

Measurement of electron beam transverse flux density distribution

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Abstract. The work presents experimental measurements of electron beam transverse flux density distribution. Experimental data is recorded during the multiple beam scanning in different directions with the particular angle step by the thin scintillation strip. The intensity of the light generated in the scintillator is proportional to the intensity of the radiation going through the strip. Generated photons is guided by the optical fiber to the photomultiplier and registered by the analyzer. The result of the work is the experimental data demonstrated dependence of the radiation intensity on detecting strip position and angle orientation. This dependence is transformed to the radiation intensity dependence on the coordinates in the beam transverse plane using special mathematical processing.

1. Introduction

Modern technology for oncology treatment causes high demands on the dose delivery accuracy especially accounting improvements in external beam radiation therapy. It is necessary to control spatial parameters of the radiation beams before radiation therapy sessions and during ones to provide accuracy of dose delivering and particularly avoid of overexposure of the healthy tissue and insufficient dose values in the tumors [1]. Currently, the control of radiation beam parameters is provided in medical practice accordingly to international protocols for clinical dosimetry [2, 3].

There are few methods to determine the radiation flux density distribution in the transverse plane of the beam. For example, it is possible to measure beam spatial parameters using matrix detectors consisted of ionization chambers [4–6] or diodes [7, 8], that is placed on the plane or inside special phantoms. The same approach is a basis for use of fluorescent screens in conjunction with optical cameras [9–11]. Beam parameters measuring with these devices provides high speed. However, these approaches are invasive and usually the beam is completely absorbed during the measurement. Simultaneously, the arrangement of detecting elements allows estimation only the shape and size of the radiation field but not the exactly intensity distribution.

Another approach to determine beam transverse flux density distribution is based on using materials, that changing properties when interact with the radiation, in a form of plates or films [12–14]. These methods have high resolution, but require consumables that leads to increases the operational cost of these devices and necessity of their parameter monitoring, for example, to perform additional calibration for particular batch of detectors.



Previously proposed method to measure electron beam transverse flux density distribution, which is devoid of the above disadvantages, is tested in a frame of this work.

2. Materials and methods

2.1. Measurement method.

The method to measure electron beam transverse flux density distribution is based on multi-angle measurements. This method means multiple strip scanning of the beam under different angles with fixed angle step. The set of measured intensity dependences on scanning angle and strip position can be transformed to the flux density distribution of the particles in beam transverse plane using mathematical reconstruction. It is previously demonstrated [15] that the minimal scan number to perform this method with reliable results is not less than 18.

2.2. Radiation source.

In the experiment TPU microtron [15] is used like a radiation source. The energy electron energy in output beam is 6.0 MeV with 1.0 mA current.

2.3. Registration system.

Scanning element is a thin scintillation strip $2 \times 6 \times 150$ mm³ sized. In the experiment, we use scintillator BC-408 by Saint-Gobain [16]. Generated in the scintillator light photons is guided by the optical fiber to the photomultiplier with the 6 mm cross-section diameter to the silicon photomultiplier [17]. The parameters of the photomultiplier is following: active area is 6×6 mm², spectral range is 300–800 nm, and registration efficiency for photons is up to 47% at 420 nm wavelength. The signal of the photomultiplier is amplified and hardware processed, and registered by the computer.

Ad-hoc software is used to control scanning system and to record experimental data. In the recording intensity data and scintillation strip position is synchronized between each other.

To verify experimental results electron beam transverse flux density distribution is measured using Gafchromic EBT2 dosimetry film [18] located perpendicularly to beam propagation axis. These films are digitized with Epson Perfection V750 Pro scanner [19] and mathematically processed with MATLAB package [20].

2.4. Experimental scheme.

Output beam is going through a circular shaped collimator with pinhole 10 mm diameter and 50 mm length. Electron beam transverse flux density distribution is measured at 50 mm from the collimator.

Scintillation strip is shifting linearly in the plane perpendicular to the beam axis by 25 mm; the angular step equals 10° . For the experiment, we use controller, rotation and linear stages by Standa [21–23].

Scintillation strip moves continuously, with speed chosen to provide 1 mm movement during 2 seconds. Measured for 2 seconds signals are averaged for higher accuracy.

Figure 1 shows experimental layout for measurement of electron beam transverse flux density distribution.

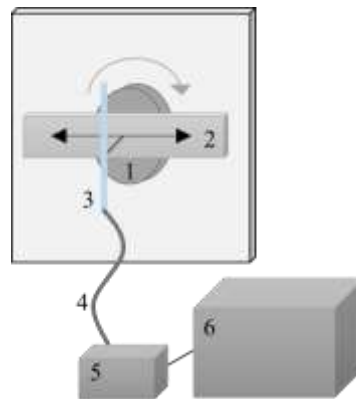


Figure 1. Experimental layout: 1 – rotation stage; 2 – linear stage; 3 – scintillation strip; 4 – optical fiber; 5 – photomultiplier; 6 – PC.

