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MEASUREMENT OF THE ELECTRON BEAM SPECTRUM BY THE ABSORBING FILTERS METHOD DURING A SINGLE PULSE

A. Drozdovsky, A.Bogdanov, S. Drozdovsky, A.Kantsyrev, A.Khurchiev, V. Panyushkin, S.Savin, A.Skobliakov, S.Visotski, V.Volkov
NRC «Kurchatov Institute» - Institute of theoretical and experimental physics, Moscow, Russia

Abstract

Equipment for measuring the spectrum of an electron beam during a single pulse has been developed and manufactured. We developed a method of processing experimental data and present the obtained results.

INTRODUCTION

The interest in measuring the energy spectrum of electron beams by the method of absorbing filters is due to the technical availability in comparison with magnetic spectrometry. Moreover, the measuring unit is compact, efficient and suitable for various research facilities.

EXPERIMENTAL FACILITY

The task of our work was to determine the spectrum of an electron beam with a maximum energy up to 300 keV during one pulse. We applied elements of the technique by [1] to obtain the spectrum from the absorption curves of the beam. The beam passed through a sequence of metal plates of same thickness located perpendicular to the beam axis at fixed interval, while the charge Qi absorbed in each plate is measured for each pulse. The measurement scheme is shown in Fig. 1.

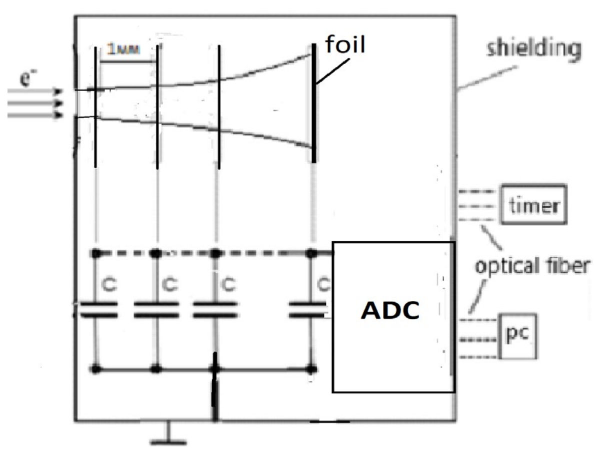

Figure 1: The measurement scheme.

Beams of energy up to 300 keV were emitted from an electron gun [2]. The current collector package consists of 16 insulated identical aluminum foils with the gap of 1 mm between. The thickness of the foils varies from 10 to 25 microns depending on the maximum electron energy. The charge of the foils after passing the beam was measured by an ADC. The charge absorbed by the nth foil $Q_n = V_n C_n$. Each foil is connected to a capacity C_n = 7 nF. The distribution of voltage V_n over the foils of thickness 16 microns after passing an electron beam through at different charging voltages is shown in Fig. 2.

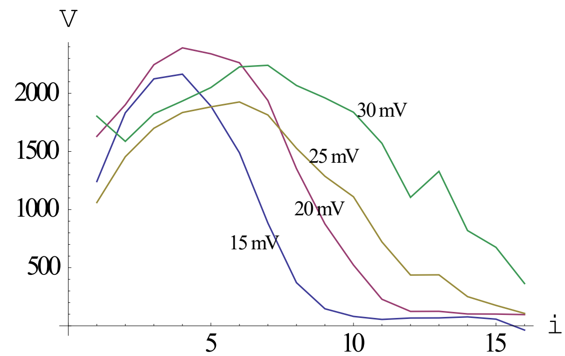

Figure 2: Distribution of voltage V_n over foils at different voltages of the pulse generator of the gun.

Measurements with foils of thickness 16 microns are suitable for the correct determination of the spectrum at charging voltages up to 25 kV. For high voltages the data is incomplete as can be seen from the absorption curves.

METHOD OF SPECTRUM RESTORING

The measurement process is related to the following system of integral equations:

$$\int_{E_{min}}^{E_{max}} K_i(\varepsilon)\, q(\varepsilon)\, d\varepsilon = Q_i\,,\quad i = 1, \ldots, n\,, \qquad (1)$$

where Q_i is the experimentally obtained charge absorbed by the plate number i, $q(\varepsilon)$ is the charge density with respect to the energy (the energy spectrum of the beam), $K_i(\varepsilon)$ is the kernel of the integral transform, with a physical meaning of the probability for a particle with the energy ε to be absorbed in the plate i. The integration is bounded by the interval $\{E_{min}, E_{max}\}$, which limits the range of particle energies in the beam. Our task is to restore $q(\varepsilon)$ from Q_i by solving this system of integral equations. After approximation $q(\varepsilon)$ and $K_i(\varepsilon)$ by step functions, piecewise constant on the intervals $\{\varepsilon_j - \Delta\varepsilon/2, \varepsilon_j + \Delta\varepsilon/2\}$, $\varepsilon_{j+1} - \varepsilon_j = \Delta\varepsilon$, the system (1) takes the discrete form:

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$\sum_j K_{ij} q_j = Q_i$, $i = 1, \ldots, n$, $j = 1, \ldots,$ (2)

where $K_{ij} = \Delta\varepsilon\ K_i(\varepsilon_j)$, $q_j = q(\varepsilon_j)$, or in matrix representation $K\,q = Q$.

