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ANALYZERS OF THE CHARGED PARTICLES FLUXES WITH THE HEXAPOLE CYLINDRICAL FIELD

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The corpuscular-optical parameters of the mirror analyzers based on hexapole-cylindrical field were determined by the approximate analytical method of the charged particles' trajectories calculation. The analysis of the characteristics of the systems with different contributions of cylindrical field and hexapole is given. Amidst the schemes, calculated earlier, there was selected one system which is more optimal by its parameters.

Keywords: hexapole cylindrical mirror analyzer, focusing, dispersion on energy.

Introduction

The cylindrical mirror analyzer (CMA) was widespread and became the basic device for many firms, manufacturing the physical analytical apparatuses. The CMA was studied in detail, and the further improvements of its electron optical parameters without additional changes it is not possible. The analyze of the energy analyzers of the charged particles beams with using of cylindrical field, from our point of view, lets to identify three tendencies. Firstly, it is usage of the supplemental elements - for example a spherical mirror in combination with cylindrical one. It was allowed to improve energy analyzers parameters greatly, and to wide its functional abilities, for example, to shift in the regime of spectrograph [1]. Secondary, the inputting of the third additional cylindrical electrode and turning to the multicascade operation regime also allows obtaining the good results [2]. Thirdly, it is a change of a one of cylindrical mirror electrode's shape with preserving of system's axial symmetry [3]. In the present work this approach was applied.

2. Analyze of the hexapole cylindrical analyzers electron optical parameters

The approximately-analytical method of the charged particles trajectories calculation was used to determine the corpuscular-optical parameters of the mirrors analyzers based on an hexapole-cylindrical field (HCF) [4]. In this case the potential of HCF in the coordinate system r, z is described by the expression

$$U(r,z) = \mu \ln r + \gamma U_h(r,z)\,. \qquad (1)$$

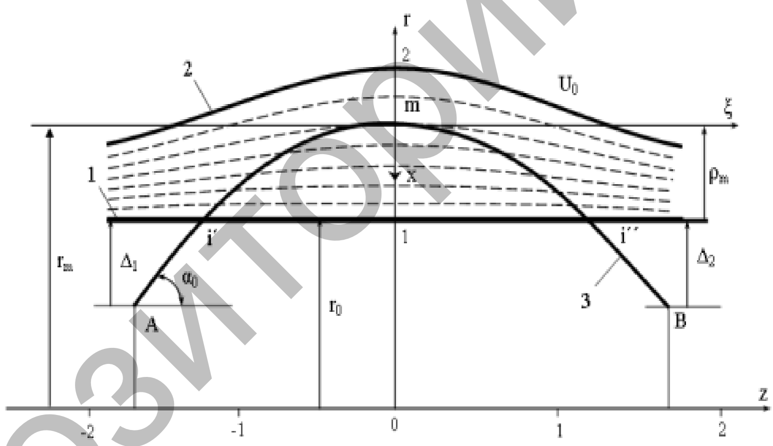
Variation of the coefficients μ and γ leads to unlimited variety of the HCF distribution. Analyzes of the equipotential families of these fields allowed choosing the schemes, those are convenient from the practical point of view. The electron-optical schemes of analyzers, built on the base of such HCF [4-8], can be divided into three groups. The principal schemes are given in fig.1(a, b, c), where A - a source, B - a receiver, 1 - an inner cylindrical electrode, 2 - an outer electrode of curvilinear profile, having the potential U_0 of the same sign as that of a particle, and coinciding with an equipotential line of the field, 3 - a trajectory of the charged particles.

To analyze the characteristics of the electrostatic mirror analyzers with HCF the spatial aberration coefficients of the first, second, and third orders were calculated. Then, the values of relative linear dispersion, specific dispersion on energy, and aberration spreading of image in the mirror's focus were found. The conditions of the angular focusing of the second order, and for the some schemes also for higher order, have been determined.

