РАДИОФИЗИКА ЖӘНЕ ЭЛЕКТРОНИКА
РАДИОФИЗИКА И ЭЛЕКТРОНИКА
RADIOPHYSICS AND ELECTRONICS

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Calculation of the structure of electrostatic quadrupole-cylindrical fields

The paper is devoted to the investigation of electrostatic quadrupole-cylindrical fields. Calculation of the structure of electrostatic quadrupole-cylindrical fields, synthesized on the basis of the sum of the base cylindrical field and axially symmetric cylindrical quadrupoles of various types, is carried out. Equipotential portraits of quadrupole-cylindrical fields of various types are presented. The analysis of obtained equipotential portraits of quadrupole-cylindrical fields is carried out. Variants of their application in corpuscular optics are discussed. The addition of components of the axially symmetric cylindrical quadrupole to the base cylindrical field selectively affects corpuscular-optical parameters of the energy analyzer, and variants of the schemes of mirror analyzers with improved quality of angular focusing can be found.

Keywords: electrostatic field, quadrupole-cylindrical field, potential of electrostatic field, equipotential portraits, energy analyzer.

Leading modern technologies and, first of all, nanotechnologies are determined by phenomena occurring on the surface. Properties of nanoscale structures, various kinds of nanomaterials, in which the surface plays an important role, are of increasing interest. At present, the investigation the solid surface is a developing field of knowledge that is of great importance for the physics of nanoscale and molecular structures, modern materials science, nano- and microelectronics, nanotechnology, condensed matter physics and chemistry, physics of thin films, etc.

Modern nanoelectronics requires the development of research methods that allow to determine the structure and composition of nanoobjects and nanosystems. A promising base for the required diagnostics are methods of electron spectroscopy [1], which are characterized by a nanometer resolution in the depth of a solid. The depth of the analysis in methods of electron spectroscopy is 0.5-2 nm.

The implementation of methods of electron spectroscopy is based on the use of complex equipment, one of main elements of which is a dispersive energy analyzer of low- and medium-energy electrons. Actual problems of modern spectral analysis are problems that must be solved in conditions of increased growth of requirements to the sensitivity of the providing device, its resolution ability, compactness, and the need for spatial combination of several research methods. Further progress of modern technologies, as well as the development of nanotechnology is largely determined by the state of diagnostic tools. Thus, the energy analysis of charged particle beams requires further improvement of existing or the development of qualitatively new corpuscular-optical systems by further development of the theory.

The most common cylindrical mirror analyzer, characterized by simplicity of implementation, along with high luminosity and satisfactory resolution, has only a radial potential gradient [2]. For improve the energy resolution, it is necessary to introduce the axially potential gradient, which was done, for example, by Wannberg [3]. The purpose of his work was calculation and justification of the analyzer operating in the spectrograph mode, since it is known that this mode is not possible for the cylindrical mirror.

Thus, one of serious problems in the development of dispersive systems for the energy analysis of charged particle beams is the determination of the deflecting field and calculation of the shape of deflecting electrodes of deflector. The search and selection of electrode configurations of the device is dictated by the simplicity of its manufacture and the possibility of high quality energy analysis.

New method of synthesizing axially symmetric Laplace multipole-cylindrical fields of practical interest for solving the problem of energy analysis of charged particle beams was first proposed in [4,5]. This method is based on the principle of superposition of simplest fields of cylindrical type and circular multipoles of various orders

$$U(r,z) = \mu \ln r + U_m(r,z), \qquad (1)$$

where μ — is coefficient determining the weight contribution of the cylindrical field; $U_m(r,z)$ — is circular multipole.

Addition of components of various order multipoles [6] (quadrupole, hexapole, sextupole, etc.) to the base cylindrical field leads to the synthesis of a wide class of various axially symmetric fields, among which variants of schemes of mirror analyzers with improved quality of the angular focusing can be found.

The article [7] is devoted to primarily to aspects of evolution of a new class of electrostatic quasi-conical energy analyzers of electron and ion beams. The potential of the difference field in the quasi conical energy analyzer is described by the following formula:

$$U = \ln r - \frac{r^2}{2} + z^2. \qquad (2)$$

The field of the quasi conical energy analyzer is close to quadrupole-cylindrical and hexapole-cylindrical fields. «Portraits» of hexapole-cylindrical fields, methods for calculation of charged particles trajectories and parameters of energy analyzers based on these fields are described in the monograph [2].

