10th ICALEPCS Int. Conf. on Accelerator & Large Expt. Physics Control Systems. Geneva, 10 - 14 Oct 2005, PO2.043-4 (2005)

THE DISTRIBUTION DENSITY MONITORING OF CHARGED PARTICLES BY COMPUTER TOMOGRAPHY METHOD

V.N.Boriskin, M.I.Ayzatsky, V.A.Gurin, V.A.Mats, A.N. Savchenko, A.A.Sarvilov, V.I.Tatanov

National Science Center, Institute of Physics and Technology, Kharkov, Ukraine

boriskin@kipt.kharkov.ua

ABSTRACT

Many-channel system for automatic measurement of the charged particle distribution density at the exit of the electron linac is described. The method of measurement of two-dimension distribution density in electron beam by secondary emission monitor is developed. The monitor work with electron beams of energy up to 12 MeV and of pulse currents up to 1 A is researched. The beam cross-sections were measured at different angles of monitor turn. The possibility was demonstrated to use obtained data for reconstruction of two-dimension distribution density in electron beam by computer tomography method.

THE MONITOR DESIGN

The monitor consists of the frame with emitting and collecting electrodes and the platform with rotation drive (Fig. 1). The collecting electrode is produced from the thin aluminium grid that applies positive voltage to 100 V. The emitting electrode consists of 16 aluminium lames of width W1=2 mm and 0.15 mm thick. The lames are locked in cadre. The inner spacing between lames is dictated by size of irradiated sample.

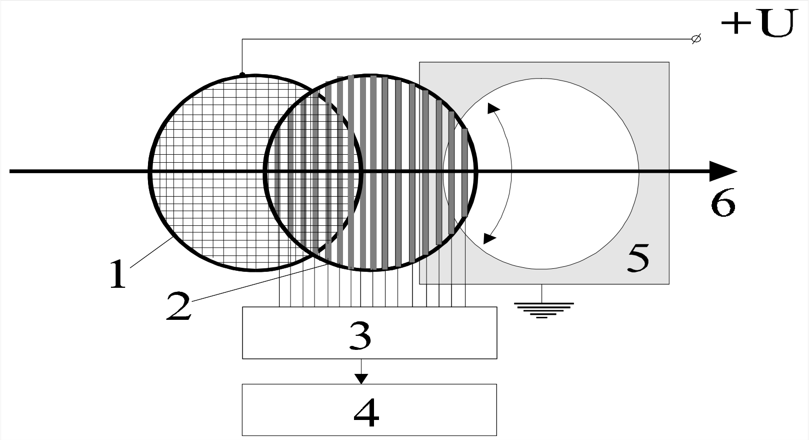

Fig. 1: The monitor block diagram.

1 - collecting electrode, 2 - emitting electrodes, 3 - measuring device, 4 - computer, 5 - device platform with rotation drive, 6 - incident beam of the charged particles.

In our case the inner monitor window diameter is 60 mm. The lame planes are parallel to one another and perpendicular to optical axis of the accelerator. The device platform is earthed. The device mechanical unit allows the rotation of emitting electrodes to 180^0 with the constant step.The currents from each electrode is simultaneously measured at any rotation point in high-energy electron passage through the lames, the positive signal come due to emission of secondary delta-electron.

The monitor signal with amplitude no more 800 mV (Fig. 1) by RK75 cable 40 m in length is fed through commutator to the digitizer entry [2]. The monitor is installed in the air at L=120 mm from the plane of accelerator exhaust foil. The center of inner monitor window is integrated with the optical axis of the accelerator by the use of the special screws.

In the air a relationship between a charge on the beam profile monitor lames and primary beam intensity may be not linear as a result of deposition of charge atmosphere particles and secondary electrons with low energy on the lames.