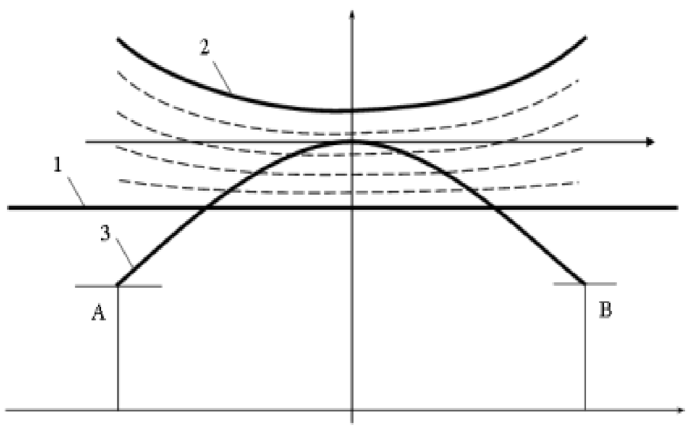
The analyses of characteristics showed that in the mirror analyzers with convex profile of the outer electrode (fig.1a) the regime of the second order angular focusing in the wide range of entrance angles change is realized. In this case the source and its image are located in the area of inner cylindrical electrode (focusing "ring-ring"). The spatial aberrations of the third order are small, therefore the focusing of the wide charge particles beams, having the initial angle of divergence up to 16^0 is possible [4]. The schemes of analyzers with HCF, resolution ability of those is 3-5 times as greater as one of the widely known cylindrical mirror analyzer (CMA) [9] have been constructed. Decreasing of the cylindrical contribution μ leads to improving of the device analytical characteristics. For one of the schemes of analyzers [5] the specific dispersion on energy, characterizing resolution ability of the device, is about 6 times as greater as the specific dispersion of CMA.

As one of the optimal constructions for energy analyses, the scheme with the third order angular focusing has been chosen. In that scheme the longitudinal aberration spreading of image in a focus of the offered device is much less as one of CMA [6].

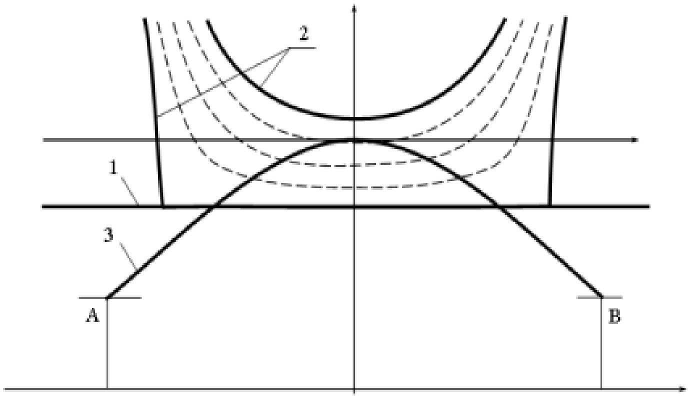
In the HCF analyzers with outer curvilinear electrode of concave profile (fig.1b), as well as in the analyzers of the first type the regime of the second order angular focusing is realized. A source and its image are also in the area of the inner cylindrical electrode [7]. However, the analytical characteristics of the energy analyzers with such distribution of HCF are worse than those of CMA.



a)



b)



c)

Fig.1. Schemes of analyzers with HCF.

The basic advantage of the HCF analyzer, given in fig.1c [8], is the presence of two face electrodes. They as well as the inner cylindrical electrode are at zero potential. The face electrodes limit the longitudinal dimensions of the analyzer, and allow to minimize influence of the edge fields on retarding field distributions in the region of passing of the analyzed particles trajectory. From the analyses of focusing conditions it has been found that in this case the schemes of the second order angular focusing “ring-axis” and “axis-axis” are possible to be realized. The more optimal scheme of the second order angular focusing, in which the face electrodes can be approximated by a conical surface at the small deflection from the radial plane of the analyzer [8] have been determined.

In the result of calculations and analyses of the hexapole cylindrical mirror energy analyzers with different relations of summands of the cylindrical field and circular hexapole was found the tendency of focusing properties improvement at cylindrical field contribution decreasing. In the schemes with less contribution of the cylindrical field the cubic angular aberration decreases. It has been found a scheme of hexapole cylindrical mirror energy analyzer where the regime of the third order angular focusing is realized [6].

3. The electron optical properties of the hexapole cylindrical analyzer at μ=1

Let’s consider the scheme [10], which has the minimal contribution of the cylindrical field μ=1. To analyze the characteristics of electrostatic hexapole cylindrical field energy analyzer the coefficients of the spatial focusing of the first, second and third orders have been calculated: $A_I = \frac{dl}{d\alpha}$, $A_{II} = \frac{1}{2!}\frac{d^2 l}{d\alpha^2}$, $A_{III} = \frac{1}{3!}\frac{d^3 l}{d\alpha^3}$. The conditions of the second order focusing have been determined as $\frac{dl}{d\alpha} = \frac{d^2 l}{d\alpha^2} = 0$.

