTION

Wire scanners are widely used for diagnostics of transverse beam size in the modern electron accelerators. The wire crosses the beam resulting in the bremsstrahlung generation and loss electrons generation. Measuring dependence of high energy photon or loss electron yield on wire coordinate one could obtain transverse beam profile projection. The minimal detectable beam size is affected by the diameter of a single wire. The smallest carbon or tungsten wires used so far have diameters of about 4 µm. If the beam size measured is comparable with the wire diameter is significantly affects the measured profile and should be taken into account. In case of smaller beam sizes one could meet the situation that measured “beam” profile contains only wire diameter. With the development of modern electron accelerators and the demands from future linear electron-positron colliders, micron and sub-micron beam sizes have to be resolved with sub-micron or better resolution. For this purpose a new generation of wire scanners should be developed and tested.

One of the possible methods to increase the resolution of the wire scanners is to decrease its size. The minimal diameter of single free-hanging wire (≈ 4 µm) is limited by the mechanical stress. However, one could consider wires with smaller size (units of microns or even sub-microns) on a substrate. In Ref. [1] authors proposed to use thin gold stripes of rectangular shape (1 µm or 2 µm width and 3 µm height) on Si_3N_4 membrane used as a substrate. In this case authors of Ref. [1] expect to increase beam size measurement resolution and to be able to resolve sub-micron beams. However, one of the paybacks while using small size wires is the limited dynamic range of the measurable beam sizes.

In this report we propose another arrangement of gold stripes on Si substrate. We propose to form a grating scanner from a set of gold stripes with variable distance between them. In this report we present the preliminary Geant4 simulations of such a grating scanner with varying gaps that show the possibility to measure beam sizes in the range of 0.5–1.5 µm.

GRATING SCANNER WITH VARYING GAPS

The scheme of the grating scanner with varying gap is shown in Fig. 1. The scanner considered in this report consists of eleven rectangular gold stripes on Si substrate of 50 µm thickness. The height of the gold stripes was equal to 10 µm. During the simulation we considered two stripe widths, namely $a = 1$ µm or $a = 3$ µm. The distance between stripes is non-equal and varies in the range of 0.25–3 µm.

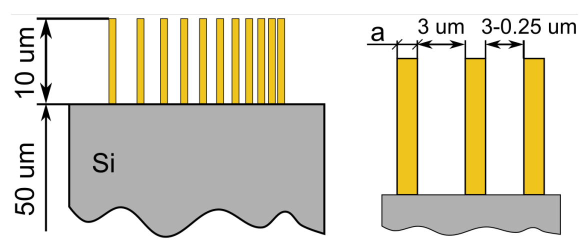

Figure 1: Schematic view of grating scanner with varying gaps.

The basic idea of beam size measurement using proposed scanner is the following. The electron beam interacts with the scanner while moving the scanner across the beam. Amount of the generated photons (or loss electrons) depends on which part of the scanner directly interacted with the beam. If the beam size is small comparing with the gap size the beam interacts either with a gold stripe and the substrate resulting in the maximal bremsstrahlung yield or with the substrate only resulting in the minimal (background) photon yield. In this case the dependence of the photon yield on the grating coordinate is oscillatory. When beam size is much larger than the gap size, the beam interacts with several stripes resulting in monotonic dependence of the photon yield on grating coordinate. The schematic view of beam interacting with the scanner is shown in Fig. 2.

The wire scanner with varying gaps was simulated using Geant4 [2]. The simulation scheme is shown in Fig. 3. The electron beam with electron energy $E_e = 1.25$ GeV and

* Work supported by Russian Ministry of Science and Higher Education, Program “Nauka” grant #3.1903.2017 and TPU Competitiveness enhancement Program
† sukhikh@tpu.ru

ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPB10

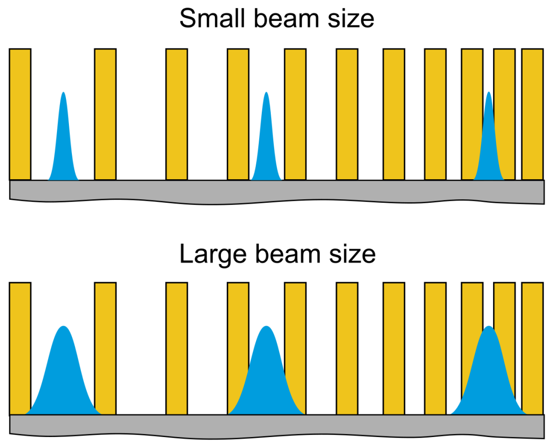

Figure 2: Schematic view of grating scanner with varying gaps interacting with small and large beams.