The values K_{ij} were calculated by the Monte Carlo method using the Geant4 software package [3]. The charges absorbed in the foils were calculated for monoenergetic beams from 10 to 300 keV with step 10 keV, filling the range quite dense. Figures 3 and 4 show the structure of the array K.

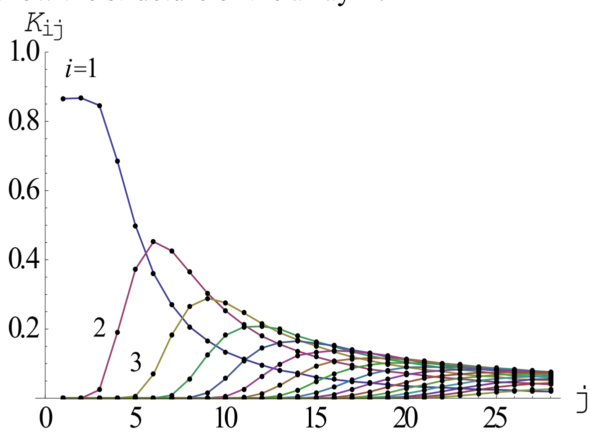

Figure 3: Distribution of absorbed charges overbeams of different energies for each plate i.

The first one shows the distribution of the absorbed charge by energy for each plate (plate – line), the second shows the distribution of the absorbed charge across the plates for each energy (energy – line).

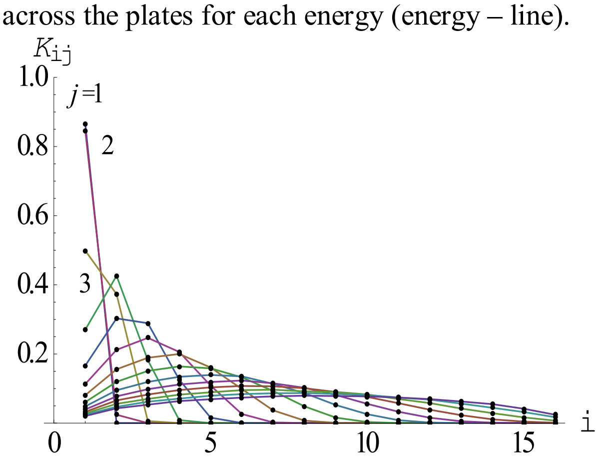

Figure 4: Charge distribution over plates for each beam

On the ordinate axis – the charge in relative units, on the abscissa axis: the first figure – the numbers of energy counts, the second – plate numbers.

The equation (1) or (2) is an ill-posed inverse problem, as well as the most arising in practice.

The related mathematical tool is the theory of correct and incorrect problems by A. N. Tikhonov [4]. To obtain an appropriate solution, Tikhonov regularization is used, which means minimizing the functional

$$\|Kq - Q\|^2 + \alpha\|q\|^2,\ \alpha > 0\,,$$

with respect to q, where $\|\,\|$ denotes the norm of a vector or matrix (operator). The first term is responsible for the fidelity and the second one for the regularity. The larger the regularization parameter α, the higher the regularity and lower the accuracy. $\alpha = 0$ corresponds to the least squares method. In our case, the search for the minimum is carried out by the conjugate gradient method.

It turned out that not the regularization is crucial, but the high-precision fitting of the input data and the transformation kernel by statistical distributions, which make the regularization parameter reduced to almost zero. The data Q is approximated by normal distribution, and the kernel K by normal and log-normal as the energy or plate is fixed respectively.

The fitting of the matrix K is performed as follows. First, for each j (fixed energy), we approximate the one-dimensional array K_{ij} (charge distribution over the plates) by the function

$$\alpha_j P_N(\sigma_j, \mu_j;\ x) + \beta_j,$$

where $P_N(\sigma, \mu;\ x)$ is normal distribution.

Then, for each i (plate is fixed), we approximate the one-dimensional array K_{ij} (charge distribution by energy) by the function

$$\alpha_i P_{LN}(\sigma_i, \mu_i;\ y - \lambda_i),$$

where $P_{LN}(\sigma, \mu;\ x)$ is lognormal distribution. Thus we get the fitted array K_{ij}.

To fit the experimental data, besides the absorption function Q_i, we need the charge passage function $\widehat{Q_i}$. They are related in the following way:

$$\widehat{Q_\iota} = \sum_{j=1+i}^{n} Q_j\ ,\ i = 0, \ldots, n,$$

$$Q_i = \widehat{Q_{\iota-1}} - \widehat{Q_\iota}, i = 1, \ldots, n.$$

The fitting of the experimental data is conducted in the following order. First, we calculate $\widehat{Q_\iota}$ from Q_i as above, then fit the one-dimensional array $\widehat{Q_\iota}$ by the function

$$\alpha C_N(\sigma, -\mu;\ -x) + \beta,$$

where C_N is the cumulative function for normal distribution. Then, by the inverse we get the fitted Q_i.

