Development of the Method for the Electron Beam Spatial Distribution Determination in the Transverse Plane

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Abstract. The article presents the device destined for flux density distribution of electrons in the beam cross section without consumables, with a resolution of about 1 mm and slightly dependent on the electron energy. The possibility of the cross section reconstruction of the electron flux density distribution by the inverse Radon transformation is shown. The results of mathematical reconstruction are illustrated and upon which the projections optimum quantity are specified. In the paper the experimental set up developed based on proposed method is introduced. The results of the experimental tests of the scanning device functionability are presented.

INTRODUCTION

Electron beams are widely used in different areas, such as industry, medicine and other applied sciences. Every day a quantity of devices based on the use of electron beams is created for various applications, which is include radiotherapy, sterilizing medical products, scientific investigation, welding, microstructuring processes, melting high-purity metals and et al. [1-5]. For all this fields it is necessary to control beam parameters.

There are various methods of determining electron beam characteristics. The focus is on beam geometric parameters such as diameter and convergence angle. However, these methods do not give a complete picture of the electron beam spatial characteristic. For this purposes it is necessary to measure the flux density distribution of electrons in the beam cross section. Existing methods for this parameter analysis have a number of drawbacks. Methods based on the use of the electronic detectors matrix have low resolution [6]. Methods based on the use of dosimetric films and luminescent detectors are limited with beam dose characteristics [7, 8]. There are many other methods that are mostly based on the use of disposable elements changing their characteristics under radiation [9]. Using of consumable materials has a number of problems such as a necessity for controlling its presence and monitoring of the material characteristics in the different manufacture batches. Accordingly, there is a necessity for a method, which allow to measure the flux density distribution of electrons in the beam cross section without consumables and slightly dependent on the electron beam energy, with a resolution of about 1 mm.

This paper describes an investigation aimed for such kind of system creation. The principle of method is based on beam transverse scanning by thin strip at different angles.

The cross section of the electron flux density distribution is reduced by the inverse Radon transformation of beam current depending on the position of the scanning element.

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TECHNIQUE OF THE BEAM CROSS SECTION DETERMINATION BY SCANNING

Operation mode

The proposed determination method of the flux density distribution of electrons in the beam cross section is consist in the beam scanning by a thin conductive plane, partially overlapping the electron flow, the current is measured by Faraday cup. Scanning is repeated many times in a predetermined plane of the beam cross section at different angles with a fixed offset angle. The experimental scheme is shown in Figure 1.

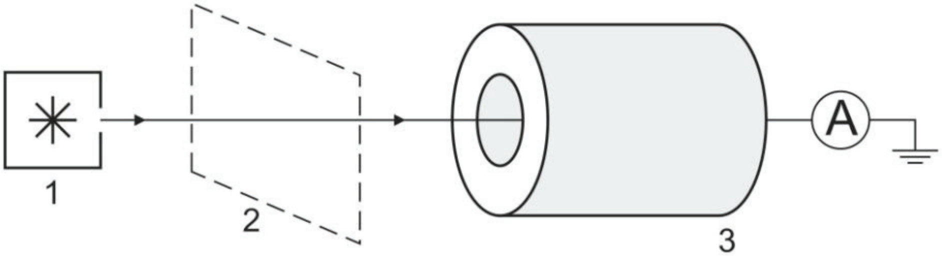


FIGURE 1. The geometry of the experiment:
1 – source of electrons;2 – scanning plane; 3 – Faraday cup

The scanning diagram of the electron beam in the cross section's plane is shown in Figure 2.

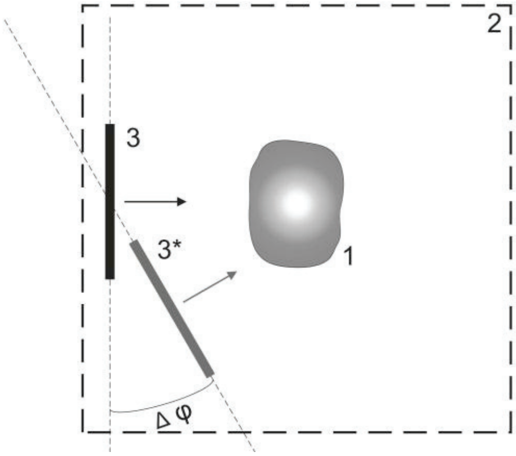


FIGURE 2. Scanning diagram:
1 – beam cross section; 2 – scanning plane; 3 – scanning strip; 3* – displacement scanning strip at the angle Δφ