The calculated basic electron-optical parameters of analyzer in dependence on the parameter of reflection $P = \sqrt{\frac{mV_0^2}{2qU_0}}\sin\alpha_0$ (m, V_0 и q – mass, velocity and charge of particles) and on the angle of trajectory entering α_o at the condition of the second order angular focusing are given in the table [10]. They are the next parameters: $\Delta = \Delta_1 + \Delta_2$ (fig.1a); ρ_m - a coordinate of trajectory turning point; ξ_m - a half of projection of trajectory on the axis of symmetry in the field of mirrors; l - a focus length, equaled to the total projection of the trajectory on the mirror’s axis of symmetry from a source to its mage, satisfying the condition of the focusing; and $D = \frac{\partial l}{\partial \varepsilon}$ - the relative linear dispersion on energy, defining by differentiation of the total trajectory projection onto symmetry axis from the source to its image on the value of energy divergence in the particles beams $\varepsilon = \frac{\Delta\omega}{\omega}$; $A_{III} = \frac{1}{3!}\frac{d^3 l}{d\alpha^3}$ - the coefficient of cubic angular aberration.

Analyses of the table data show that in the offered mirror energy analyzer the second order angular focusing regime is realized in the wide range of values of P and αo parameters. In this case, a source and its image are in the region of the inner cylindrical electrode. It means that the condition of the angular focusing is performed only for the schemes of charged particles focusing from the ring source to the ring detector ($\Delta_1 + \Delta_2 < 1$). The only one scheme of hexapole cylindrical analyzer, focusing on the scheme "ring-axis" with the parameters P=0.7045, α_o=44.86, $\Delta_1 + \Delta_2 = 1$ is out of the practical interest. For this scheme the coefficient of cubic angular aberration, corresponding to aberration of the device is very great A_{III} ~ 33.16.

The more optimal mirror analyzers with HCF according to the electron-optical characteristics are realized in the range 0.52 < *P* < 0.64, where the aberration coefficients of the third order are not great. Two schemes with the parameters P=0.5754, α_o=40.97660 and *P*=0.6242, α_o=46.50650, providing the conditions of the third order angular focusing $\frac{dl}{d\alpha} = \frac{d^2 l}{d\alpha^2} = \frac{d^3 l}{d\alpha^3} = 0$ have been found. However, the scheme of the hexapole cylindrical analyzer, with the parameters *P*=0.60, α_o=43.74200, D=1.7967, A_{III}=0.7340 is in a great interest. In this scheme the cubic aberration A_{III} is not equal to zero, but it is small and at the same time it has maximum in the range of parameter of reflection 0.52<P<0.64. It means that the coefficient of spatial aberration of the next order A_{IV} at this point is zero. It allows concluding that the analyzer angular focusing is closed to ideal.

The scheme of the hexapole cylindrical analyzer, corresponding to the regime of angular focusing, closed to the ideal one, is related to the first group, shown in fig.1a. An angle of entrance to the mirror field axial trajectory is equal to α_o=43.742, and the initial angular divergence for trajectories' sides branches is 16^0 ($\Delta\alpha = \pm 8^0$).

An image spreading at a focus of mirror energy analyzer due to the angular divergence 16^0 in the axial plane is defined by the cubic aberration $\Delta l = A_{III}(\Delta\alpha)^3$ [9] and equal to $\Delta l = 0.004$.

All this means that the energy analyzer with HCF enables to provide sharp focusing of the charged particles with great angular divergence in the axial plane. For comparison, the width of particles beam image line of the same angular divergence in CMA is about 20 times as great and equals to $\Delta l =$ 0.084.

If the ring slits A and B are narrow, and the angular divergence of beam is great, that a measure of analyzer resolution ability can be value of specific dispersion on energy. It equals to ratio of linear dispersion on energy to width of image line at a mirror's focus

$$\delta = \frac{D}{\Delta l} = \frac{D}{A_{III}(\Delta\alpha)^3}. \qquad (2)$$

The magnitude of specific dispersion on energy of hexapole cylindrical analyzer for the particles with initial angular divergence 16^0 equal to δ =449.68. It is about 7 times as greater as the specific dispersion of CMA.

4. Conclusions

The electron-optical parameters of mirror energy analyzers, based on electrostatic HCF, have been calculated. The conditions of angular focusing for the particles trajectory with great angular divergence of beam in the axial plane have been determined. It was established that on the base of hexapole cylindrical fields the energy analyzers of high luminosity with the second and third orders angular focusing may be constructed, if a source and its image are in the region of inner cylindrical electrode.

The electron-optical characteristics of hexapole cylindrical mirror analyzer having angular focusing, closed to the ideal one, that provides working regime at the condition of high resolution and high luminosity have been found.

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