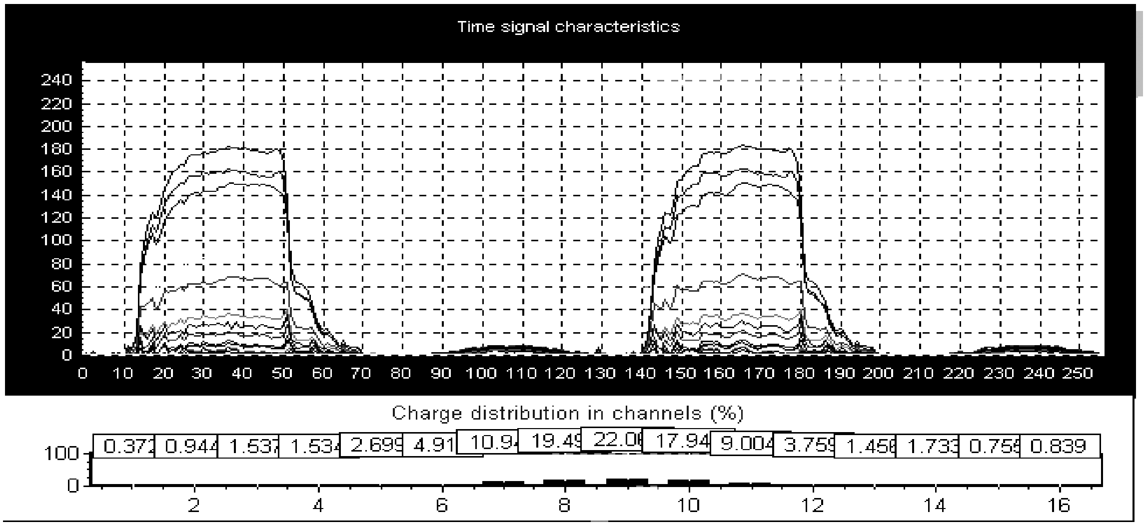

Fig.2. Videogram of the monitor signal measurement

However in our case these effects have insignificant impact. In the work [3] we showed that at the energy range covered secondary emission current from aluminium lames is directly proportional to electron beam charge. Secondary emission coefficient is 3,1 %. Pulse signal trains from monitor lames are given in Fig. 2. The pulse area is directly proportional to total charge of electrons captured by monitor lames.

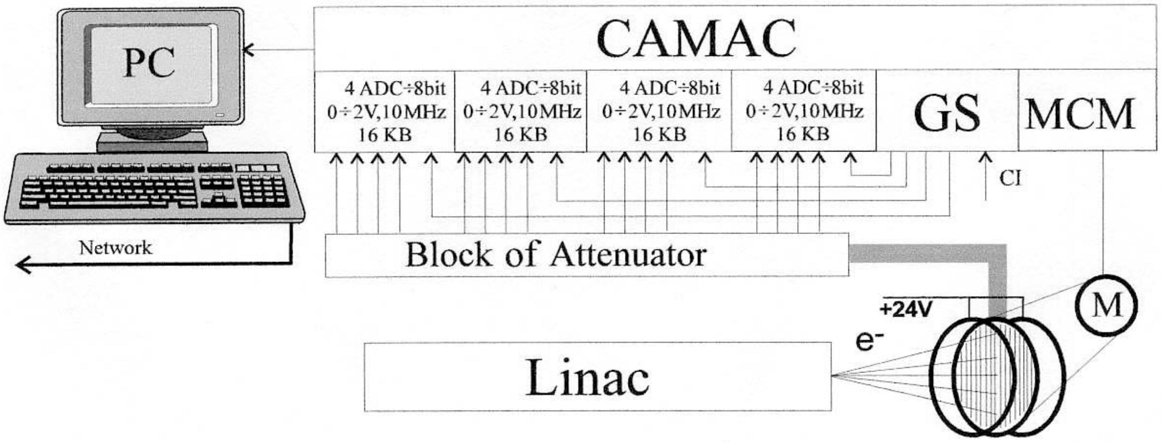

Fig.3. Schematic representation of beam cross-section control. ADC – digitizers, GS – synchronizer module, M – the step electric motor , MCM – module for control over the step electric motor.

The electrode current values measured at different angles of the monitor turning it use by computer (Fig. 3) to evaluate the distribution density of charge particles in the beam cross-section and the beam position relative to emitting electrodes by mathematical computer tomography method.

RECONSTRUCTION OF THE PARTICLE DISTRIBUTION DENSITY FROM BEAM SECTIONS.

As evidenced by the foregoing, value of signal from monitor lame is proportional to total charge of the electrons passed through it. If the lame wide is infinitely small total charge from the lame is calculated by formula:

$$R(r,\varphi)=k\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(x\cos\varphi+y\sin\varphi-r)dxdy \qquad (1)$$

where $f(x, y)$ - distribution function of beam particles in the plane of the monitor;
r – the distance of the origin of the coordinates to one of the monitor lames;
φ - the angle of monitor turn relatively X axis;
k - proportionality coefficient.

Equation (1) is named Radon transformation. The several various mathematical methods are created to reconstruct function *f(x, y)* from Radon equation [4,5]. The algorithm used in our work is exhibited on the server [5]. In this publication is shown if function *R* have continuous derivative with respect to *r* and it can be interpolated by 3d degree polynomials so reconstructed in discrete form function *f(x, y)* is represented by formula (2).

$$f^*(x,y)=1/(2\pi N)\sum_{j=1}^{N}\sum_{i=1}^{M}(R(r_i,\varphi_j)S_0(z)) \tag{2}$$

$$S_0(z)=x\cos\varphi_j+y\sin\varphi_j+a+(1-i)h \tag{3}$$

$$z=x\cos\varphi_j+y\sin\varphi_j,\ r_i\le a,\qquad 0\le\varphi_j<\pi$$

where M – lame quantity; N – turn quantity; a – inner window radius; h – distance of lame axis.

