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NUMERICAL INVESTIGATION OF THE ABERRATIONAL COEFFICIENTS OF A BOX SHAPED CATHODE LENS

Abstract. In the present article, the numerical investigation of the aberration coefficients that determine the electron-optical characteristics of a three-electrode cathode lens is carried out. This paper discusses the theoretical and practical aspects of the design of new cathode electron lenses with two symmetry planes, which ensure a higher quality of focusing of charged particles, which, in their turn, leads to the improvement of the technical characteristics of analytical instruments and processing installations. It is noted that the investigated elements are used in electron microscopes, mass spectrometric devices, as well as in electron-lithographic and ion-lithographic installations of nano and micro electronic technologies. Numerical calculations of the aberration coefficients were performed according to the program for electron cathode lenses with two symmetry planes, provided that it forms a crossover. The aberration coefficients are calculated from complex formulas. In calculating the aberration coefficient, the Simpson formula was used to solve the integral, the fourth-order Runge-Kutta numerical method was used for solving the second-order differential equation. As a result of the calculations, a comparative analysis of the aberration coefficients was carried out. The three-electrode cathode lens discussed in this paper, with certain lens parameters, makes it possible to focus charged particles with the lowest values of aberrations.
Keywords: cathode lens, electron, ion, focusing, aberration, instrument.

In order to focus the electron beam in the electron-optical equipment, electronic lenses are used. When they are designed, mathematical modeling plays an important role, which allows tosignificantly reduce the time and money spent on experiments in order to optimize the performance of lenses. Modeling of electrostatic electronic lenses is performed in two stages: calculation of the electrostatic field and analysis of its electron-optical characteristics [1, 2].

When developing electronic optical devices and devices that include elements of electronic optics, it is very important to consider the amount of influence of each of its elements that affects the quality of the electron-optical image.

Aberrations play an important role in electronic and ion optics. In practice, they limit the possibilities of beam devices. The main aberrations that determine the resolving power of most electronic optical instruments are spherical and chromatic. They cause distortions in the image of source points located both outside the optical axis and on it. For the correction of spherical aberration the multi-electrode lenses - octupoles and sextupoles are usually used [3]. The correction of chromatic aberration up to the present time was carried out mainly with the help of superimposed electric and magnetic quadrupoles [4]. However, the use of a magnetic field has a number of disadvantages that significantly complicate the practical work with the system. The chromatic aberration of a linear image can also be corrected in a purely electrostatic lens.

The problems of aberration reduction in electrostatic lenses are investigated in many scientific works with different methods for improving aberration characteristics, such as the use of different forms of electrodes [5-7]. There are several methods for correcting chromatic and spherical aberrations in electron and ion optics by calculating the drift-transit time of image particles [8,9]. Methods for filtering the effects of spherical and chromatic aberrations of wide acceptance angle electrostatic lenses (WAAEL) are described in [10-21].

The present paper covers the numerical investigation of aberration coefficients of three-electrode cathode lenses with two symmetry planes containing a set of plane electrodes arranged symmetrically and parallel to the symmetry planes of the field.

In the Cartesian x, y, z coordinate system, the case of a three-electrode cathode lens is to be considered (Figure 1), whose cathode is located in the xy plane at the value of the third coordinate $z = 0$. It is noted that the third coordinate for the considering lens is its main optical axis. The cathode potential is assumed to be zero. Two pairs of flat plate electrodes are symmetrically positioned to the xz plane, the distance from this plane to the electrodes is assumed equal to l_y, the other two pairs of flat plate electrodes are symmetrically positioned to the yz plane at a distance l_x. In the direction of the main optical axis z, these pairs of electrodes are separated by a slit located at the xy plane with the coordinate z_1 [1].