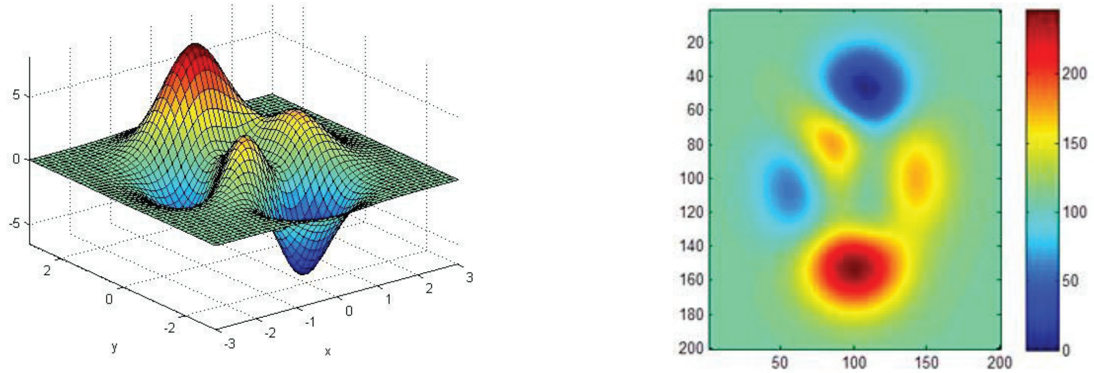
The data of the beam current is recorded by Faraday cup. The part of the electrons is absorbed in scanning strip under passing through the beam. From the dependence between the current value measured by the Faraday cup, from the scanning strip angle and its position, the dependence of current density distribution of electrons in the scanning plane can be obtained by means of the inverse Radon transform [10].

The parameters optimization

As it is known, the quality of the reconstruction carried out by the inverse Radon transform depends on the number of input data. In our case of the scanning direction number, consequently the scan direction offset angle determines the accuracy of the electron flux density distribution measurements. However, the increasing of the scanning direction number leads to increases not only the data set time and complexity of the subsequent data processing, but also the complexity of the scanning device. Thus, it is necessary to define the minimum amount of the beam scanning direction, which will be sufficient for reconstruction. To solve this problem the test data as a complex Gaussian distribution in the matrix of 200×200 were taken:

$$f(x,y)=3(1-x)^2\, e^{-x^2-(y+1)^2} -10\left(\frac{x}{5}-x^3-y^5\right) e^{-x^2-y^2} -\frac{1}{3}e^{-(x+1)^2-y^2}. \tag{1}$$

The function graph of two variables in three-dimensional view and its two-dimensional form for the future transformations is shown in Figure 3.

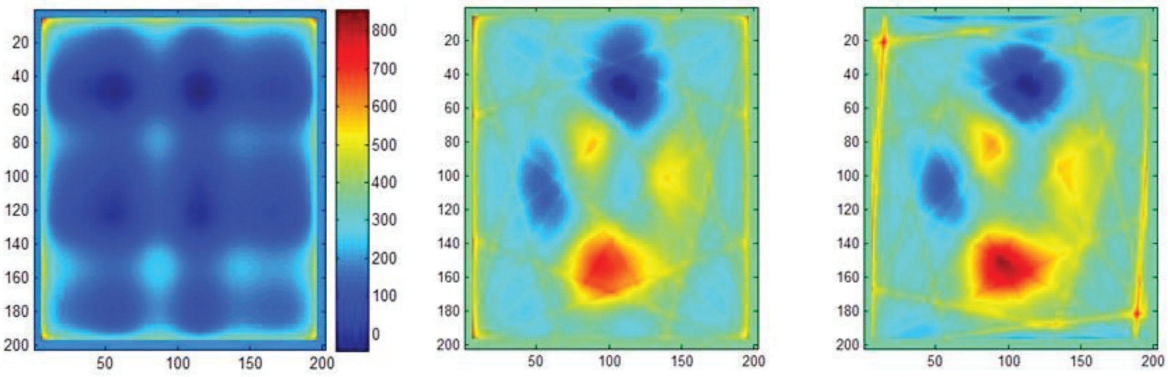


(a) (b)

