UDC 537.533.34

NUMERICAL MODELING OF HEXAPOLE-CYLINDRICAL ANALYZER OF CHARGED PARTICLES WITH A CONCAVE OUTER ELECTRODE

Assylbekova S.N.[1], Saulebekov A.O.[2], Kambarova Zh.T.[3]

[1]Nazarbayev Intellectual School, Astana, Kazakhstan
[2]Lomonosov Moscow State University, Kazakhstan branch, Kajimukana str. 11, Astana, 010010, Kazakhstan
[3] Ye.A. Buketov Karaganda State University, Universitetskaya Str.28, Karaganda, 100026, Kazakhstan
saulebekov@mail.ru

In work the results of numerical modeling of the long-focus electrostatic energy analyzer based on hexapole-cylindrical field with a concave outer electrode were given. Trajectory analysis of the motion of charged particles in the electron-optical scheme of energy analyzer was carried out. Electron-optical parameters of the energy analyzer were numerically calculated. Luminosity and instrumental function were calculated. The numerical calculation of the electron-optical scheme of energy analyzer was conducted by the "Focus" program for modeling of axially-symmetric systems of corpuscular optics with any electrode geometry.

Keywords: electrostatic field, hexapole-cylindrical field, energy analyzer, modeling, instrumental function, electron-optical scheme, electron-optical parameters.

Introduction

In work [1] the motion of a charged particle in the hexapole-cylindrical field (HCF) for the following contributions of cylindrical field and hexapole $\mu = 5/2$, $\gamma = -1$ was reviewed, in this case, the potential in r, z coordinate system is described by the following expression:

$$U(r,z) = \frac{5}{2} Lnr - U_h(r,z). \qquad (1)$$

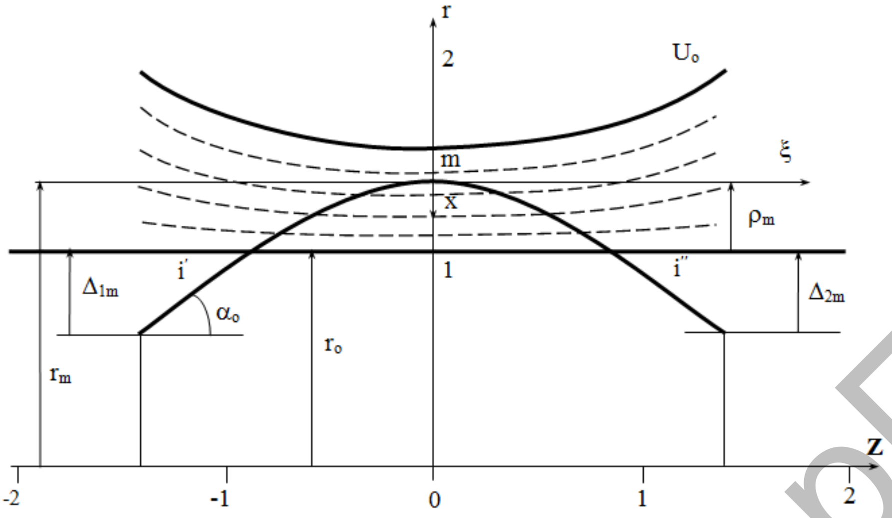
where

$$U_h(r,z) = \frac{1}{2}\left\{ Lnr\left[z^2 - \frac{1}{2}r^2 - \frac{1}{2} \right] + \frac{1}{2}r^2 - \frac{1}{2} \right\} \qquad (2)$$

- circular hexapole, μ - the coefficient defining the weight contribution of the cylindrical field $Ln\, r$, γ - weight component of circular hexapole.

Authors of work [1] studied the scheme of HCF-analyzer with $\mu = 5/2$ and $\gamma = -1$ by approximate-analytical method, where the "axis-axis" type second order angular focus is realized. This type of focusing does not provide the long focus. The scheme of energy analyzer with hexapole-cylindrical field (1) is shown in Fig.1.

Let consider the motion of particles in the axial plane of the mirror in the area from i' to i''. In regime of the mirror reflection the beam of charged particles moves along trajectories, having top **m** in the field region and previously called "return" [2]. "The return" trajectory of charged particles consists of two branches, symmetric relatively to the top **m** of the trajectory, located on the *r* axis of coordinate system *r, z*. When a certain ratio of geometric and energy parameters, the beam of charged particles exiting from the ring source A reflectes by mirror field and focuses the ring image B.



