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CALCULATION OF THE INSTRUMENTAL FUNCTION OF THE COMBINED ENERGY ANALYZER OF CHARGED PARTICLES BEAM

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In this work the model of combined energy analyzer consisting of electrostatic mirror fields was studied by numerical calculations. A trajectory analysis of the motion of charged particles in the given electron-optical system was held. The instrumental function of the device for a case of a point source was first developed in order to optimize the size of output aperture and crossing windows of energy analyzer, what allowed estimating the energy resolution of the instrument. The spectrometer enables to analyze charged particles beams leaving the source at angles about 90^0 *at the instrumental energy resolution of 2%.*

Keywords: hyperbolic mirror, cylindrical mirror, charged particles, the instrumental function, the energy resolution.

Introduction

Earlier [1] we calculated electron-optical characteristics of the electrostatic energy analyzer combined of successive hyperbolic (HM) and cylindrical mirrors (CM). The novelty of the proposed device is a new mutual arrangement of electron mirrors in the two-stage energy analyzer, that allows input charged particles beam to the field of hyperbolic mirror at angles close to a right angle.

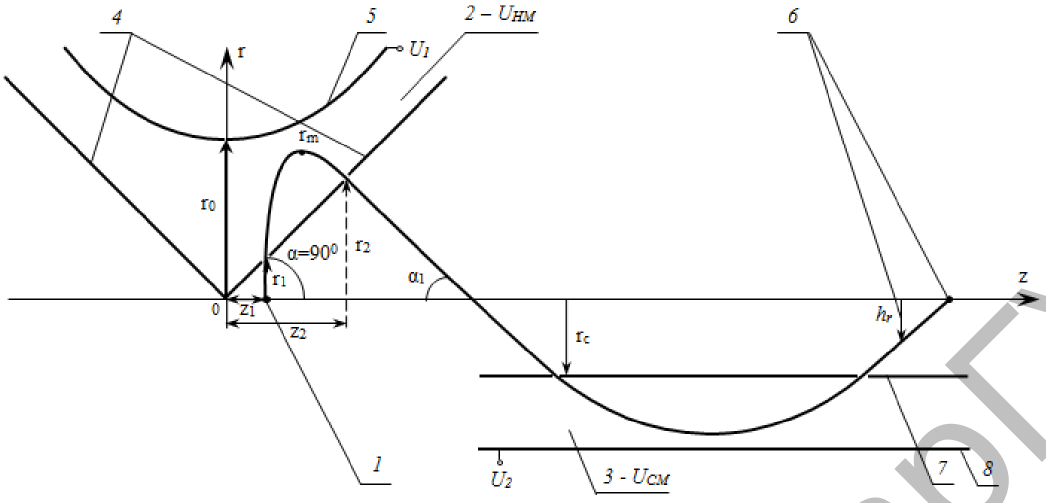
The scheme of mirror energy analyzer of combined successive HM and CM is shown in Fig.1 [1]. The figure shows the cross-section of the system by a plane r, z. The analyzer consists of a point source (1), arranged in series with mirrors with hyperbolic (2) and cylindrical (3) distribution of fields and the detector. HM is formed between two conical electrodes (4), which are under the zero potential, and an electrode of a hyperbolic shape (5), having a potential of the same charge as particles.

1. Modeling of electron-optical scheme of combined energy analyzer composed of successive electrostatic HM and CM

In this work the electron-optical scheme of energy analyzer combined of successive electrostatic HM and CM was analyzed, with the using of the "Focus" modeling program of axially-symmetric systems of corpuscular optics [2], in order to validate results obtained by analytical calculation formulas.

Fig. 2 demonstrates the distribution of the electrostatic field in the energy analyzer combined of successive electrostatic HM and CM. Fig.3 shows a three dimensional image of cross section of the electrostatic field in the combined system of mirrors. Here we calculated values of potentials at nodes of the mesh of the partition area and also painted the output field with colours, corresponding to value of potential at each point - the greater the potential, the "warmer" is the colour.