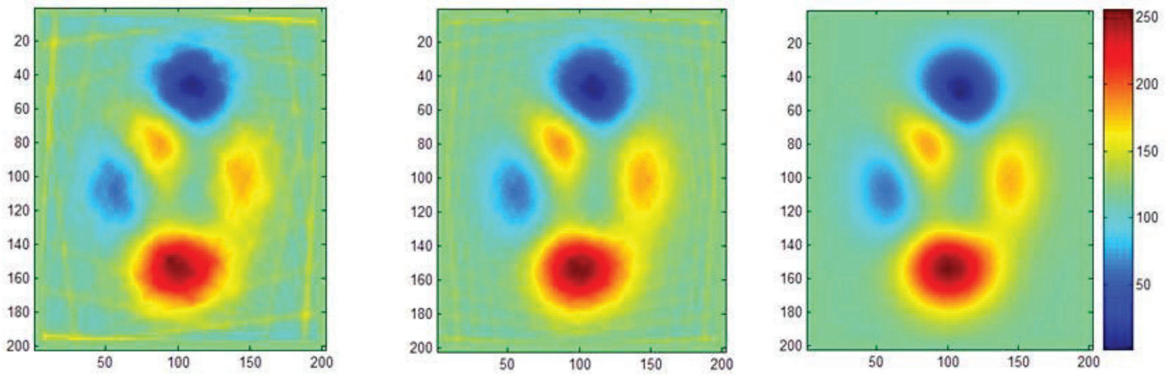
FIGURE 3. Test data at 200×200 matrix: a) a three-dimensional construction; b) a two-dimensional construction, converted for further processing

The further data processing was performed by built-in functions of MATLAB software [11]. From the initial data (Fig. 3b) two-dimensional projections were generated in the plane provided in the figure. The offset angle of projection directions is determined by selected number of projections, with taking into account that a full offset angle should be at least 180°. After that the transformed initial data were reconstructed by inverse Radon transform from the resulting projections.

Figure 4 presents the results of reconstruction, derived from a different number of projections. Figure 4a shows a reconstruction of 4 projections with an offset angle of 90°; Fig. 4b – the reconstruction of 10 projections with an offset angle of 18°; Fig. 4c – the reconstruction of 12 projections with an offset angle of 16°; Fig. 4d – the reconstruction of 23 projections with an offset angle of 8°; Fig. 4e – the reconstruction 46 projections with an offset angle of 4°; the Fig. 4f – the reconstruction of 180 projections 180 with an offset angle of 1°.



(a) (b) (c)

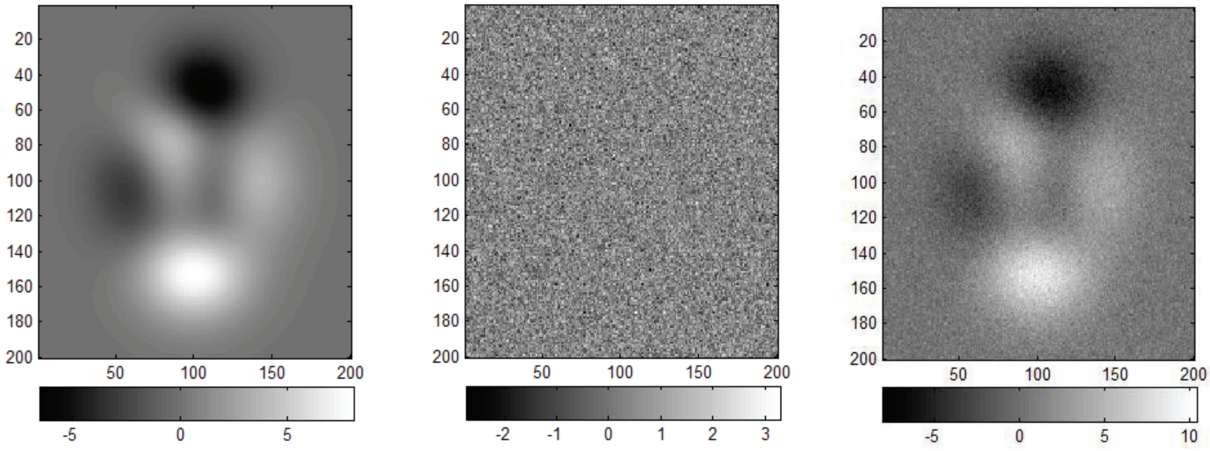


(d) (e) (f)

FIGURE 4. The results of the reconstruction: a) 4 projections, step 90°; b) 10 projections, step 18°; c) 12 projections, step 16°; d) 23 projections, step 8°; e) 46 projections, step 4°; f) 180 projections, step 1°

It is shown that with the projection number decreasing the artifacts associated with the oscillations at the edges appear significantly. For the projection number less than 10 the reconstruction results deteriorate considerably, in accordance with this fact we have concluded that 10 is the minimum number for such kind objects. According to the obtained data, we can conclude that for a reliable reconstruction the optimal number of the projections is about 23.