A – Source, i' - entrance ring slit, i'' - exit ring slit, B - Receiver

Fig.1. Scheme of hexapole-cylindrical energy analyzer at $\mu = 5/2$, $\gamma = -1$

The electrostatic field is formed in the space between the two axially-symmetric coaxial electrodes, where inner electrod has cylindrical shape (radius r_o) and is located at ground potential; the profile of external electrode repeats equipotentials of field and is under deflecting potential U_o. The profile of external electrode is defined on the basis of calculation of equipotential lines in the hexapole-cylindrical field by the MathCAD program (Fig.2).

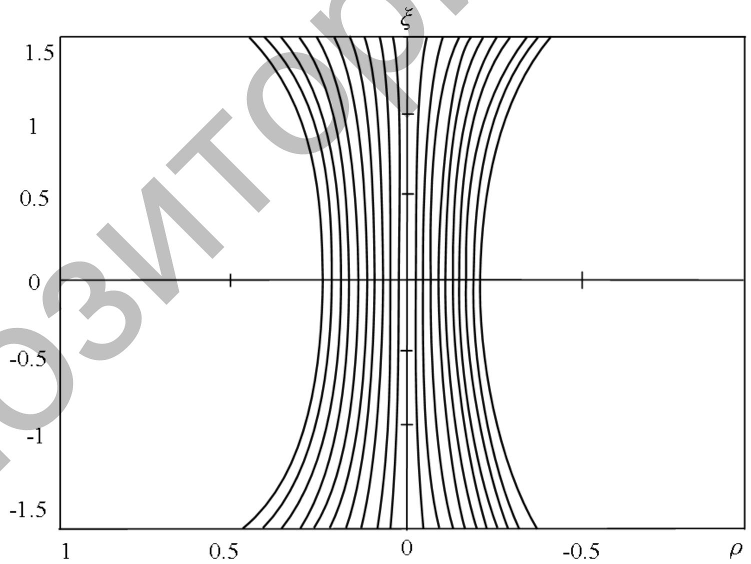


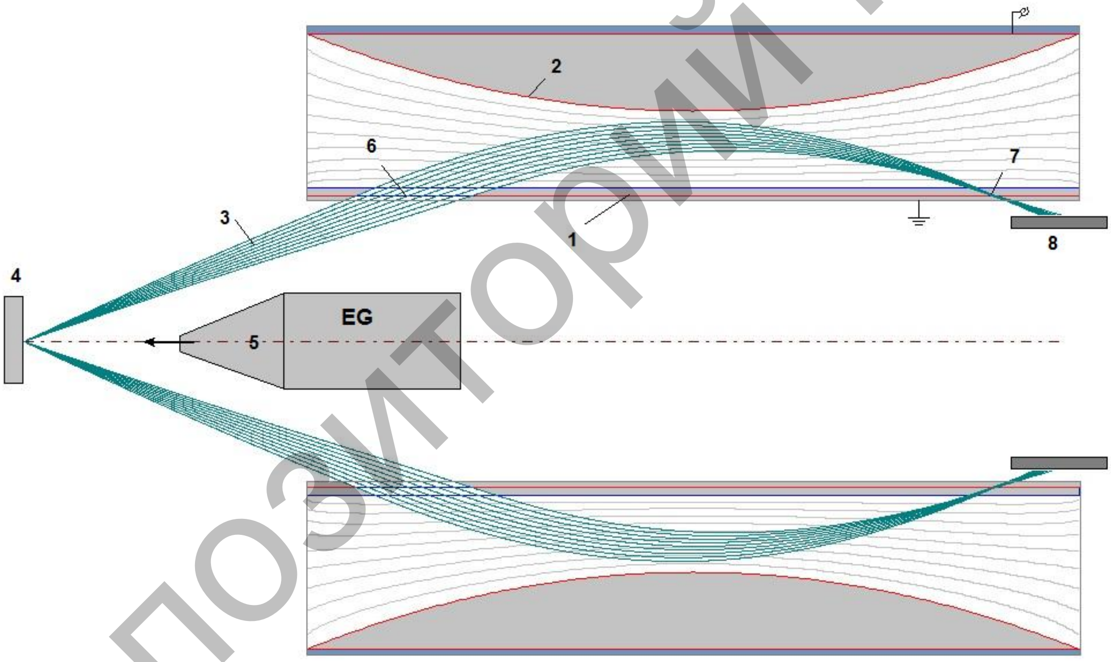
Fig.2. Equipotential lines corresponding to the superposition of hexapole and cylindrical field $U(\rho,\xi)=\frac{5}{2}\ln(1+\rho)-U_h(\rho,\xi)$