To estimate ellipse dimensions in a section of beam in monitor plane we used the photometric method.

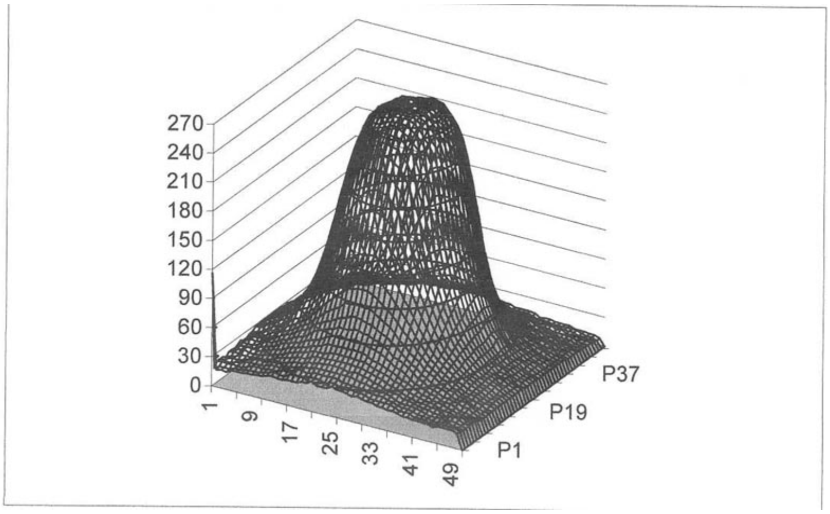

Fig. 4. 3D- darkening density distribution on the glass by the action of electron pulse train of accelerator KUT in a monitor plane (120 mm from exhaust foil).

To receive the quantitative estimation of the beam electron distribution density is used EPSON 1660 scanner. We customary suggest that glass darkening is linear with the beam electron density distribution at short exposure. Results shown on the Fig. 4 were obtained at 0.5 A pulse current and electron energy 12 MeV (pulse quantity was equaled 400). It is seen that the beam electron distribution density agrees closely with normal distribution. Thus the employment of algorithms from the work [5] is justified in our case.

A distribution density error estimate depends on several factors.

1. On the function calculation (2) the distance of the nodal grid points *(x, y)* is bound to be greater than monitor lame wide. If the foundation wide of function peaks are smaller than the lame wide this peaks are faired in reconstruction.

2. The measurement error of signal value from the monitor lames (Fig.2) is determined by the measuring channel parameters. We employed ADC with 8 bits and sampling frequency 10 MHz. Accordingly a relative measurement error of R value varied in the range from 1 to 10 % with the signal amplitude from the lames (Fig. 2).

3. To choose emitting electrode lame quantity *(M)* and monitor turning quantity *(N)*, the function values $f(x,y)=exp((y^2+x^2))$ were calculated under changes of x and y from +4 to –4 with the step equaled 0.2 Integral values R were computed for distinct M and N and by formulae (1-3) the $f^*(x,y)$ function values were computed in the same points that $f(x,y)$. For the error estimate of the distribution function reconstruction the value $d2=(f^*(x,y)- f(x,y)^2/k$ (k - the nodal grid point quantity) is calculed. The results of the calculation are shown in Fig. 5.

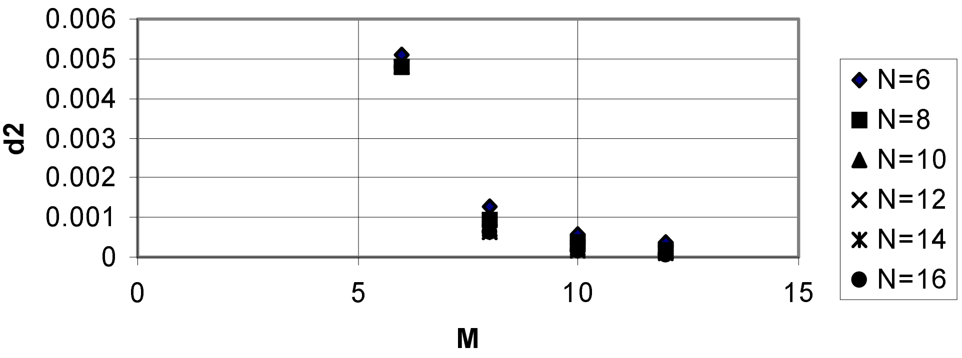

Fig.5 The relationship between function reconstruction error *(d2)* and lame quantity (*M*) for various monitor turning values (*N*).