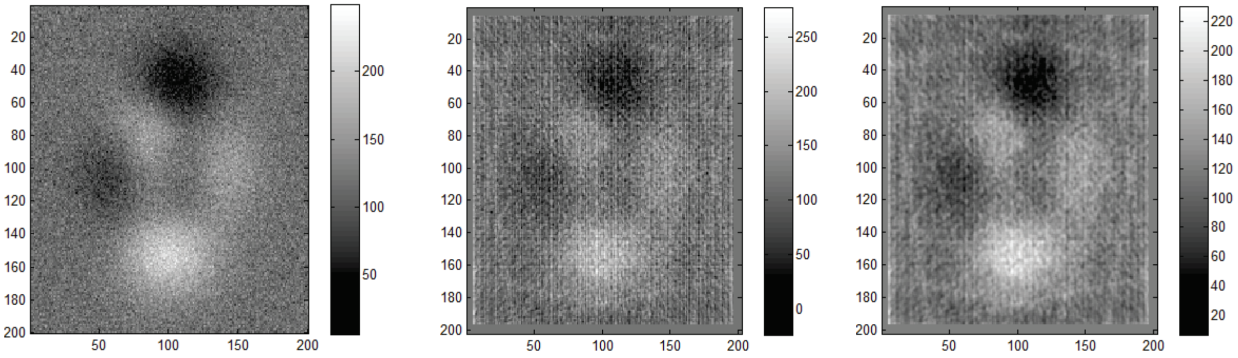
As it known the common problem with application of inverse integral transforms to experimental data consists in their utmost sensitivity to experimental errors and noise signals. For analyses of these factors we generated noisy image by the addition of Gaussian noise to the initial data (Fig. 5c). The Gaussian noise with a mean equal to the average of initial data, and with a deviation of 5% of the full range of initial data was generated (Fig. 5b).



(a) (b) (c)

FIGURE 5. Test data at 200×200 matrix:
a) clear initial data; b) Gaussian noise; c) noisy initial data

Figure 6 presents the results of noisy initial data reconstruction of 21 projections with an offset angle of 9° (Fig. 6b). For obtaining better reconstruction results we used the Hamming filter (Fig. 6c). It is shown that the reconstruction is in good agreement with noisy image.



(a) (b) (c)

FIGURE 6. The results of the reconstruction:
a) noisy initial data; b) 21 projections, step 9°; c) 21 projections, step 9° with Hamming filter

The scanning device concept

From the results of the parameters optimization, it was decided to develop scanning device, allows obtaining data in 21 directions with displacement 9° and the total angle offset of 180°. For optimization dataset procedure it was proposed to scan in one cycle by several strips disposed at different angles relatively to each other. For comparison strips offset values with relative to the beam axis, the step increment of the entire device should be multiplied by the sine of strip tilt angle. The resolution of such kind devise depends on scanning strip thickness.

Figure 7 illustrates the schematic representation of the proposed scanning device. The positions of the scanning beam profile are indicated by dashed circles. On the rectangular aluminium plate (1 cm thickness) the windows with various shapes are produced so that the plate is presented as a rectangular frame carrying the carcass function with seven strips (1 mm thickness) arranged relatively to each other at various angles in increments of 9°.

