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To cite this article: A O Saulebekov *et al* 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **110** 012005

Conversion of the electrostatic energy analyzer of charged particles into double spectrograph regime in energy and angle

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Abstract. The possibility to convert the combined electrostatic energy analyzer of charged particles into double spectrograph regime in energy and angle has been studied. The analyzer consists of the hyperbolic and cylindrical mirrors. The correlation, expressing condition of the first-order focal line straightening of the particles beams of various energies, has been obtained. The possibility of simultaneous registration of the finite energy interval of charged particle distribution by means of a position-sensitive detector has been substantiated.

1. Introduction

In modern research rapidity of analysis and its informative value play an important role. Spectrograph regime allows to the conduct simultaneously analysis of charged particle beams in a certain energy interval, and angular analysis allows to get information about the electronic structure of the surface region of the solid. In space research for analysis of the energy spectrum of particles electrostatic analyzers are used for a long time. Using the spectrograph regime is also actually.

The conversion of electrostatic energy analyzer of charged particles into the spectrograph regime involves the solving of the problem on focal line straightening. The analyzer focal line is a focus of foci of beams of various energies. Usually its shape is complicated and differs from straight. Position-sensitive detectors have a simple configuration as a plane strip, part of a cylindrical surface or a right circular cone. Consequently it is necessary to solve of the problem on the focal line straightening and to identify the optimal regime of its alignment with the detector surface. Only on the basis of these data it is possible to predict the effectiveness of the energy analyzer conversion into spectrograph regime.

As a criterion of focal line straightening the equality of the slope angle of the tangent to the focal line to zero was accepted, which leads to the condition $d\Delta/d\varepsilon = 0$, where $\varepsilon = (W - W_0)/W_0$ is the kinetic energy spread in a beam. This condition should be considered together with condition of the angular focusing of charged particles beam.

In work [1] criteria of the second-order focal line straightening on divergence angle in the symmetry plane for systems, composed of electrostatic mirrors with two-dimensional fields having a symmetry plane, was derived. The system composed of successively arranged two coaxial cylindrical mirror analyzers, allowing focal line straightening in terms of maintaining second-order angular focusing in a wide energies range, has been calculated. The results of calculations of the characteristics of the energy analyzer composed of two successively arranged electrostatic hyperbolic mirror analyzers in regime of the focal line straightening and the second-order angular focusing were presented. It was shown that in these two cascade systems the high quality of focal line straightening and focusing of beams of various energies along it is carried out.

In work [2] the possibility to convert the electrostatic energy analyzer composed of a spherical mirror (SM) and a cylindrical mirror (CM) to double spectrograph regime (in energy and azimuthal angle) has been theoretically substantiated. The second-order focusing of charged particles beams of various energies along the straightened focal surface is conserved. This surface shaped as a belt of a right circular cone. The concrete scheme of energy-angle resolved spectrograph has been calculated. The advantage of the proposed scheme of spectrograph is the property to analyze charged particles beams emitted by the source at angles close to a right angle (90^0).

Earlier, in work [3] we proposed scheme of combined energy analyzer composed of successively arranged hyperbolic mirror (HM) and CM. The scheme for an energy- and angle-resolved spectrometer which provides angular second-order focusing, high luminosity and exit angle 90^0 from the source has been theoretically substantiated. This focusing angle allows building an effective diagram of angular measurements. The proposed electron-optical scheme can be oriented in the double spectrograph regime in energy and angle.

The aim of this work is study the possibility of conversion of HM and CM system into spectrograph regime.

2. Solving of the problem on focal line straightening in combined system composed of hyperbolic and cylindrical mirrors

We shall use the formalism proposed in work [2] for study the possibility to convert an electrostatic energy analyzer into the double spectrograph regime in energy and angle. It is necessary to maintaining angular focusing along a straightened focal line.

The scheme of energy analyzer is shown in Fig.1 [3]. The energy analyzer consists of successively arranged HM and CM. A charged particle fan-shaped beam is injected into the system, the beam mid-plane being perpendicular to the symmetry axis z ($\alpha \leq 90^0$). A point-like source is placed at the z axis.