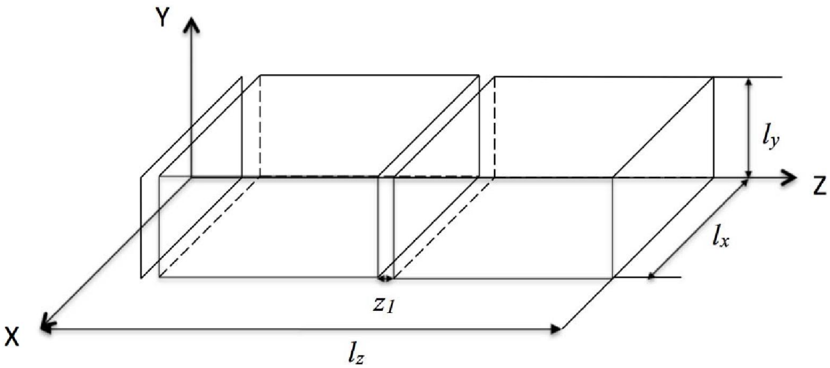

Figure 1 – Three-electrode cathode lens

Numerical calculations of the aberration coefficients were performed according to the program for electron cathode lenses with two symmetry planes, provided that the crossover was formed (Figure 2).

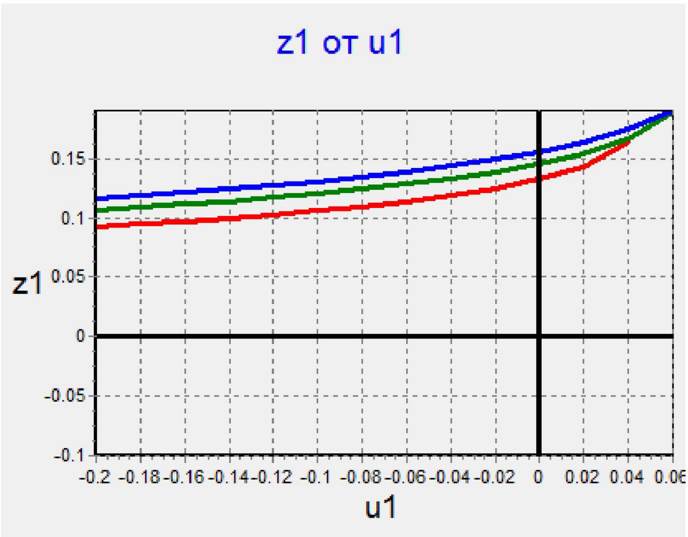

Figure 2 – Graph of conditions for the formation of a crossover of a three-electrode cathode lens

The aberration coefficients are calculated from complex formulas. For example, the aberration coefficient D_{x31} is calculated in the following way

$$D_{x31} = -\frac{1}{\Phi'_k} \cdot h_x(z_c) \cdot I_{x2} \tag{1}$$

where

$$I_{x2} = \int_{z_k}^{z_{on}} \frac{w_x}{\sqrt{\Phi}} \cdot \left(w_x^2 \cdot Q_8 + 2 \cdot w_x'' \cdot Q_1\right) dz_{on} \tag{2}$$

$$h_x = q_x \cdot \sqrt{\Phi} \tag{3}$$

where

$$Q_1 = -\Phi \cdot w_x'^2 + \varphi_{20} \cdot w_x^2 \tag{4}$$

$$Q_8 = \varphi_{20}' \cdot w_x' - 4 \cdot \varphi_{04} \cdot w_x \tag{5}$$

$$2 \cdot \Phi \cdot w_x'' + \Phi' \cdot w_x' - 2 \cdot \varphi_{20} \cdot w_x = 0 \tag{6}$$

$$2 \cdot \Phi \cdot q_x'' + 3 \cdot \Phi' \cdot q_x' + \left(\frac{3}{2} \cdot \Phi'' - 2 \cdot f_{\kappa в}\right) \cdot q_x = 0 \tag{7}$$

The drift-transit time and other motion parameters of charged particles are counted from the moment of their emission from the cathode surface, on which the condition $\varphi_k = \varphi(x_k, y_k, z_k) = 0$ is satisfied. Therefore, when solving (2), an uncertainty is faced, which is eliminated by the following formula

$$\int_{z_k}^{z_{on}} \frac{\sigma}{\sqrt{\Phi}} dz_{on} = 2 \cdot \frac{\sigma(z_u)}{\Phi_u'} \cdot \sqrt{\Phi(z_u)} - 2 \cdot \int_{z_k}^{z_u} \frac{\sqrt{\Phi}}{\Phi'} \cdot \left(\sigma' - \frac{\sigma \cdot \Phi''}{\Phi'}\right) dz_{on} + \int_{z_u}^{z_{on}} \frac{\sigma(z)}{\sqrt{\Phi}} dz_{on} \tag{8}$$

Where z_k - coordinate of the cathode, z_u - coordinate of a point a few steps from the cathode.