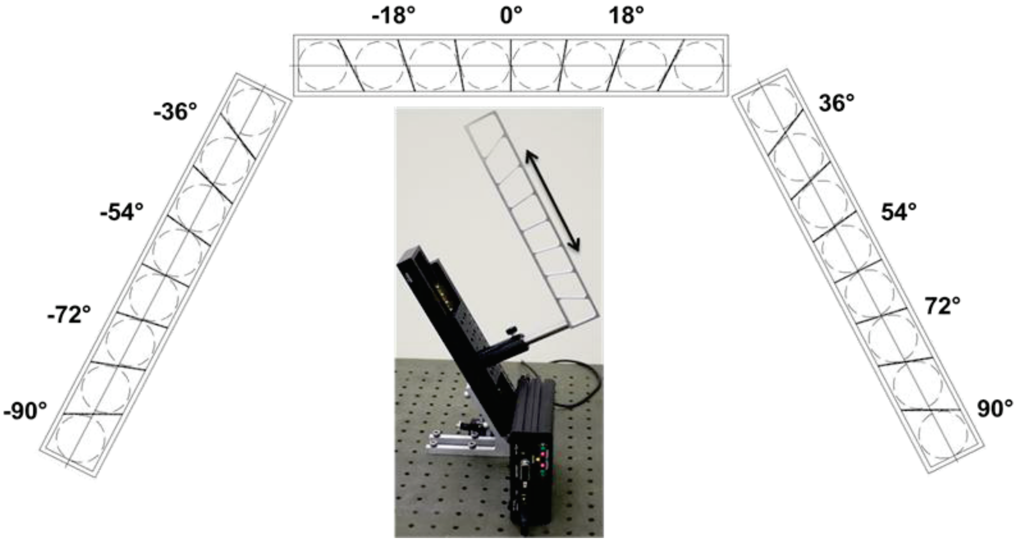
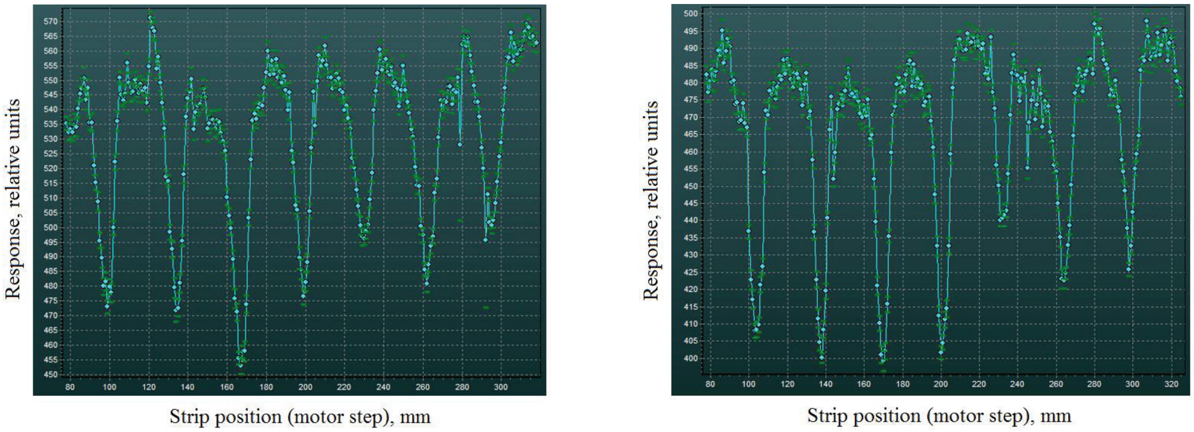


FIGURE 7. The scanning device scheme

By moving the frame in such a way that the electron beam has passed all the positions indicated by dashed circles, and performing it in three directions with 63° angle displacement, we obtain 21 projections with total offset angle equal to 180°.

Experimental tests of the scanning device

At the last stage of this investigation the experimental tests of the scanning device were carried out. The experimental geometry is shown on the Fig. 1. The Tomsk Polytechnic University microtron was used as emitting source in pulsed operating mode with electron beam energy equal to 6.1 MeV, beam size at output equal to 2.0 mm^2 [12]. Two variants of the electron beam fields were considered: first – “clean” electron beam without any barriers; second – deformed electron beam by metallic barrier. Figure 8 illustrates the seven projections of the microtron extricated electron beam obtained by device at the one scanning position for the undeformed and deformed cases. The data was received by Faraday cup.



(a) (b)

FIGURE 8. The data obtained by experimental set up from the undeformed (a) and deformed (b) electron beams

Figure 6 shows that there are the differences between electron beam profiles for the undeformed and deformed cases, these points to operability of experimental set up.

SUMMARY

In the frame of this investigation the calculation algorithm allows obtaining the optimum quantity of the projection is sufficient for subsequent reconstruction was created with the help of MATLAB software. The operation capability of proposed method for the experimental errors and noise signals based on inverse integral transforms are demonstrated.

It is shown that if the number of projections is getting less than 10 the reconstruction results deteriorate considerably. Based on obtained data we made a conclusion that it should be about 20 projections for a reliable reconstruction.

The calculation results reveal the possibility of creating a device allows measuring the flux density distribution of electrons in the beam cross section. This device provides data in 21 directions with displacement 9° and the total angle offset of 180°. For optimization dataset procedure it was proposed to scan at one cycle by several strips disposed at different angles relatively to each other. There are the following advantages for this method: the profiles can be obtained without consumables, with the resolution of more than 1 mm and weakly dependent on the electron energy.

The results of the experimental tests of the scanning device show the sensibility of this device for any changes of the radiation flux intensity.

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