Fig. 4 presents trajectories of charged particles in the electron-optical scheme of combined energy analyzer of successive HM and CM. The total length of the electron-optical system is equal to 12.1. Radii of inner (3) and outer (4) electrodes of CM are equal to 1 and 2.5 respectively. Potentials of hyperbolic electrode (2) and the outer electrode CM are equal to 1. The inner electrode CM (3) and conical electrodes (1) are at a zero potential.



1 - the source of charged particles beam, 2 - HM, 3 – CM, 4 - conical transparent electrodes,
5 – the hyperbolic electrode, 6 - image of source, 7 - inner cylindrical electrode,
8 – the outer cylindrical electrode

Fig.1. Scheme of energy analyzer combined of successive HM and CM
(in cross section by plane r, z)

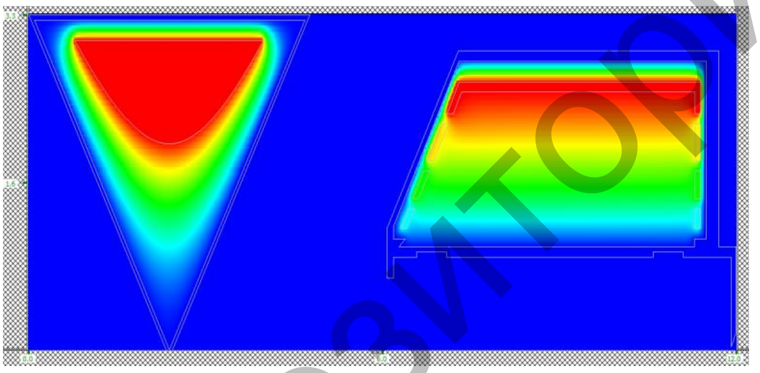


Fig.2. The distribution of the electrostatic field in the combined energy analyzer

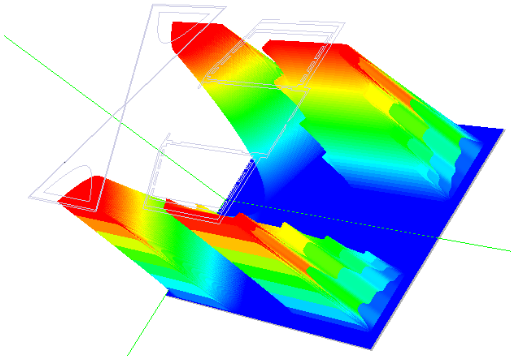


Fig.3. Three-dimensional image of cross section of the field in the combined energy analyzer

Asymptotes of hyperbolic electrode have an angle β=arc tan √2=54.4^0. All dimensions are expressed in relative units. Marked parameters are crucial to setting geometric parameters of electrodes.

Main elements of CM are two coaxial cylindrical electrodes with different radii. To correct the boundary field at butt ends of cylindrical electrodes corrective rings under potentials (in fractions of the outer cylinder's potential *V*) are placed in accordance with logarithmic law of variation of a cylindrical field with radius. For example, in the case of three pairs of adjusting rings their potentials have the following values are 0.25*V*, 0.5*V* and 0.75*V*. Thus, the analyzing field is formed between cylinders. Widths of input and output slits in the inner cylindrical electrode are equal to 0.5 respectively. By changing the potential *V* we can analyze the whole spectrum of energy *E* of charged particles. Electrodes of HM are chosen to be transparent for passing of charged particles. Opaque segments of electrodes are coloured in red in the program.