All the calculations were performed in Wolfram Mathematica.

RESULTS

We illustrate our method by an example of calculating the spectrum of a beam with the source voltage 17.5 keV. The described above fitting of the

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passing function is depicted in the Fig. 5. On the abscissa axis – the plate numbers, on the ordinate axis – the charge in relative units. The points represent the discrete passing function, the line represents the continuous fitting function.

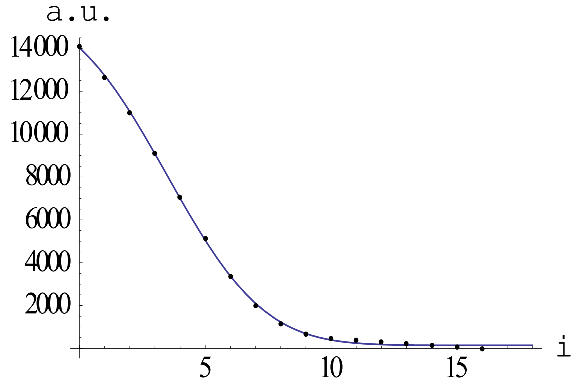


Figure 5: The passing function $\widehat{Q}_\iota$.

Next, we solve the equation $K\ q = Q$ by Tikhonov regularization with $\alpha = 0$ and get a quite regular and accurate solution, shown in Fig. 6a. On the abscissa axis – the energy in keV, on the ordinate axis – the charge density with respect to the energy.

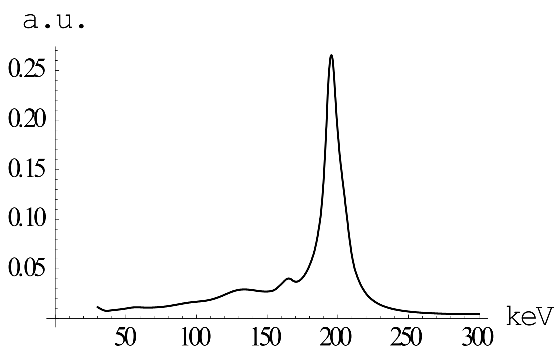


Figure 6a: With fitting.

For comparison, we give the results of processing the same beam with regularization without fitting in Fig. 6b.

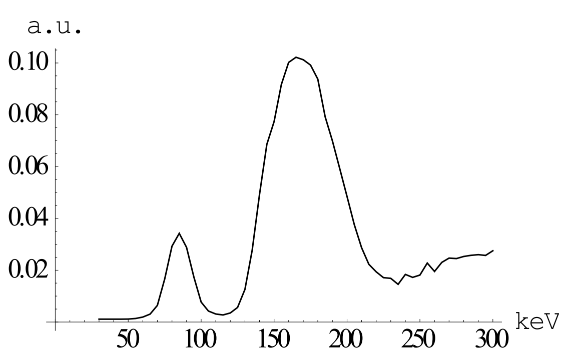


Figure 6b: Without fitting.

A series of measurements, carried out at different operating modes of the accelerator (Fig. 7).

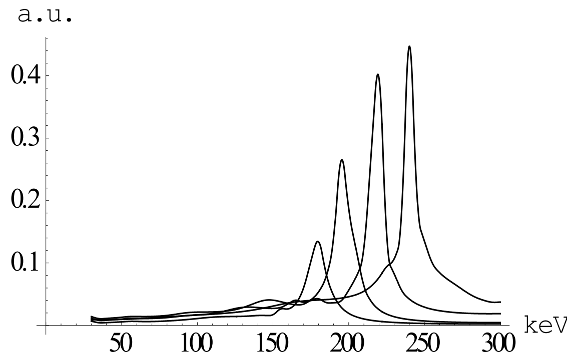
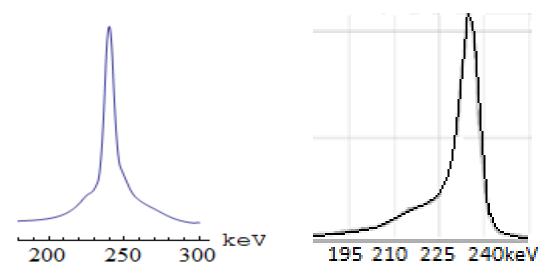


Figure 7: Spectrum at voltage 15, 17.5, 20, 25 kV.

CONCLUSIONS

The validity of the technique applied is confirmed by the fact that the spectrum obtained during charging the voltage of 17.5 kV (Fig. 8a) sufficiently matches the spectrum (Fig. 8b) measured on a magnetic spectrometer [2]. In this case, both the maximum energies of the electrons are almost the same.



(a) (b)

Figure 8: (a) - The spectrum from the absorbing filters method.; (b)- The spectrum on a magnetic spectrometer.

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