The «portrait» of the field in the quasi conical analyzer has a rather complex form, equation reference goes hereand the field structure is inhomogeneous along the symmetry axis.

Calculation of the structure of electrostatic quadrupole-cylindrical fields synthesized on the basis of the sum of the base cylindrical field $\mu \ln r$ and axially symmetric cylindrical quadrupoles $U_q(r,z)$ of various types was performed:

$$U_q(r,z) = U_0\left[\mu \ln r + (r-1)z\right]; \qquad (3)$$

$$U_q(r,z) = U_0\left[\mu \ln r + \frac{1}{2}\left(z^2 - (r-1)^2\right)\right]; \qquad (4)$$

$$U_q(r,z) = U_0\left\{\mu \ln r + \frac{1}{2}z^2 + \frac{1}{4}\left[1-r^2\right] + \frac{1}{2}\ln r\right\}; \qquad (5)$$

$$U_q(r,\mathrm{z}) = U_0\left(\mu + z\right)\ln r. \qquad (6)$$

Adding $\mu \ln r$ fields and quadrupoles $U_q(r,z)$, we can easily determine equipotential equations that determine the structure of the field and profiles of deflecting electrodes of mirror analyzers.

Figure 1-4 show equipotential portraits of electrostatic quadrupole-cylindrical fields.

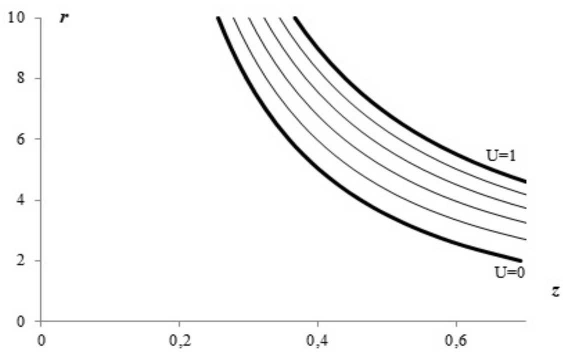

Figure 1. Equipotential portrait of the quadrupole-cylindrical field (3)
$U_q(r,z) = U_0\left[\mu \ln r + (r-1)z\right]$ at $\mu = 1$

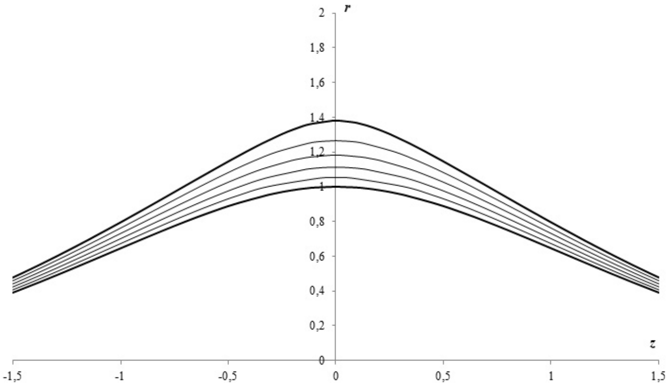

Figure 2. Equipotential portrait of the quadrupole-cylindrical field (4)

$$U_q(r,z) = U_0\left[\mu \ln r + \frac{1}{2}\left(z^2 - (r-1)^2\right)\right] \text{ at } \mu = 1$$

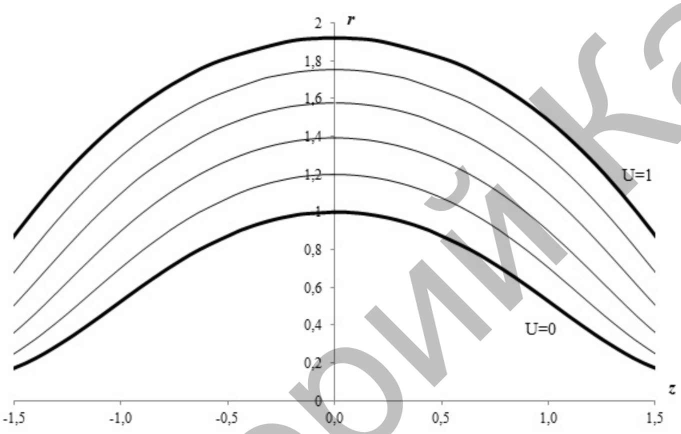

Figure 3. Equipotential portrait of the quadrupole-cylindrical field (5)

$$U_q(r,z) = U_0\left\{\mu \ln r + \frac{1}{2}z^2 + \frac{1}{4}\left[1 - r^2\right] + \frac{1}{2}\ln r\right\} \text{ at } \mu = 1$$