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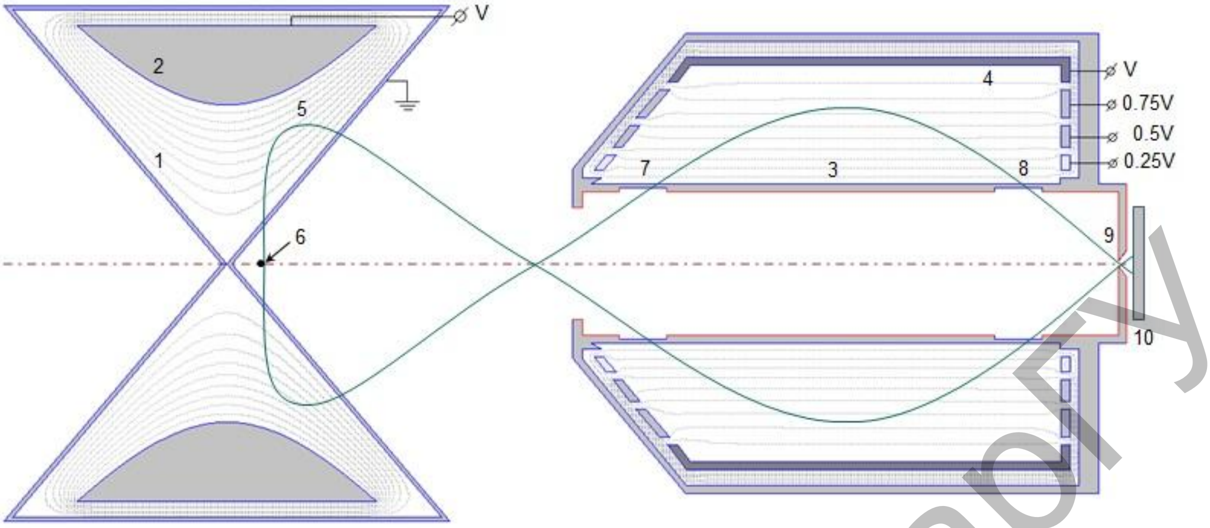

1 - conical electrodes , 2 - hyperbolic electrode, 3 - inner cylinder,
4 - outer cylinder, 5 - charged particles, 6 - point source,7 - input window of CM,
8 - output window of CM, 9 - circular output aperture, 10 – the detector

Fig.4. Trajectory of charged particles in the electron-optical scheme of combined energy analyzer of successive HM and CM

Fig. 4 shows the case characterized by large values $\alpha = 90^0$. The energy of the particle or rather the ratio of the energy of a charged particle to the potential of the electrode is 1. A point source is located on the symmetry axis of the energy analyzer in a distance from the hyperbolic mirror equal to x=1.13. Referring to Fig. 4, charged particles (5) from the point source (6) through the conical transparent electrode (1) of HM are reflected from hyperbolic electrode (2), then enter the field of CM. Charged particles, which passed through the output aperture (9), fall onto the position-sensitive detector (10), and thus are recorded. As a result of the focusing effect of two mirrors on the charged particles beam, a point image of source on the symmetry axis of the analyzer is produced. Thereby, the "axis -axis" type focusing is performed in the system.

The instrumental function is one of the main characteristics of both axial electrostatic energy analyzers and many other electron and ion-optical devices [3-5]. Instrumental function (transmission curve, instrument line, apparatus function, response function) of axial electrostatic energy analyzer is proportional to dependence of monoenergetic electron beam passing through the exit slit of the energy analyser from energy of electrons [3,4]. If instrumental function is known, it is not difficult to identify a resolution and transmission capabilities of a device. In electron optics there is a method called "trajectory". Applying of this method can give you new basic characteristics of studied energy analyzer.

The following algorithm can construct instrumental function for the energy analyzer based on axial-symmetric fields. Firstly, the range of variation of the charged particles' initial angles and energies are determined. The instrumental function of energy analyzer is determined by calculating a large number of charged particle trajectories for initial conditions, varying in width (radius) of circular output diaphragm. To simplify calculations, it was considered a motion of charged particles in one of planes passing through the mirrors axis, i.e. the device's instrumental function was determined excluding non-axial trajectories of charged particles. Thus, in the numerical calculations additional "broadening" of the instrumental function by non-axial energy analyzer "rays" was not taken into account. Motion trajectories of charged particles in this energy analyzer were found by numerical solution with the "Focus" program.

2. Results and discussion

For calculation of the instrumental function of electron-optical system in the case of the point source, initial conditions are given in the program, i.e. charged particles with the initial angle of 90^0 and having initial energy within the emission range (more precisely *E/V*) equal to 0.9-1.1 *eV/V* are launched from the point source.

Figures 5.1 and 5.2 present instrumental functions of the combined energy analyzer in the case of a point source with a small (R_d = 0.025 R_{in}; 0.05 R_{in}) and large (R_d = 0.075 R_{in}; 0.1 R_{in}) radii of the output aperture.