3. Results and discussions

The set included 19 dependences of radiation intensity on scintillation strip location and angular orientation is measured in the experiment. The first measurement was performed for the beam went through the circular shaped collimator. Measured data is used for synogram formation, shown in Figure 2.

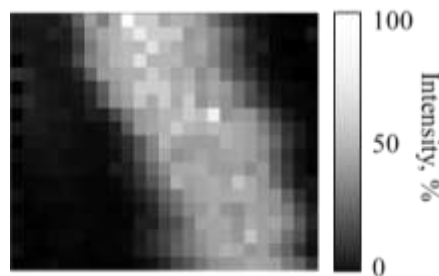


Figure 2. Scan results of the electron beam by the scintillation strip in synogram form.

Figure 3 shows electron beam shape, measured by dosimetry film and by the proposed method.

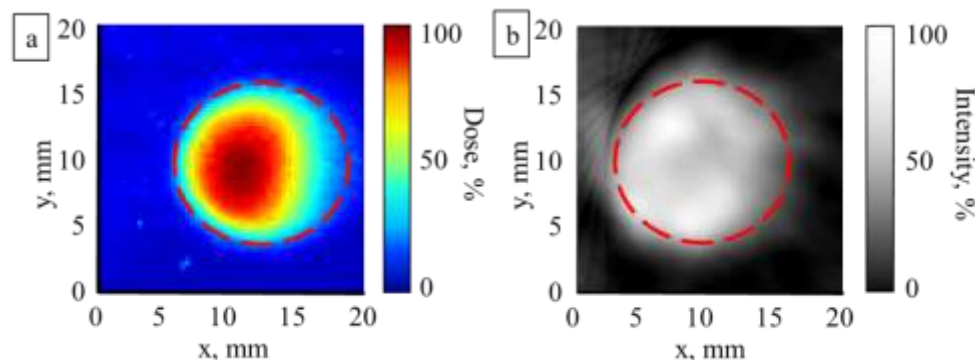


Figure 3. Results of collimated beam profile measured by: a – dosimetry film; b – scintillation strip.

As can be seen from Figure 3 the proposed method allows measurement of electron beam transverse flux density distribution. The difference between results measured by different system is caused by the resolution of the detector based on scintillator that depends on thicknesses of the strip. Besides, high quantity of the secondary photons generated in the collimator, that is not registered by the film due to low thickness. In order to avoid errors, connected with Cherenkov radiation generation in optical fiber, it is shielded with lead foil. However, it is impossible to shield it in a region of optical fiber and scintillator connection. Therefore, in a case of sensitive detector position close to Cherenkov radiation

critical angle electrons can penetrate through the optical fiber and generate Cherenkov photons in there, that cause edges blurring (Figure 3b).

The second experiment with the deformed electron beam is also performed to estimate method applicability. Metal target, which is partly cover the beam, is placed in the beam propagation axis in the second experiment in order to deform it. The thicknesses of the target provide total absorption of the beam. Figure 4 shows registered data in synogram form.

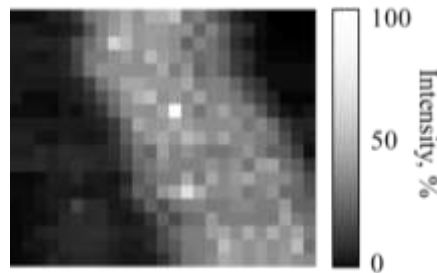


Figure 4. Deformed beam scan results registered by the scintillation strip in a synogram form.

Figure 5 shows shape of electron beam deformed by the additional metal target, registered by dosimetry film and by the investigated method.

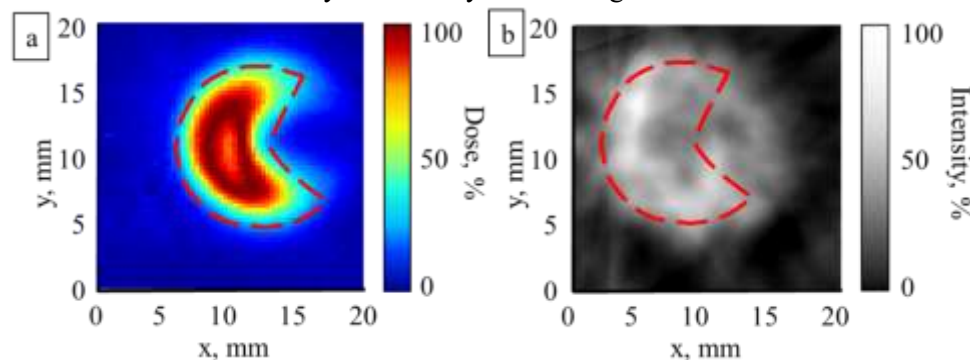


Figure 5. Deformed beam profiles measure by: a – dosimetry film; b – scintillation strip.

As can be seen in Figure 5b there is hot spot in a region where the beam is not covered. Besides, the sizes of the beam can be estimated with this method, however, the level of the results is not high, because of previously described errors. Besides, the secondary gamma-radiation is generated in a metal target covering the beam and provide contribution to the registered signal. Therefore, in Figure 5b one can see only partial decrease of the intensity after the target (about 40%) instead of total absence.