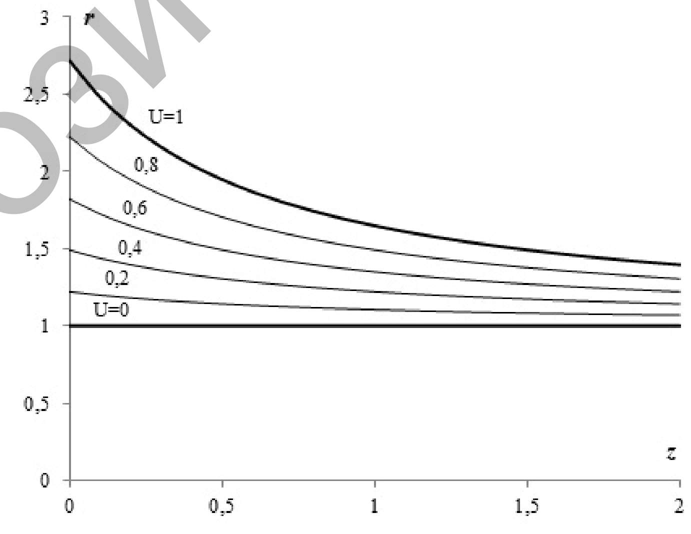

Figure 4. Equipotential portrait of the quadrupole-cylindrical field (6)

$$U_q(r,z) = U_0\left(\mu + z\right)\ln r \text{ at } \mu = 1$$

From calculations of equipotential distributions of quadrupole-cylindrical fields it is established that for fields of (4) and (5) forms generators of both inner and outer electrodes have a curved line shape. The basic trajectory of particle motion in such fields is not described by an elementary function, an analytical solution of differential equations of motion is very difficult, and in this case numerical methods of integration are preferable.

In the mirror with quadrupole-cylindrical field (3) the inner electrode has a cylindrical shape. However, the great steepness of the generator of the outer electrode, inherent in this field, makes the task of practical implementation of such a scheme difficult and unnecessary.

Electron mirror with quadrupole-cylindrical field (6), whose inner electrode has cylindrical shape, is more accessible for an analytical investigation of its electron-optical properties and for the construction of a high luminosity energy analyzer on its basis.

It should be noted that the quadrupole-cylindrical field (6) at the value of $\mu = 1$ coincides with the well-known Wannberg field proposed for the development of a device operating in the spectrograph mode [3]

$$U(r,z) = \frac{U_o}{\ln r_1/r_o}(1+Az)\ln r/r_o, \qquad (6)$$

where A is small dimensionless parameter.

Figure 5 shows the equipotential portrait of the Wannberg field $U(r,z) = U_0(1+Az)\ln r$ at A=0,034.

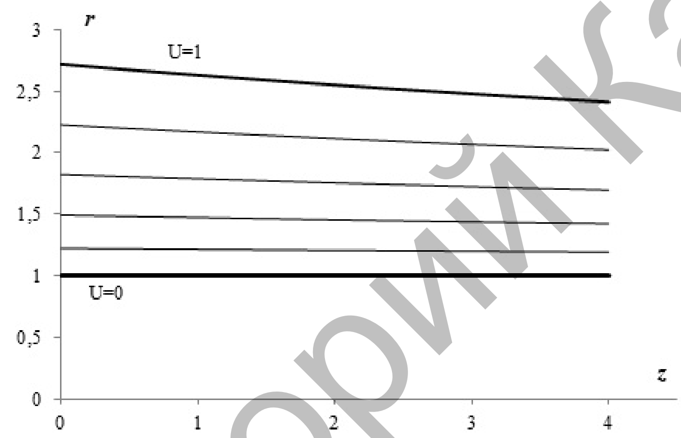

Figure 5. Equipotential portrait of the Wannberg field
$U(r,z) = U_0(1+Az)\ln r$ at A=0,034

The field is formed in the space between two axially symmetric coaxial electrodes, the inner of which has a cylindrical shape (with radius r_o) and is located under the Earth potential, and outer electrode having a curvilinear profile $r = r_o \exp\left[\frac{\ln(r_1/r_o)}{(1+Az)}\right]$ under the deflecting potential U_0 (Fig. 6).