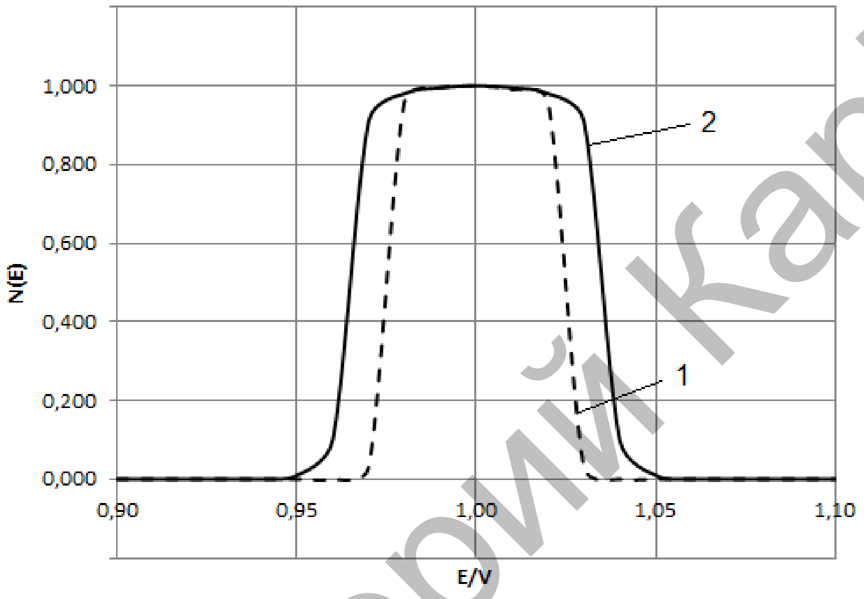

Fig. 5.1. The instrumental function of analyzer with small radii of the output aperture.
The radius of the output aperture: 1 – 0.025 R_{in} ; 2 – 0.05 R_{in}

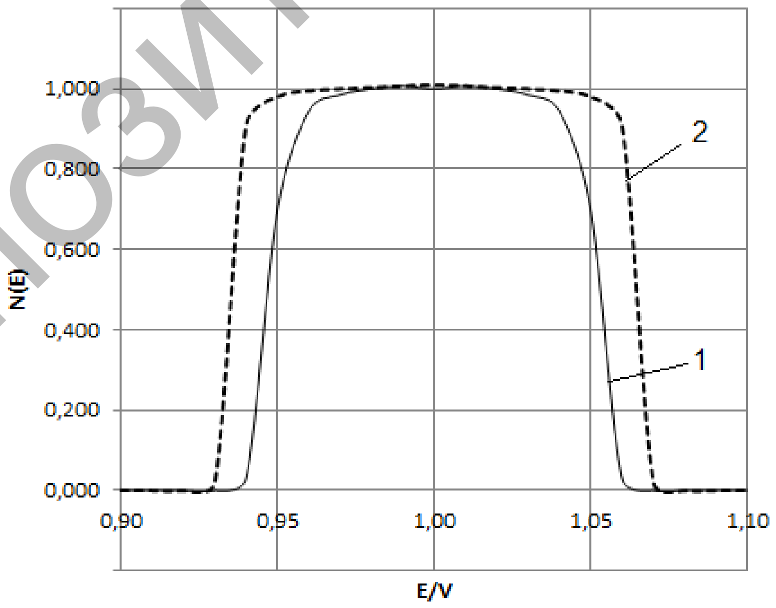

Fig.5.2. The instrumental function of analyzer with large radii of the output aperture.
The radius of the output aperture: 1 – 0.075 R_{in} ; 2 – 0.1 R_{in}

On graphics of instrumental functions for combined energy analyzer with small (R_d = 0.025

R_{in}; 0.05 R_{in}) and large (R_d = 0.075 R_{in}; 0.1 R_{in}) radii of the circular output aperture (Fig. 5.1 and 5.2) can be seen that the width at half-height increases with increasing of the output aperture radius. Fig. 6 shows the dependence of the width of the instrumental function $\Delta E_{1/2}$ at half-height from the output aperture radius. Fig. 6 shows that it is a linear relationship.