Gaussian transverse profile (rms $\sigma_e = 0.5$–$3\,\mu m$) interacted with the scanner resulting in bremsstrahlung generation that were counted by the photon counter. The primary electron beam was turned away by the bending magnet. The grating was moved in transverse (x) direction with the step 0.1 µm. The dependence of the registered number of photons on transverse position was simulated.

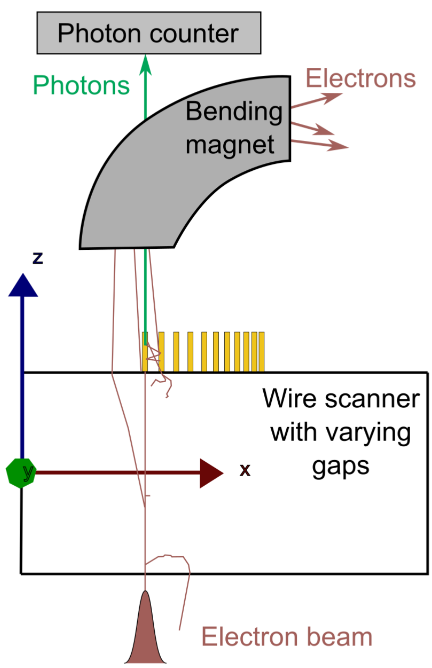

Figure 3: Schematic view of Geant4 simulation geometry.

Figure 4 shows an example of the Geant4 simulation results. Row a) shows dependence of the photon yield on grating scanner coordinate for stripe width equal to 1 µm. Row b) shows the same for stripe width equal to 3 µm.

In Figure 4 one can see that visibility (ratio between minimum and maximum) depends both on the coordinate and on the beam size. The photon yield increases with decrease of the the gap size but at the same moment the visibility decreases. One can also see that the influence of background from the substrate is not significant and signal-to-noise ratio is of about 3–4.

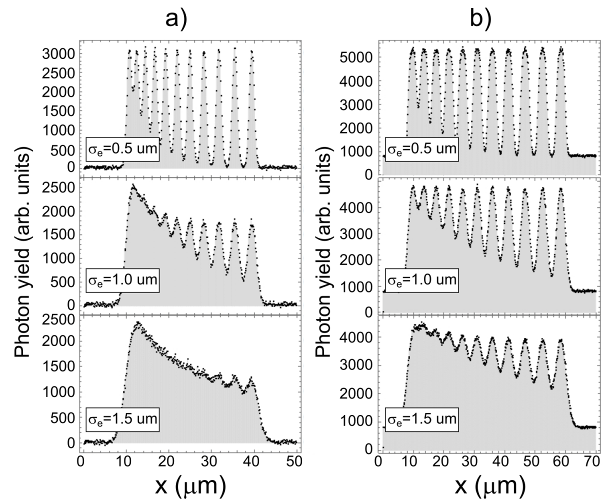

Figure 4: Grating size scans simulated by Geant4 for different beam sizes. Row a) - stripe width is equal to 1 µm, row b) - stripe width is equal to 3 µm.

In order to obtain the beam size from the scan the following procedure was developed. For each period of the scan the position of the photon yield minimum and maximum was found as it is shown in Fig. 5.

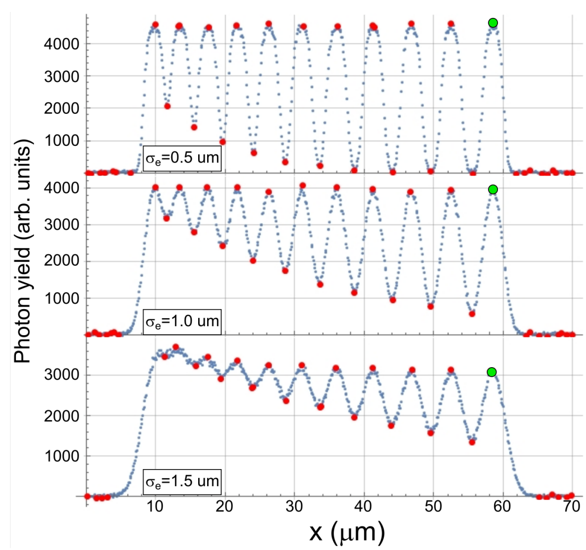

Figure 5: Grating size scans simulated by Geant4 for different beam sizes for stripe width is equal to 3 µm. Red dots - positions of the minima and maxima, green dot - position of the maximum used for normalization.