When calculating the aberration coefficient in order to solve the integral (2), the Simpson formula was used, the fourth-order Runge-Kutta numerical method was used for solving the second-order differential equation (6), (7). The calculation of electrostatic field was performed in the article [1].

Aberration coefficients D_{xnj} and D_{ynj} (n=2,3; j=1, 2,...,12) along the axis x and y are determined by similar formulas.

When performing the calculations the values for $u_2 = 1$, $l_y = 0.1$, $l_z = 1$ and corresponding values for u_1 and z_1 (Figure 2) were taken with the condition of crossover formation. The size of the lens is regulated by distance of electrodes l_x from the plane yz. The results of calculations of a set of aberration coefficients are presented in graphs (Figure 3 - Figure 8). In the figures, the red line corresponds to the value $l_x = 0.06$, green - $l_x = 0.08$, blue - $l_x = 0.1$. The graphs show the dependence of the aberration coefficients on the potential of the first electrode u_1 for three different values of l_x.

A number of aberration coefficients were obtained, characterized by zero or negative values ($D_{x31} - D_{x310}$, $D_{y31} - D_{y310}$ and D_{y312}). The aberration coefficient becomes positive for D_{x311}, D_{x312} and D_{y311}, but its value remains small when $l_x = l_y = 0.1$, and negative for D_{x312} as well as for D_{y312}.

Particularly interesting fact for D_{x311} and D_{y311} is that when the potential of the first electrode increases, consequently the distance between the electrodes z_1, the value of the aberration coefficient decreases, which is characterized by a positive aberration coefficient for all three different values of l_x.

The analysis of the graphs shows that the considered three-electrode cathode lens for the certain values of applied potentials and electrode sizes makes it possible to significantly reduce the aberration values.