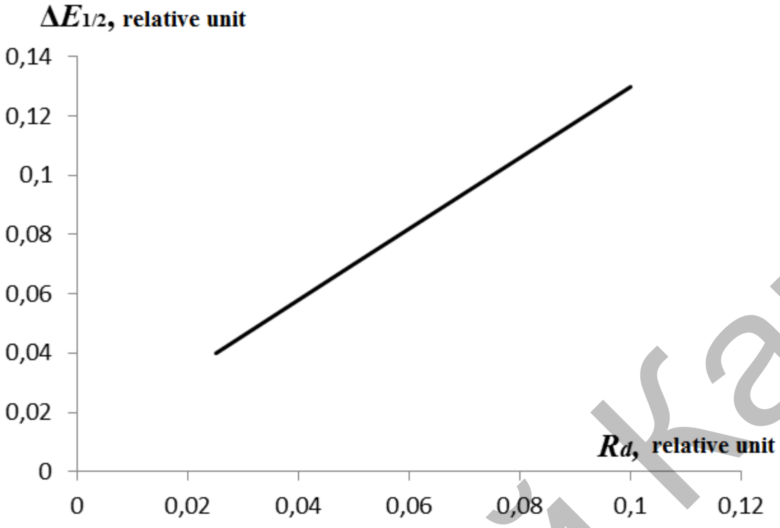

Fig.6. The dependence of the instrumental function width at half-height from the radius of the output aperture

From results of numerical calculations it was determined that the optimal radius of output aperture is R_d=0.02 R_{in}. Fig. 7 shows the instrumental function of the combined system based on electrostatic HM and CM with optimal radius of output aperture.

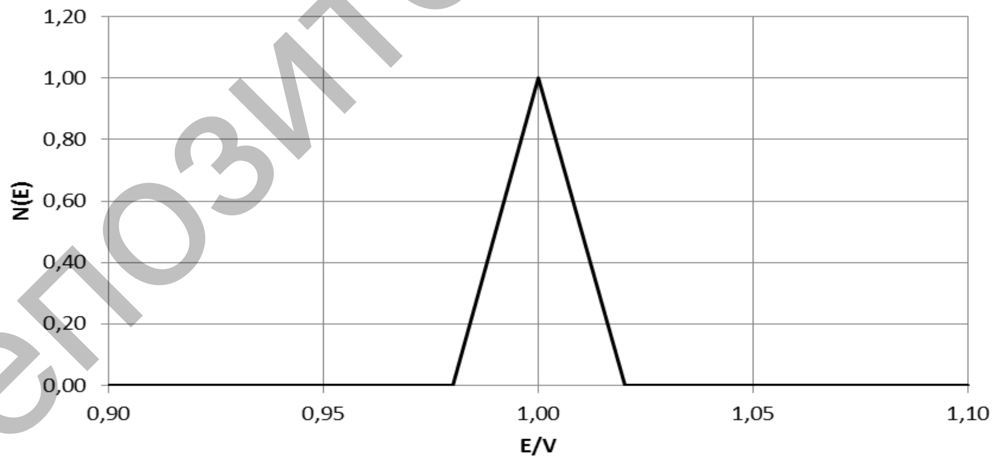

Fig. 7. The instrumental function of the combined system of successive HM and CH at optimum output aperture radius R_d = 0.02 R_{in}

Graphics of instrumental function (Fig.7) shows that the instrumental function is the combined energy analyzer at the optimal radius of the circular output aperture is a symmetrical curve close to an isosceles triangle. As it seen in Fig.7, only charged particles with energy *E/V*=1 *eV/V* pass through the output aperture and reach the detector. The aperture truncates particles of the same energy differing by 1% or more.

Thus, the relative energy resolution at half-height of instrumental function of the combined energy analyzer with optimal output aperture radius 0.02 R_{in} is 2% of the case of a point source.

Conclusion

Thereby the numerical model of the combined energy analyzer of electrostatic mirror fields has been obtained. The instrumental function of energy analyzer in the case of a point source at different radii of the circular output aperture was calculated. The dependence of instrumental function width for combined energy analyzer at half-height from the radius of the output aperture has been studied. The optimum radius of the output aperture was determined.

The spectrometer allows analyzing beams of charged particles leaving the source at an angle close to 90^0 and the instrumental energy resolutions of 2%.

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