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The electron-optical scheme of the energy analyzer of small-sized electron spectrometer

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The electron-optical scheme of the axially-symmetric electrostatic mirror-type energy analyzer of charged particles beam based on a multipole electrode system is proposed. The field of the energy analyzer is designed as a superposition of the base cylindrical field and set of circular octupole coaxial with base field. The trajectory analysis of the electron-optical system was carried out by a numerical method. Corpuscular-optical parameters of system are calculated. The "ring-ring" type third-order angular focusing scheme is found. The proposed energy analyzer has compactness and high corpuscular-optical parameters. The instrumental function of device is calculated.
Keywords: spectrometer, electron-optical scheme, energy analysis, energy analyzer.

1. Introduction

Studies of the energy distribution of charged particles are carried out in special instruments called spectrometers or energy analyzers. Since the limits of energy change in the methods of secondary electron spectroscopy lie in the range from a few keV to eV, only electrostatic systems are used as energy analyzers.

Energy analysis of charged particle beams in electric fields is the subject of many works. As a rule, the choice of electrode configurations is dictated by the ease of fabrication and evaluation of the expected electron-optical characteristics of the device. The preferred scheme of the energy-analyzing system is the variant that combines, with small masses and dimensions, both high quality focusing and energy resolution.

A brief review of the most well-known and recent works in the field of corpuscular optics shows that the proposed new types of efficient energy analyzers are built mainly on the basis of various modernization and combination of single electrostatic mirrors, as well as on the basis of new synthesized fields of non-classical type. Due to this, it seems relevant to further search for new axially-symmetric fields with broader analytical capabilities, in which the implementation of high-resolution and high-luminosity energy analysis is possible.

The discussion of the possibility of using a multipole class of fields in the synthesis of analyzing systems is justified and necessary, because it can lead to the creation of luminosity devices necessary for the implementation of highly sensitive methods for the analysis of corpuscular particle flows.

The multipole approach to the synthesis of deflecting fields was proposed by Zashkvara V.V. and Tyndyk N.N. [1, 2]. The application of this approach makes it possible to develop effective methods of energy analysis of charged particle beams. The method is based on the principle of superposition of the simplest fields of cylindrical type and circular multipoles of different order.

The schemes of electrostatic energy analyzers based on multipole-cylindrical fields were studied in sufficient detail by the authors. The subsequent papers [3–7] are devoted to the study of their focusing properties and functionality, to the search for optimal schemes with high focusing parameters and energy resolution.

The authors of the work previously carried out the calculation and analysis of equipotential portraits of electrostatic octupole-cylindrical fields for different weight contributions of the cylindrical field and circular octupole in order to determine the electrode configuration of the energy analyzer [8, 9].

In the work, axially-symmetric electrostatic mirror-type energy analyzer is proposed based on the results of numerical calculations.

2. Electron-optical scheme of energy analyzer

The potential of the electrostatic octupole-cylindrical field is described in the coordinate system *r, z* by the following expression:

$$U(r,z) = \mu \ln r + \omega U_{oct}(r,z), \tag{1}$$

Where

$$U_{oct}\left(r,z\right) = \frac{1}{4!}z^4 + \frac{1}{2}z^2\left\{\frac{1}{4}\left(1-r^2\right) + \frac{1}{2}\ln r\right\} + \frac{1}{64}r^4 + \frac{1}{16}r^2 - \frac{1}{8}\ln r\left[\frac{1}{2} + r^2\right] - \frac{5}{64}, \tag{2}$$

is circular octupole, μ is the coefficient specifying the weight contribution of the cylindrical field *lnr*, ω is the weight component of the circular octupole.

The trajectory analysis of charged particles in field of the energy analyzer was performed on the basis of a numerical calculation method by using the CAE "Focus" software for numerical simulation of electron optics systems [10].

Fig.1 presents the equipotential portrait of field based on the superposition of a cylindrical field and a circular octupole at the values of the weight contributions of a circular octupole ω = 1 and a cylindrical field μ = 2.