Numerical calculation of electron-optical parameters of the energy analyzer

In this work the numerical modeling of electron-optical scheme of energy analyzer based on hexapole-cylindrical field with external electrode with concave profile at the $\mu = 5/2$, $\gamma = -1$ is carried out by the program "Focus" for modeling of axially-symmetric systems of corpuscular optics with any electrode geometry. "Focus" numerical program allows to graphically regime input and modification of design, calculate the potential distribution in the select area and conduct trajectory analysis of system [3].

Fig.3 shows the course of the trajectories of charged particles in electron-optical system. A point source located from the system Z = - 1 on the symmetry axis. Particles emerge from the point source in interval of polar angles from 30^0 to 38^0 and go to the detector under the potential effect of the external concave electrode. "Axis-ring" type focusing is performed in the system. The ratio of the energy of the charged particle to the potential of the electrode E/V = 1,8. The position source is x = 0; y = 0. Step of angle changes was 1^0. The total length of the electron-optical system is 4. The potential of the outer electrode with a curved profile is 1. The radius of the inner cylindrical electrode is 1. The inner cylindrical electrode is under zero potential. Electrodes are selected transparent in the place of the charged particles transmission. Entrance and exit slits in the analyzer tightened fine-grained metal grids, only diffusing beam in azimuth. All sizes are expressed in relative units.

The secondary electrons (3) exciting from investigated sample (4) by the primary radiation (5) (electrons), through a special entrance window (6) in the inner cylinder tightening by dimensional grid, enter in the HCF and its motion deflecting to the cylinder axis are focused on the surface of the cylindrical electrode. The electrons which passed through the grid of the exit window (7) in the inner cylinder (1) are registered by the detector (8). In the scheme "axis-ring" type second-order angular focusing is performed.



1 - cylindrical electrode, 2 - external concave electrode, 3 - secondary electrons, 4 - investigated sample, 5 - the primary electrons, 6 and 7 - the entrance and exit slits, 8 – detector, EG - electron gun

Fig.3. Electron-optical scheme of long-focus HCF - analyzer at the $\mu = 5/2$ and $\gamma = -1$, providing "axis-ring" type angular focusing mode

For calculate the instrumental function of electron-optical scheme of HCF for the case of the "axis - ring" type angular focusing, particles start from a point source in a range of initial angles in of 30^0-38^0 and in a range of initial energy (or rather E / V) 1,782-1,818, where V - the maximum capacity. A step change of the angle in the calculation of the instrumental function is 0.5^0. Fig.4 shows the instrumental function of the electron-optical scheme of long focus HCF-analyzer for the "axis-ring" type second order angular focusing. Relative energy resolution at half-instrumental function of HCF- analyzer with a radius of the output aperture 0.026 R_{in} is 1.1% in the luminosity $\Omega/2\pi$=8 %.

Table 1 shows the results of calculations of electron-optical parameters of HFC- analyzer.

High luminosity, high energy resolution, long distance sample – analyzer and relatively easy implementation of the calculation of the external electrode with curvilinear profile are important characteristics of the developed energy analyzer.

Note the advantage of the hexapole-cylindrical analyzers. Classical cylindrical mirror analyzer [4] basically can not provide a long focus. In recent decades, it was proposed several new designs of axial-symmetrical energy analyzers, alternative to cylindrical mirror. Quasiconical energy analyzer [5], in spite of some of its obvious advantages (much better energy resolution than the cylindrical mirror) has a very small distance "sample-analyzer." In the plant process its application is limited. Allow this problem is possible on the basis of the proposed electrostatic hexapole-cylindrical field, as proposed in [6].