On these results we chose the parameters of monitor prototype: $M = 16$; $N = 32$; $a = 30$mm; $h = 3{,}2$mm.It is hoped that the function reconstruction error will be not worse than 10 % in the any point.

In figures 6,7 the results of experimental use of the monitor on the one-section technological LEA KUT are given [6].

RESUME

The prototype of the secondary emission monitor for work in air was created using the method of measurement of two-dimension distribution density in electron beam. The experimental research showed the possibility to use the charged particle beam cross-sections measured at different angles for reconstruction of two-dimension distribution density by computer tomography method.

At present time on-line control channel of beam cross-section has been tested on the linac KUT.

The result of the photometric measurement of the beam electron distribution density is shown on the Fig. 4. The thickness of glass used for photometry was equaled 3 mm.

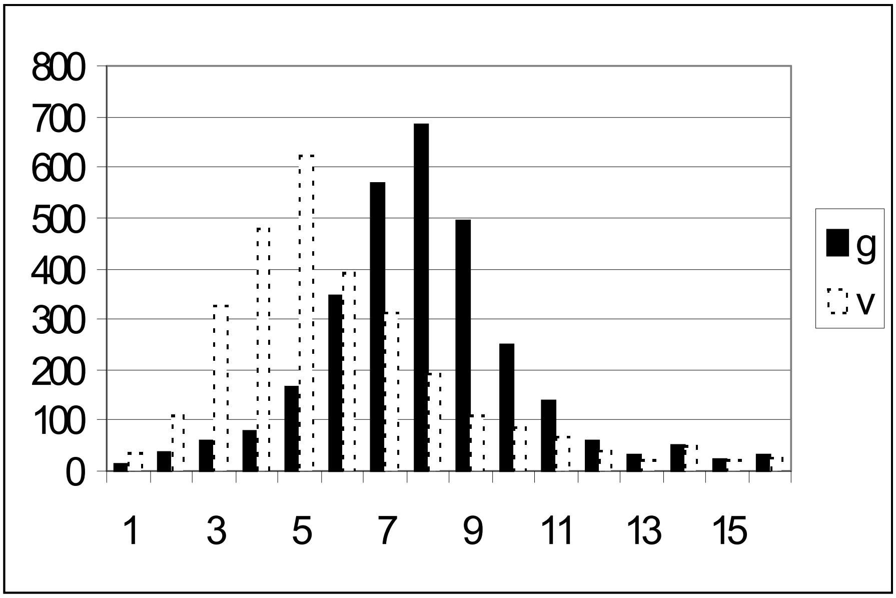

Fig. 6. The signal histogram from monitor lames. The horizontal (g) and vertical (v) cross-sections of accelerator KUT

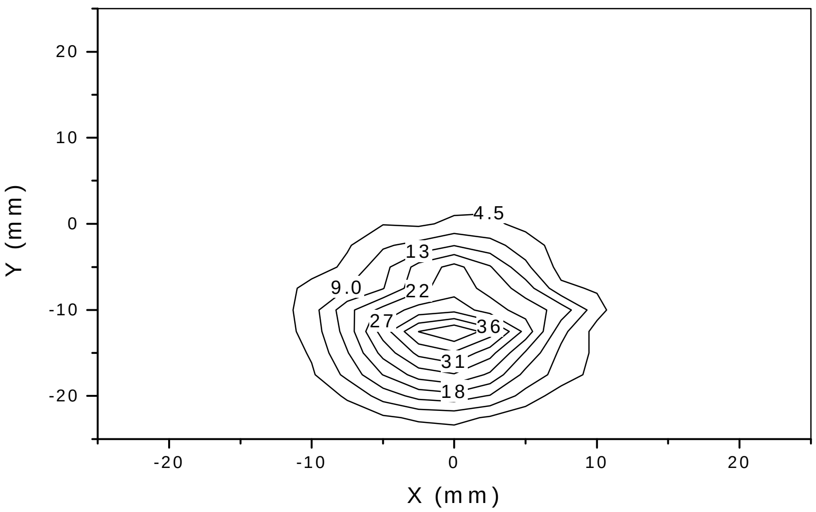

Fig. 7. Example of tomography reconstruction of particle distribution density in beam of the linac KUT. The distance from exhaust foil to monitor is 120 mm

At present time on-line control channel of beam cross-section has been tested on the linac KUT. Authors are grateful to Yu.P. Stepanovsky, A.N. Dovbnya, and V.L. Uvarov for helpful discussion

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