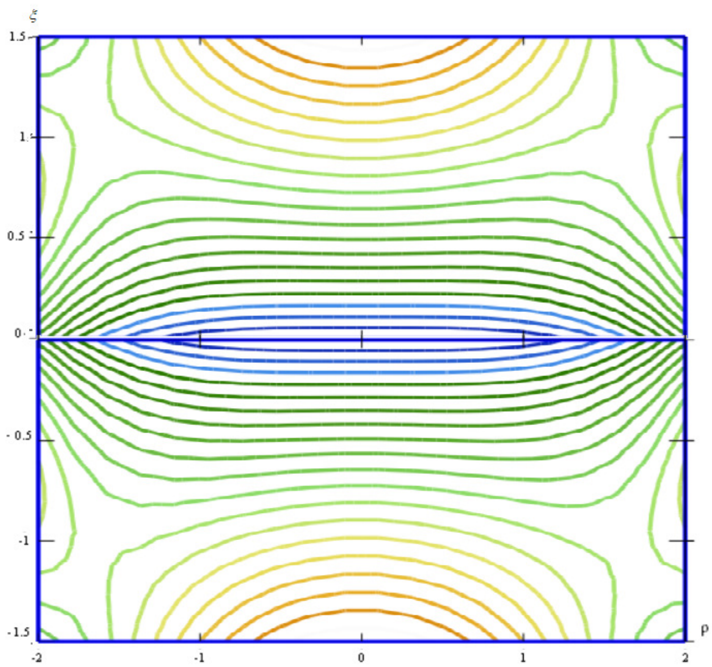

Fig.1. Equipotential field $U(r, z) = \mu\ln(r) + \omega U_{oct}(r, z)$.

Fig.2 presents the electron-optical scheme of the energy analyzer based on the octupole-cylindrical field at ω = 1 and μ =2. The energy analyzer contains two coaxial electrodes: the inner electrode *1* has a cylindrical shape of radius r_0 and is under zero potential, the outer electrode *2* has a curvilinear profile and is under the deflecting potential U_0. A field that decelerates and deflects charged particles is created between the electrodes, which have the properties of an electrostatic mirror. The profile of the outer electrode *2* repeats the equipotential surface of the electrostatic octupole-cylindrical field.

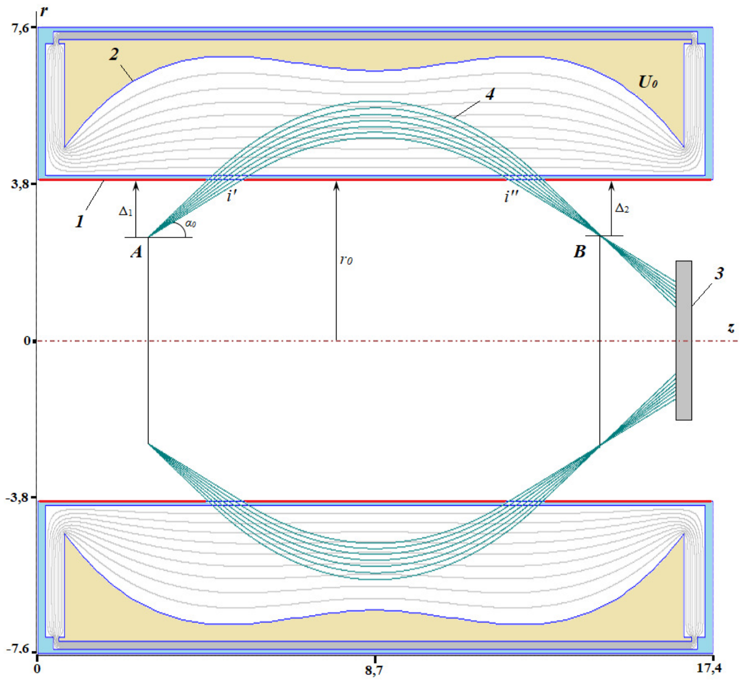

Fig.2. The electron-optical scheme of the energy analyzer: 1 – inner grounded cylindrical electrode, 2 – outer deflecting electrode, 3 – a position-sensitive detector, 4 – charged particle beam, A – ring source of charged particles, B – ring image, *i′* – entrance ring slit, *i″* – exit ring slit.