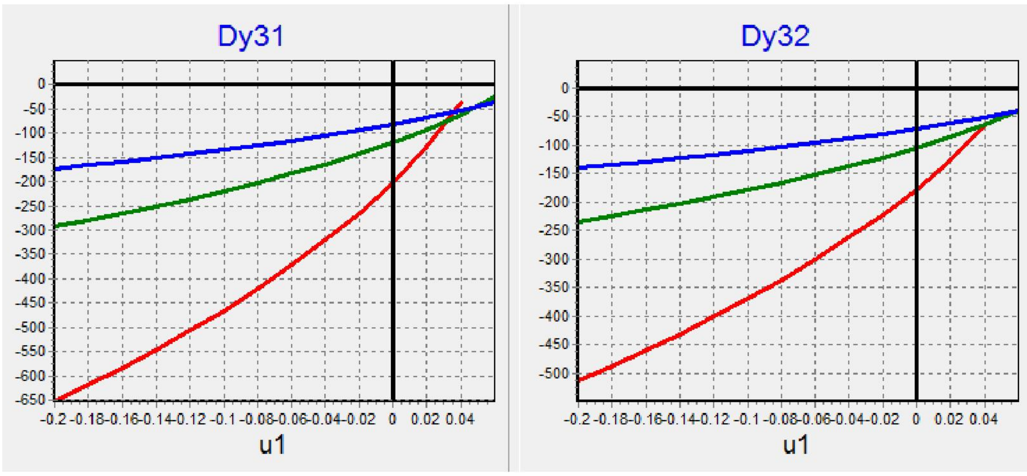

Figure 3 – Graphs of the aberration coefficients D_{y31}, D_{y32}

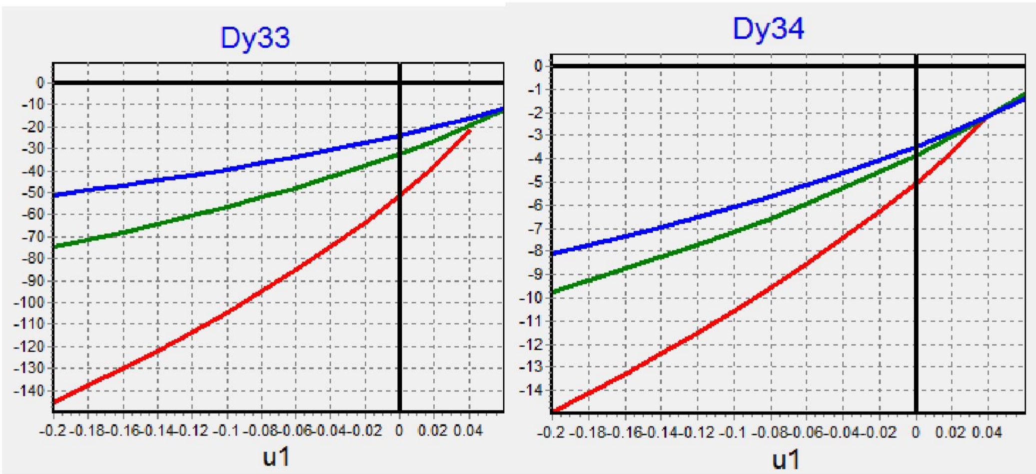

Figure 4 – Graphs of the aberration coefficients D_{y33}, D_{y34}

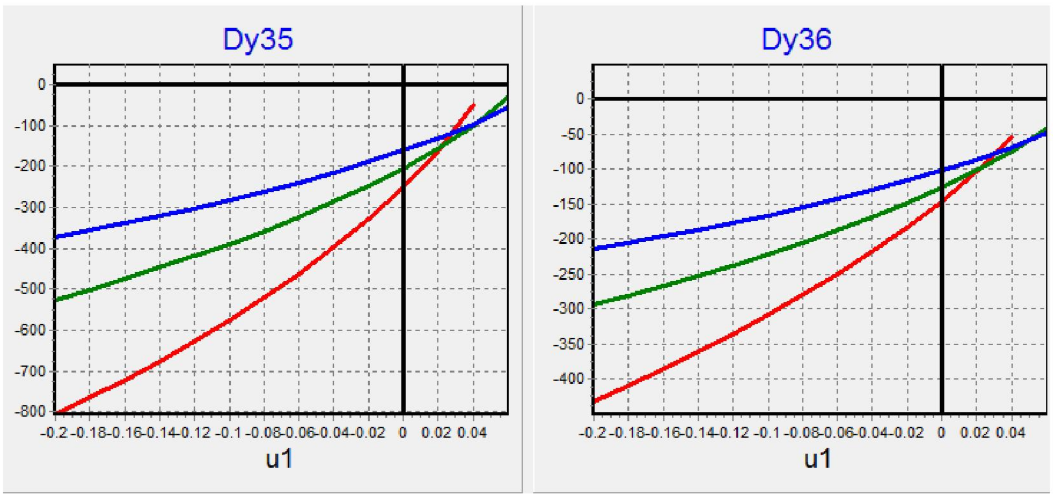

Figure 5 – Graphs of the aberration coefficients D_{y35}, D_{y36}

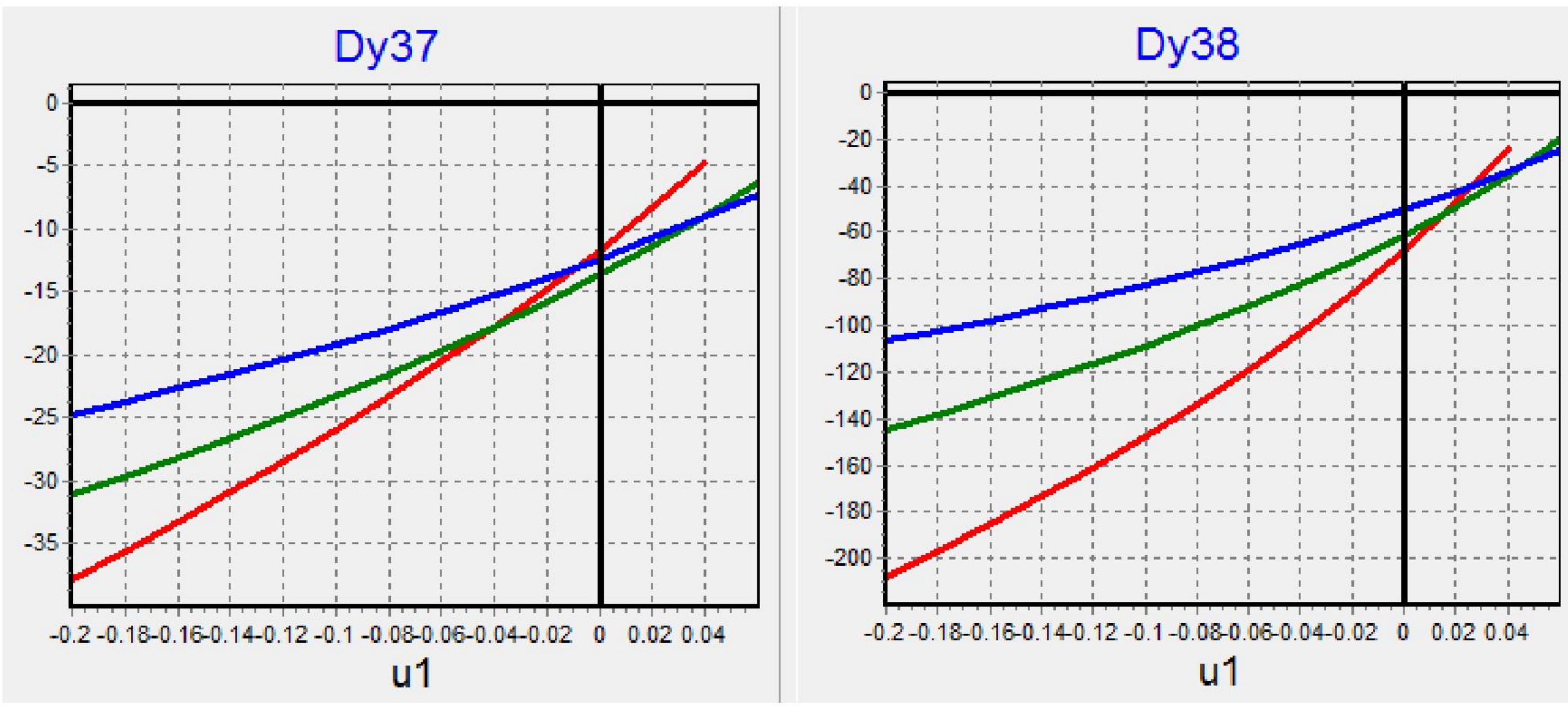

Figure 6 – Graphs of the aberration coefficients D_{y37}, D_{y38}

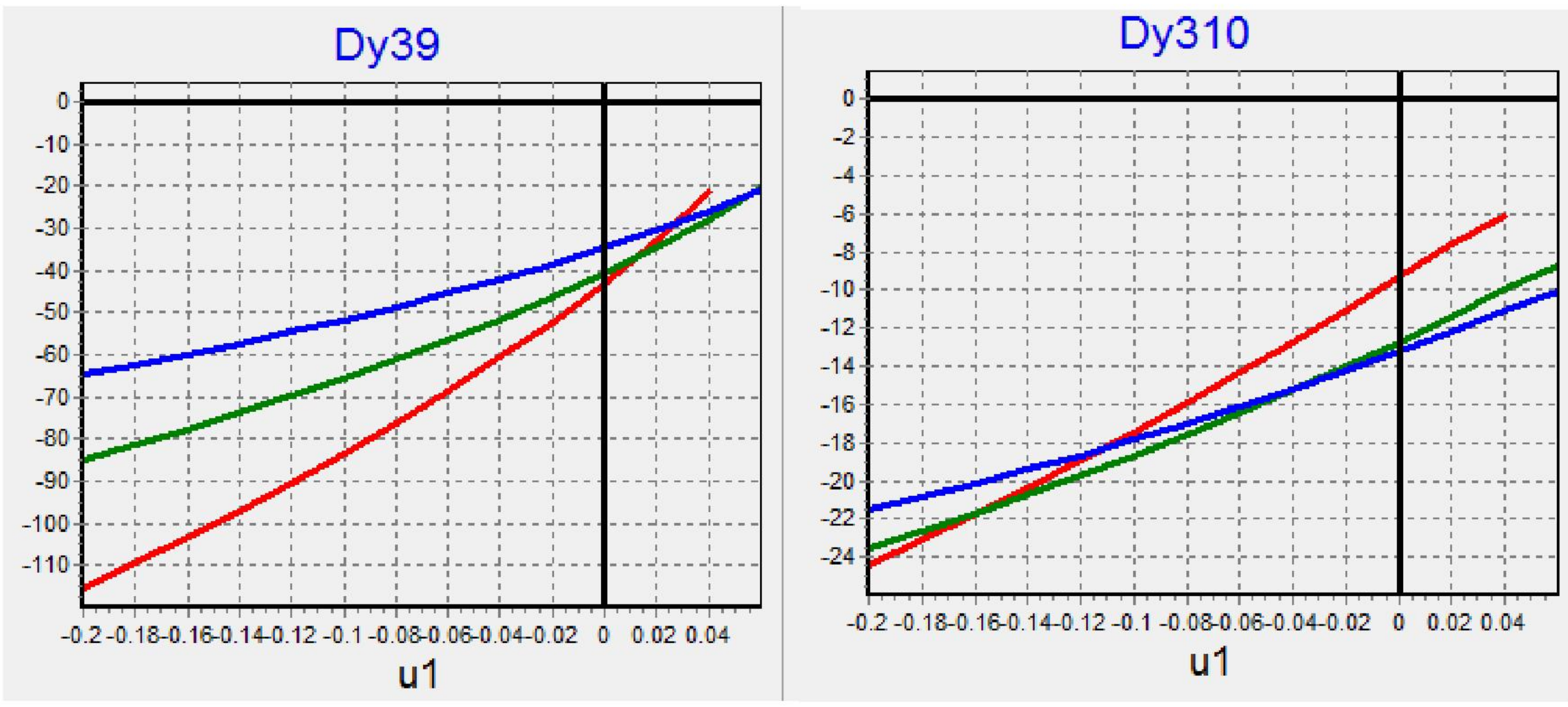

Figure 7 – Graphs of the aberration coefficients D_{y39}, D_{y310}

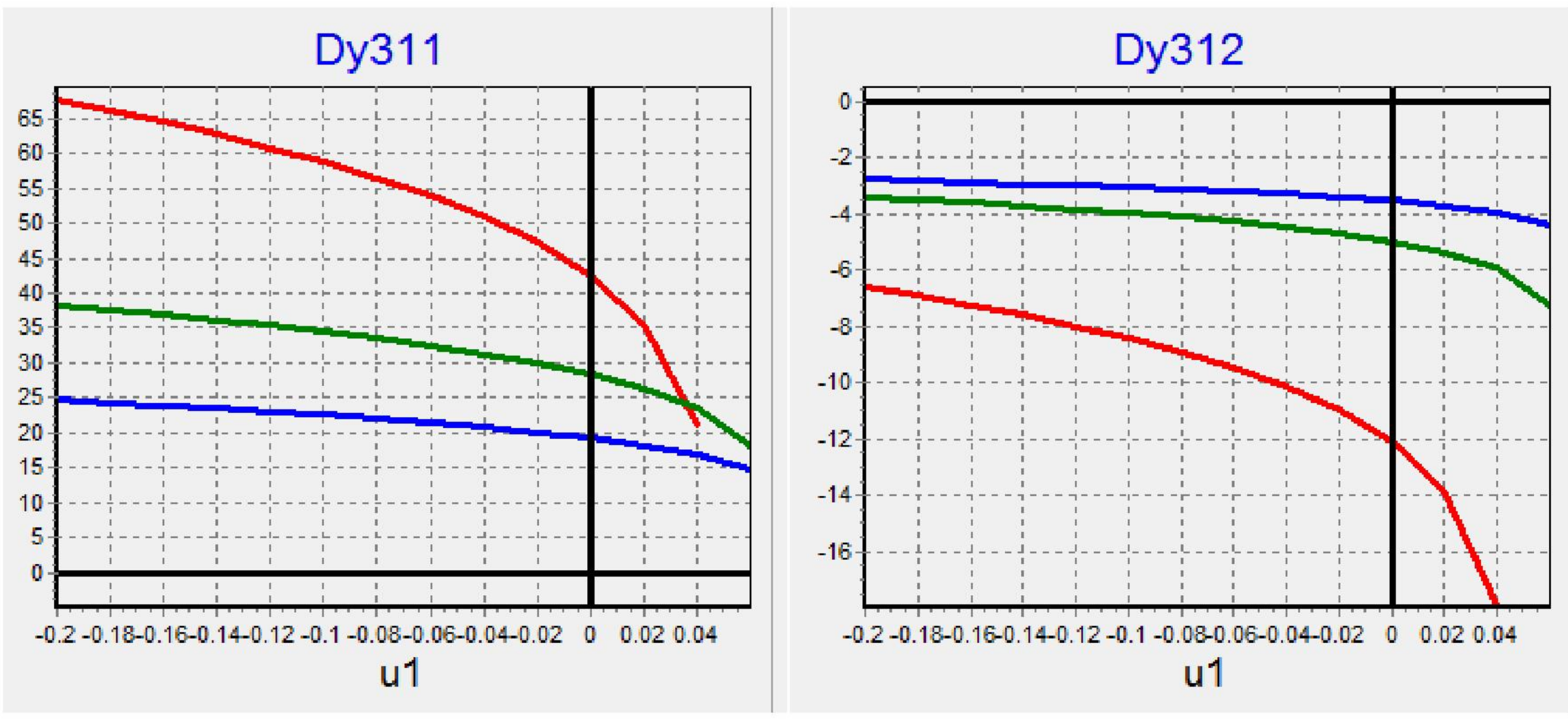

Figure 8 – Graphs of the aberration coefficients D_{y311}, D_{y312}

Properties of a cathode lens with a cylindrical shape of electrodes were investigated in [2]. The results shown in [2] indicate that an increase in the number of electrodes can give some improvement