In order to estimate electron beam transverse flux density distribution accounting described factors that influence on the reconstruction results, the data is renormalized to equate 40% intensity level to 0%, while keeping the maximum at 100% level. Figure 6 shows results after renormalizing.

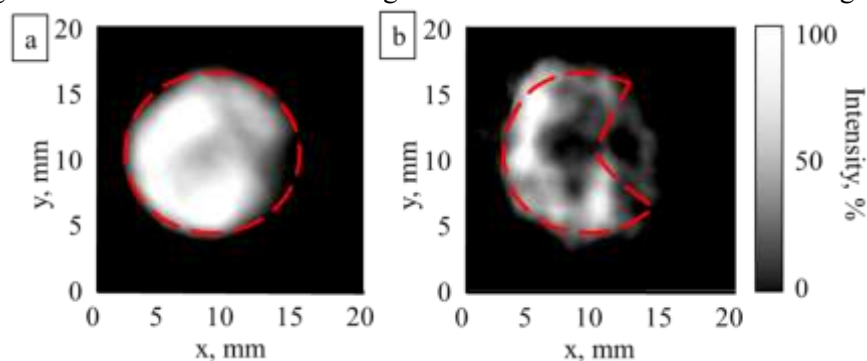


Figure 6. Beams profiles after final processing: a – beam after circular shaped collimator only; b – after circular shaped collimator and metal target.

Figure 6 demonstrates possibility of electron beam transverse profiles estimation with proposed method.

4. Conclusion

In this work, we test the method for measurement of electron beam transverse flux density distribution based on multi-angular scan. It is shown that obtained data allow us to estimate the transverse profiles of electron beams, despite of the presence of many factors that adversely affect the result of the measurement. Approach of background subtraction allows significant improvement of the results quality. Further work is aimed at method accuracy improvement by increasing the speed of the registration system, and accordingly, the statistical sample.

Acknowledgment

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References

- [1] Van Elmpt W *et al* 2008 *Radiother. Oncol.* **88** (3) 289–309
- [2] Almond P R *et al* 1999 *Med Phys.* **26**(9) 1847–1870
- [3] Andreo P 2000 *IAEA technical report series* **398** 242
- [4] Amerio S 2004 *Med. Phys.* **31**(2) 414–420
- [5] Spezi E, Angelini A L, Romani F and Ferri A 2005 *Phys. Med. Biol.* **50**(14) 3361
- [6] StarTrack with OmniPro-Advance The universal QA solution. Available at: <http://www.else.com/wp-content/uploads/2015/07/StarTrack.pdf>
- [7] Létourneau D *et al* 2004 *Radiother. Oncol.* **70**(2) 199–206
- [8] Jursinic P A and Nelms B E A 2003 *Med. Phys.* **30**(5) 870–879
- [9] Monti A F and Frigerio G 2006 *Radiother. Oncol.* **81**(1) 88–96
- [10] Hesse B M, Spies L and Groh B A 1998 *Phys. Med. Biol.* **43**(12) 3607
- [11] Cremers F *et al* 2004 *Med Phys.* **31**(5) 985–996
- [12] Borca C *et al* 2013 *J. Appl. Clin. Med. Phys.* **14**(2) 158–171
- [13] Zhu X R *et al* 2003 *Med Phys.* **30**(5) 912–919
- [14] Childress N L and Rosen I I 2004 *Med Phys.* **31**(8) 2284–2288
- [15] Stuchebrov S *et al* 2016 *AIP Conf. Proc.* **1772** 060016
- [16] BC-400, BC-404, BC-408, BC-412, BC-416 Premium Plastic Scintillators. Available at: <https://www.crystals.saint-gobain.com/sites/imdf.crystals.com/files/documents/bc400-404-408-412-416-data-sheet.pdf>
- [17] Sensl: J-Series High PDE and Timing Resolution, TSV Package. Available at: <http://sensl.com/downloads/ds/DS-MicroJseries.pdf>
- [18] GAFCHROMIC EBT2. Available at: http://www.elimpex.com/new/products/radiation_therapy/Gafchromic/content/GAFCHROMIC%20EBT2.pdf
- [19] EPSON Perfection V700 Photo and V750 Pro: User's Guide. Available at: <https://files.support.epson.com/pdf/prv7ph/prv7phug.pdf>
- [20] Matlab. Available at: <https://uk.mathworks.com/products/matlab.html>
- [21] Standa. 8SMC5-USB-Stepper & DC Motor Controller: Available at: http://www.standa.lt/products/catalog/motorised_positioners?item=525&prod=stepper-dc-motor-controller
- [22] Standa. 8MR190-90-Large Motorized Rotation Stage. Available at: http://www.standa.lt/products/catalog/motorised_positioners?item=325&prod=motorized_rotati_on_stage
- [23] Standa. 8MT177-100-Motorized Stage. Available at: http://www.standa.lt/products/catalog/motorised_positioners?item=242&prod=motorized_stage