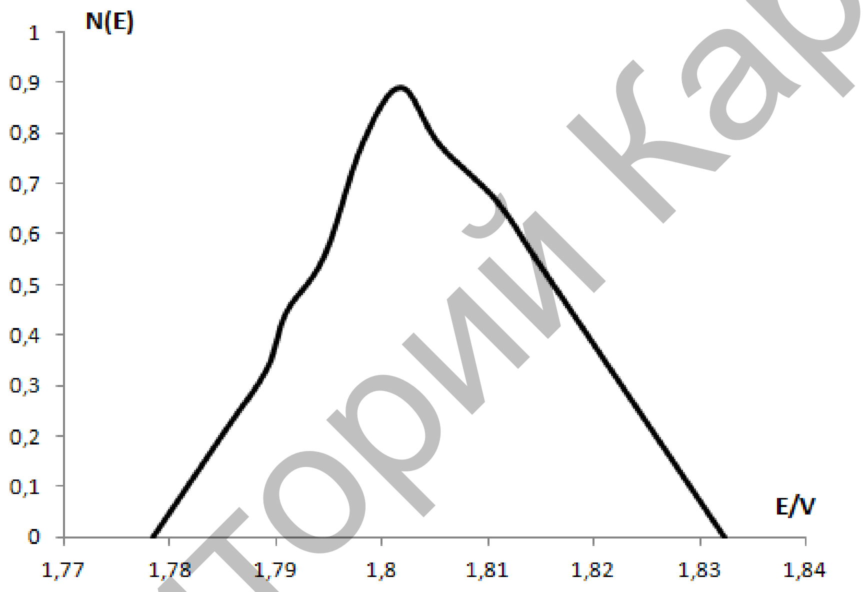


Fig. 4. Instrumental function of HCF-analyzer

Table 1. The electron-optical parameters of HCF-analyzer

Focusing type	"Axis-ring"
Focusing order	2
Central angle of focusing	37^0
X coordinate of the focusing	3,82
Y coordinate of the focusing	0,9
Reflection parameter	1,0

Conclusion

The numerical model of the electron-optical scheme of hexapole-cylindrical energy analyzer with a shape concave of outer electrode was obtained. Instrumental function of energy analyzer was calculated. The electron-optical parameters of HCF - analyzer for "axis-ring" type second-order angular focusing were determined. It was established that on the basis of hexapole-cylindrical field can be built with long-focus mirror luminosity energy analyzers with second-order focusing.

Proposed long focus mirror analyzer based on HCF due to the possibility of sharp focusing broad beams of charged particles has a significant advantage in resolving ability compared with the existing similar electron mirrors.

REFERENCES

1. Ashimbaeva B.U., Chokin K.Sh,. Saulebekov A.O. Calculation and analysis of the electron-optical characteristics of the electrostatic hexapole-cylindrical field. *Izvestiya NAN RK, Physics -mat. series* (in Russian), 2003, V.3, No. 6 , pp. 48-54.
2. Zashkvara V.V., Ashimbaeva B.U., Chokin K.Sh. Calculation of trajectories in a multipole cylindrical field. *Journal of Electron Spectroscopy and Related Phenomena*, 2002. V.122, pp.195-202.
3. Trubitcyn A.A. The program "Focus" modeling of axially-symmetric electron-optical systems: algorithms and characteristics. *Prikladnaya fizika (in Russian)*, 2008, No. 2, pp.56-61.
4. Zashkvara V.V., Korsunskii M.I., Kosmachev O.S. Focusing properties of electrostatic mirror with a cylindrical field. *Zhurnal tekhnicheskoi fiziki (in Russian),* 1966, V. 36, No.1, pp. 132-138.
5. K. Siegbahn, N. Kholine, G. Golikov. A high resolution and large transmission electron spectrometer. *Nuclear Instruments & Methods in Physics Research*, **1997,** A 384, pp**. 563-574.**
6. Trubitcyn A.A., Tolstoguzov A.B., Saulebekov A.O., Suvorov D.V., Tarabrin D.Yu., Kambarova Zh.T., Kuksa P.I. Design long focal length Auger-microanalyzer. Vestnik of RSREU. Ryazan (in Russian), 2012, V.42, No. 4 (1), pp.54-59.

Article accepted for publication 25.05.2015