in certain types of aberrations. At the same time, a comparison of these results with similar doubly symmetric elements shows that the values for the aberrations of doubly symmetric lenses are often smaller than the values for similar aberrations in axisymmetric lenses. Thus, in a number of cases the use of focusing elements with two symmetry planes gives better conditions for the formation of electron and ion fluxes with the necessary beam focusing parameters.

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ҚОРАПТЫ КАТОД ЛИНЗАСЫНЫҢ АБЕРРАЦИЯЛЫҚ КОЭФИЦИЕНТТЕРІНЕ ЕСЕПТІК ЗЕРТТЕУ

Аннотация. Көрсетілген жұмыста үшэлектродты катод линзасының электронды-оптикалық сипаттамарын анықтайтын аберрациялық зерттеулер жүргізілген. Жұмыста зарядталған бөлшектерді фокустаудың жоғарғы сапасын қамтамассыз ететін екі симметрия жазықтығына ие жаңа катодты электронды линзаларды құрастырудың теориялық және практикалық сұрақтары қарастырылған. Бұл өз кезегінде технологиялық құрылғылардың техникалық сипаттамаларын жақсартуға мүмкіндік береді. Атап өтсек, зерттеліп отырған элементтер электронды микроскоптарда, масс-спектрометриялық құрылғылардат және де нано мен микро электронды технологиялардың электронды-литографиялық және ионды-литографиялық құрылғыларында қолданылады.

Түйін сөздер: катодты линза, электрон, ион, фокус, аберрация, құрылғы.

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ЧИСЛЕННОЕ ИССЛЕДОВАНИЕ АБЕРРАЦИОННЫХ КОЭФФИЦИЕНТОВ КОРОБЧАТОЙ КАТОДНОЙ ЛИНЗЫ

Аннотация. В настоящей работе проведены численные исследования аберрационных коэффициентов, определяющие электронно-оптические характеристики трехэлектродной катодной линзы. В работе рассматриваются теоретические и практические вопросы проектирования новых катодных электронных линз с двумя плоскостями симметрии, которые обеспечивают более высокое качество фокусировки заряженных частиц, что в свою очередь приводит к улучшению технических характеристик аналитических приборов и технологических установок. Отметим, что исследуемые элементы используются в электронных микроскопах, масс-спектрометрических приборах, а также в электронно-литографических и ионно-литографических установках нано- и микроэлектронных технологий. В результате проведенных расчетов был проведен сравнительный анализ коэффициентов аберраций. Рассмотренная в работе трехэлектродная катодная линза при определенных параметрах линзы позволяет осуществить фокусировку заряженных частиц с наименьшими значениями аберраций.

Ключевые слова: катодная линза, электрон, ион, фокусировка, аберрация, прибор.