The ratio of each minimum to the right maximum (green dots in Fig. 5) was plotted vs. the transverse coordinate (see Fig. 6). The obtained dependence could be fitted by the following function:

$$R(x) = A_0 \exp[-x/x_0], \tag{1}$$

ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-WEPB10

where A_0 and x_0 are the free fit parameters.

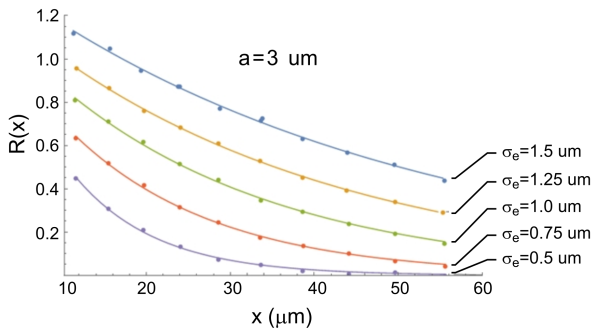

Figure 6: Dependence of the minima to the maximum ratio on transverse coordinate for different beam sizes. Stripe width is equal to 3 μm.

Figure 7 shows the dependence of the fit parameter x_0 on the beam size used during the simulation. One can see that the dependence is linear both for 1 μm stripes and 3 μm ones. From Fig. 7 one can see that due to linear dependence of x_0 fit parameter on beam size σ_e one could obtain actual beam size from the dependence of photon yield on grating shift (see Fig. 4)

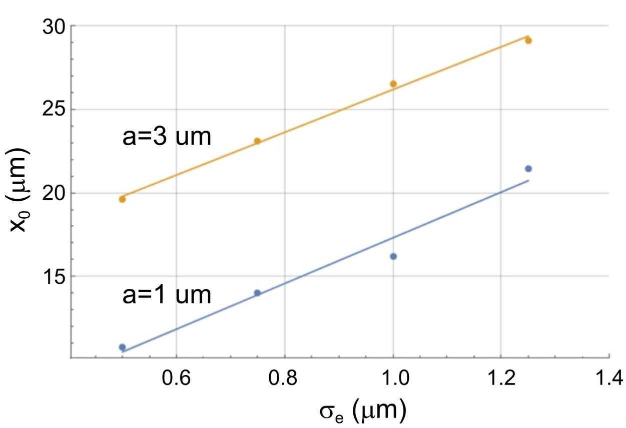

Figure 7: Dependence of the fit parameter x_0 on the beam size σ_e used during the simulation and linear fit. Blue - stripe width is equal to 1 μm, Yellow) - stripe width is equal to 3 μm.

CONCLUSION

New type of wire scanner with varying gaps is proposed and simulated using Geant4. Scanning of the Gaussian beam with such type of a scanner allows to measure beam sizes in the wide range. In the simulated case one could measure beam sizes in the range 0.5–1.5 μm with sub-micron resolution. The scanning range could be increased if one increases stripe width and amount of stripes. In this report gold stripes of 10 μm height on 50 μm Si substrate were simulated resulting in the good signal-to-nose ratio. In order to check the feasibility of the proposed scanner the experimental verification is needed.

REFERENCES

[1] S. Borrelli, G. L. Orlandi, M. Bednarzik, C. David, E. Ferrari, V. A. Guzenko, C. Ozkan-Loch, E. Prat, and R. Ischebeck, "Generation and measurement of sub-micrometer relativistic electron beams", arXiv:1804.04252v1 [physics.acc-ph], 11 Apr. 2018.

[2] J. Allison *et al.*, "Recent developments in Geant4", *Nuclear Instruments and Methods A*, vol. 835, pp. 186–225, 2016.