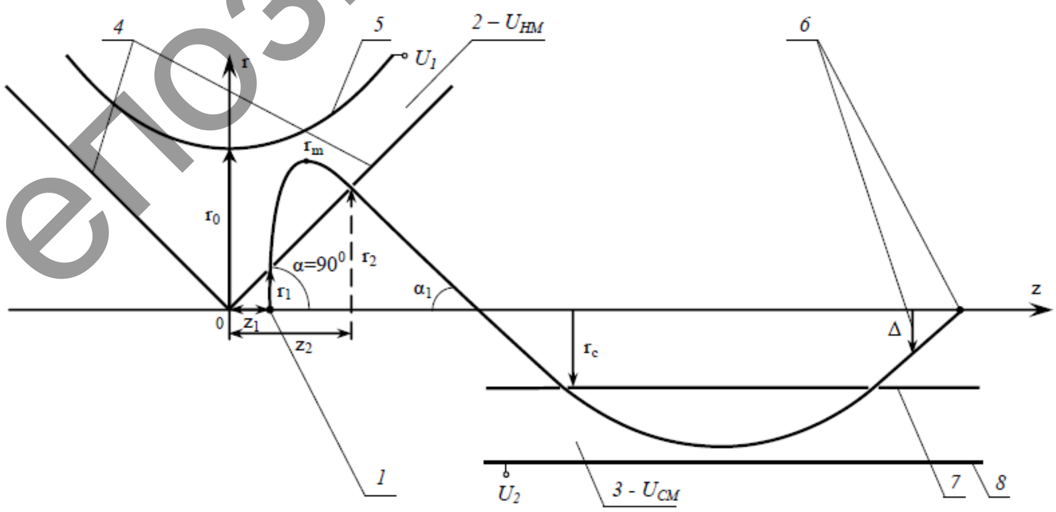

Figure 1. The energy analyzer scheme. 1 – the source of a charged particle beam, 2 – HM, 3 – CM, 4 – the transparent conical electrodes, 5 – the hyperbolic electrode, 6 – the source image, 7 and 8 – the CM block electrodes.

The slope angle of a tangent to the focal line is determined by the relation

$$tg\gamma = \left.\frac{d\Delta}{d\varepsilon}\right|_{\varepsilon=0} \Big/ \left.\frac{d\ell}{d\varepsilon}\right|_{\varepsilon=0} \quad (1)$$

Focal line straightening requirement implies that $\frac{d}{d\varepsilon}(tg\gamma)=0$, it results in the following equation:

$$\left.\frac{d^2\Delta}{d\varepsilon^2}\right|_{\varepsilon=0} - tg\gamma\cdot\left.\frac{d^2\ell}{d\varepsilon^2}\right|_{\varepsilon=0} = 0 \quad (2)$$

The derivatives $d\Delta/d\varepsilon$ and $d^2\Delta/d\varepsilon^2$ are defined by the relations derived as a result of differentiation of the angular first-order focusing condition $\left.dl/d\alpha\right|_{\alpha=\alpha_0}=0$ with respect to ε, which involves $\Delta(\varepsilon)$ as a parameter. "Strengthening" of focal line straightening criterion (2) carried out by the imposition of extra requirement. This requirement is the angular second-order focusing condition along the straightened focal line:

$$\left.\frac{dl}{d\alpha}\right|_{\alpha=\alpha_0} = \left.\frac{d^2 l}{d\alpha^2}\right|_{\alpha=\alpha_0} = 0 \quad (3)$$

The set of Eqs. (2) and (3) is the criterions of the second-order focal line straightening.

All parameters with length dimension are expressed in units of central radius r_0 of HM deflecting electrode. The length of the projection of a charged particle trajectory to the symmetry axis *z* in the section from the point-like source to its image [3]:

$$l = l_{HM} + l_{CM}, \qquad l_{HM} = z_2\left(1+\cot\alpha_1\right) - z_1,$$

$$l_{CM} = \frac{l_{CM}}{r_0} = \mu\cot\alpha_1\left(2+4P_1\theta_1-\Delta\right) \quad (4)$$

$$P_1^2 = \frac{W}{qU_2}\sin^2\alpha_1 \quad (5)$$

- reflection parameters of CM, $\theta_1 = e^{P_1^2}\int_0^{P_1} e^{-x_1^2}$, Δ is a quantity defining the distance of an image from the energy analyzer's z axis, $\mu = r_c/r_0$ is a coefficient that determines the quantity of inner cylindrical electrode radius r_c in units of r_0, the radius of the trajectory vertex in the CM field is calculated from equation $r_m = \mu\exp\left(P_1^2\right)$.