The range of initial entering angles of particles into the analyzer is 30–42°. The ratio of the kinetic energy of the charged particle to the potential of the outer electrode is E/U = 1.61E[eV]/U[V] = 1.61. The position of the source in the coordinate system is $x = 2.85$; $y = 2.5$. The potential of the outer cylindrical electrode is 1. All dimensions are expressed in conventional units.

3. Calculation results

According to the scheme, the charged particles beam from the ring source *A* enters the analyzer field through the entrance slit *i′*, is reflected by the field, then returns to the zero potential region through the exit slit *i″* and is focused into the ring image *B*. Then the particles are registered by a position-sensitive detector *3*. Due to the curvilinear profile of the outer electrode *2*, the scheme provides a sharp 3rd-order angular focusing of charged particles near 36° with a divergence angle $\Delta\alpha = \pm 6°$. Table 1 presents the results of numerical calculation of the corpuscular-optical parameters of the octupole-cylindrical energy analyzer of charged particles beam in the “ring-ring” angular focusing regime.

Table 1. Corpuscular-optical parameters of the octupole-cylindrical energy analyzer

Parameter	Values
Focusing order	3
Central angle of focusing	36°
Xfoc coordinate of the focus point	14.75°
Yfoc coordinate of the focus point	2.5°
Reflection parameter, *P*	1.0

For calculate the instrumental function of the octupole-cylindrical energy analyzer, particles are launched from a ring source in the range of initial angles of 30–42° and in the range of initial energies of 1.60–1.62. Fig.3 presents the instrumental function of the octupole-cylindrical analyzer in the the “ring-ring” type third-order angular focusing regime.

The relative energy resolution at half-height of the instrumental function of the octupole-cylindrical energy analyzer with an exit diaphragm of radius $0.012r_0$ is 0.5% at luminosity $\Omega/2\pi = 12.3\%$. The results of numerical simulation are in good agreement with the data of calculations by the approximate – analytical method.

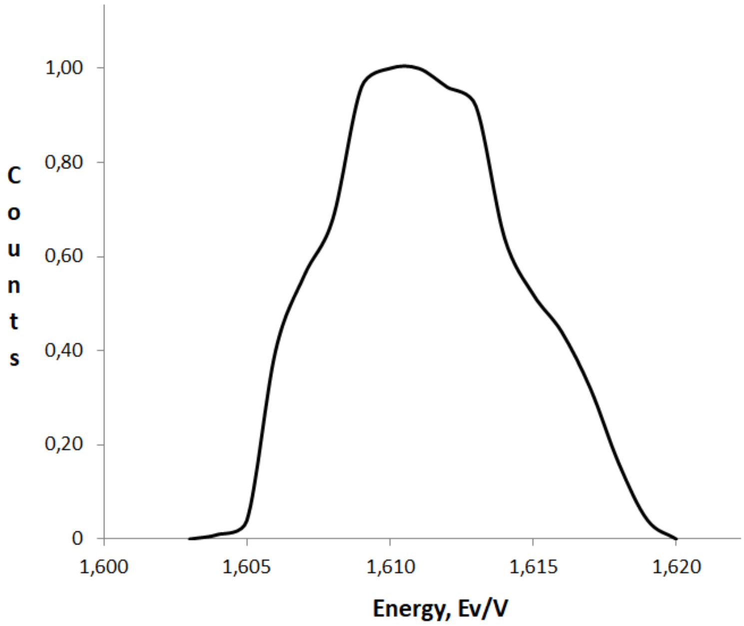

Fig.3. The instrumental function of the octupole-cylindrical energy analyzer at $\mu = 2$, $\omega = 1$ (the “ring-ring” type angular focusing regime).

4. Conclusion

The numerical model of the octupole-cylindrical energy analyzer is obtained. The corpuscular-optical properties of the electron-optical system are calculated. Angular focusing conditions are determined for particle trajectories with significant angular divergence of the beam in the axial plane. The energy analyzer is characterized by compactness, high focusing quality and energy resolution, and can be used to develop a small-sized highly sensitive electron spectrometer.

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