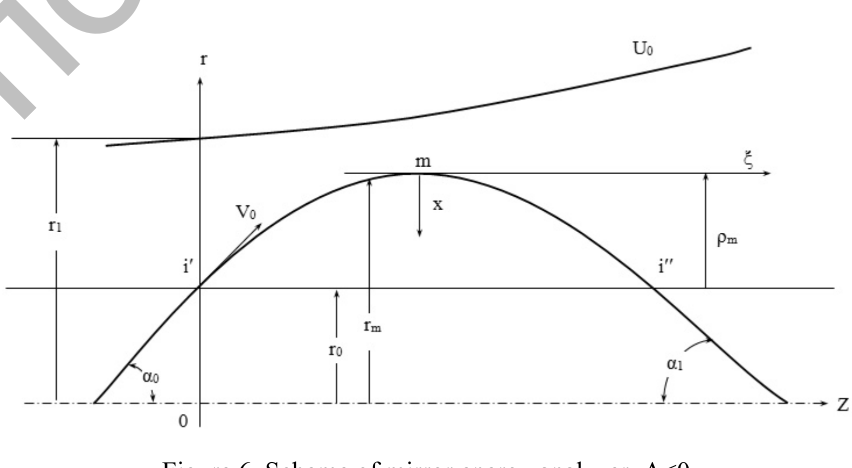

Figure 6. Scheme of mirror energy analyzer, A<0

The presence of a small parameter A gives an additional degree of freedom in the selection of the required distribution of the electrostatic field and expands the possibility of finding the most optimal scheme of the analyzer on the basis of the quadrupole-cylindrical fields.

Thus, calculation of the structure of electrostatic quadrupole-cylindrical fields is performed. Graphic visualization of equipotential portraits of quadrupole-cylindrical fields of various types is given. From the analysis of equipotential portraits of quadrupole-cylindrical fields, it is established that schemes with a field distribution $U_q(r,z)=U_0(\mu+z)\ln r$ in which the inner electrode with zero potential has a cylindrical shape belong to most convenient variants for the practical realization of quadrupole-cylindrical mirrors.

Further calculations will be directed to the investigation of electron-optical properties of quadrupole-cylindrical mirror analyzers.

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Электрстатикалық квадрупольді-цилиндрлік өрістердің құрылымын есептеу

Мақала электрстатикалық квадрупольді-цилиндрлік өрістерді зерттеуге арналған. Базалық цилиндрлік өріс және әр түрлі өстік симметриялы цилиндрлік квадрупольдердің қосындысы негізінде синтезделген электрстатикалық квадрупольді-цилиндрлік өрістердің құрылымы есептелген. Әр түрлі квадрупольді-цилиндрлік өрістердің эквипотенциалдық суреттері келтірілген. Квадрупольді-цилиндрлік өрістердің алынған эквипотенциалдық суреттеріне талдау жүргізілген. Олардың корпускулалық оптикада қолдану нұсқалары талқыланған. Базалық цилиндрлік өріске өстік симметриялы цилиндрлік квадрупольдің құраушыларын қосу энергия талдағыштың корпускулалы-оптикалық параметрлеріне таңдамалы әсер етіп, бұрыштық тоғыстаудың жақсартылған сапасына ие болатын айналық талдағыштардың сұлбалар нұсқаларын анықтауға мүмкіндік береді.

Кілт сөздер: электрстатикалық өріс, квадрупольді-цилиндрлік өріс, электрстатикалық өрістің потенциалы, эквипотенциалдық сурет, энергия талдағыш.

Ж.Т. Камбарова, А.О. Саулебеков

Расчет структуры электростатических квадрупольно-цилиндрических полей

Статья посвящена исследованию электростатических квадрупольно-цилиндрических полей. Проведен расчет структуры электростатических квадрупольно-цилиндрических полей, синтезированных на основе суммы базового цилиндрического поля и осесимметричных цилиндрических квадруполей различного вида. Представлены эквипотенциальные портреты квадрупольно-цилиндрических полей различного вида. Проведен анализ полученных эквипотенциальных портретов квадрупольно-цилиндрических полей. Обсуждены варианты их применения в корпускулярной оптике. Подключение компонентов осесимметричного цилиндрического квадруполя к базовому цилиндрическому полю избирательно влияет на корпускулярно-оптические параметры энергоанализатора, и могут быть найдены варианты схем зеркальных анализаторов с улучшенным качеством угловой фокусировки.

Ключевые слова: электростатическое поле, квадрупольно-цилиндрическое поле, потенциал электростатического поля, эквипотенциальные портреты, энергоанализатор.

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