As a criterion of focal line straightening of system, we accepted the equality of slope angle of a tangent to the focal line at the point of its cross with the axial trajectory of the beam.

The first requirement imposed on the parameters of a mirrors system is the angular first-order focusing condition $\left.dl/d\alpha\right|_{\alpha=90^0}=0$. From it for the mirrors system follows:

$$\Delta = 2+4P_1\theta_1+\frac{z_2}{\mu}-\frac{\sin^2\alpha_1\left(4\mu\omega\, z_1\cot\alpha_1 - S^2\sin\alpha_1\right)}{\mu\left(1+\cot^2\alpha_1\right)\left(z_1+\frac{z_2\sin\alpha_1}{\left(1+\cot\alpha_1\right)}\right)} \quad (6)$$

$$S = \sqrt{2\frac{W}{qU_1}}\sin\alpha \qquad (7)$$

- reflection parameters of HM, connecting its geometrical and energy characteristics, $\omega = P_1\theta_1 + P_1^2\left(1+2P_1\theta_1\right)$.

The second requirement is the focal line straightening of the charged particle beams of various kinetic energy. We shall differentiate of the expression (6) with respect to ε and equate the result to zero. We obtain the equation expressing the first-order focal line straightening condition of α in a direction parallel to the symmetry axis of the system $dl/d\alpha\big|_{\alpha=90^0} = d\Delta/d\varepsilon\big|_{\alpha=90^0} = 0$.

Independent variables μ, S, α_1, P_1 included in the equation of first-order focal line straightening can vary over a wide range. However, there are limits on the ratio of the radii $\mu = 0,5-1$. This is justified, because it reached a reasonable compromise in the selection values of the electron-optical characteristics of the combined energy analyzer. In addition requirements for construction of real scheme of spectrograph will also be simplified.

The base detail of spectrograph is an inner cylindrical electrode, as well as in commercial devices with widely known cylindrical mirror analyzer [4, 5]. In the body of this electrode must be made two aperture windows. Aperture windows covered one-dimensional grids of nichrome wire with thickness of 0.15 mm, placed along the generators of cylinder by 1 mm spacing.

When selecting the radius size of the inner cylinder through the reflection parameters of the HM and CM (Eqs.(5) and (7)), the others geometric and energy parameters of the combined analyzer are calculated.

3. Conclusions

The double spectrograph of charged particle beams (in energy and angle) composed of electrostatic hyperbolic and cylindrical mirrors has been studied. It is shown that in case of simultaneous registration of the distribution of charged particles of the finite interval in both energy and angle the focal surface has shape of truncate cone. As a criterion of focal line straightening the equality of slope angle of a tangent to the focal line at the point of its cross with the axial trajectory of the basic beam was accepted. The relation for the condition of first-order focal line straightening of particles of various energies in the combined system of mirrors has been established.

Acknowledgement

This work was supported by the grant GF4-0815 of the Ministry of Education and Science of the Republic of Kazakhstan.

References

[1] Zashkvara V V and Ashimbaeva B U 1991 The focal line straightening in the mirrors with two-dimensional electrostatic fields *Zhurnal Tekhnicheskoi fiziki.* **61(10)** 8-18 [in Russian]

[2] Zashkvara V V and Ashimbaeva B U 1994 Theoretical basis for the scheme of an elecrtrostatic energy and angle-resolved spectrograph *Nucl. Instr. and Meth.* A **340** 514-523

[3] Ashimbaeva B U, Chokin K Sh, Saulebekov A O, Kambarova Zh T 2012 The combined energy analyzer composed of electrostatic mirror fields *J. Electron Spectrosc.and Relat.Phenom.* **185** 518-522

[4] Zashkvara V V, Ashimbaeva B U 1998 Cylindrical mirror analyzer with adjustable angular focusing *J. Electron Spectrosc. and Relat. Phenom.* **94 (1–2)** 89-96

[5] Trubitsyn A A 1995 A cylindrical mirror analyser with high energy resolution *J. Electron Spectrosc. and Relat.Phenom.* **73 (3)** 305–310