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STUDY OF THE POSSIBILITY OF TRANSFER OF ESA-12 ELECTRON SPECTROMETER OF DOUBLE PASS CYLINDRICAL MIRROR TYPE INTO A SPECTROGRAPH MODE

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In the article, the possibility of transfer of ESA-12 electron spectrometer double pass cylindrical mirror type into a spectrograph mode is studied. The obtained modernized scheme is the design on the basis of three coaxial cylinders with the "axis-axis" focusing, which is able to operate in the spectrograph mode. The modeling of electron-optical scheme of the modified energy analyzer by means the numerical program "Focus" for modeling the corpuscular optics systems is conducted. It is noted, that when using the proposed scheme can significantly increase the accuracy and rapidity of investigations of the angular and energy distributions of charged particles beams.

Keywords: electron spectroscopy, cylindrical mirror, energy analyzer, spectrograph, angular focusing, modeling of an electron-optical scheme

Introduction

Electron spectroscopy is of great importance in investigations of a solid surface. The main element of an electron spectrometer is an energy analyzer of a mirror or deflector type. In electron spectroscopy it is very often difficult to obtain complete information due to insufficient performance at registration of energy spectra of electrons. This problem is most acute in photoelectron spectroscopy with energy and angular resolution. A potential for improving rapidity of energy analysis of charged particle beams involves the use of dispersive energy analyzers operating in a spectrograph mode that enables us to simultaneously register the distribution of the analyzed flows of charged particles at finite energy and angular intervals using a position-sensitive detector placed along the focal line of the energy analyzer.

At the Institute of Nuclear Physics of the Academy of Sciences of the Czech Republic (Ržez near Prague) the ESA-12 electron spectrometer of double pass cylindrical mirror type with the second-order focusing was operated for a long time for research in nuclear spectroscopy and atom physics. In [1, 2] the design and the detailed description of the spectrometer are given, as well as examples of measurements performed on it.

When applying a single channel detector in the ESA-12 spectrometer the measurement of intensity values of spectra was carried out in real time. Disadvantage of these measurements is that the full range can be obtained only by means of its serial scans. This method of recording the spectrum is too long and becomes rough in the study of processes developing in time. We have faced the problem of modernization this device in order to enlarge the performance capabilities of the spectrometer, as the design allows its further modernization. In this regard, it was necessary to consider the possibility of transfer the ESA-12 electron spectrometer into a spectrograph mode that will provide ease of operation and maintenance of the device.

The ESA-12 electrostatic electron spectrometer was designed for investigation of low-energy electron spectra. Electron-optical scheme of the spectrometer enables the use of extended sources. The scheme of a longitudinal cross-section of the spectrometer is shown in Fig.1. According to the scheme, the charged particles beam coming from a point source is reflected twice in the electrostatic field of the mirror and reaches the detector.

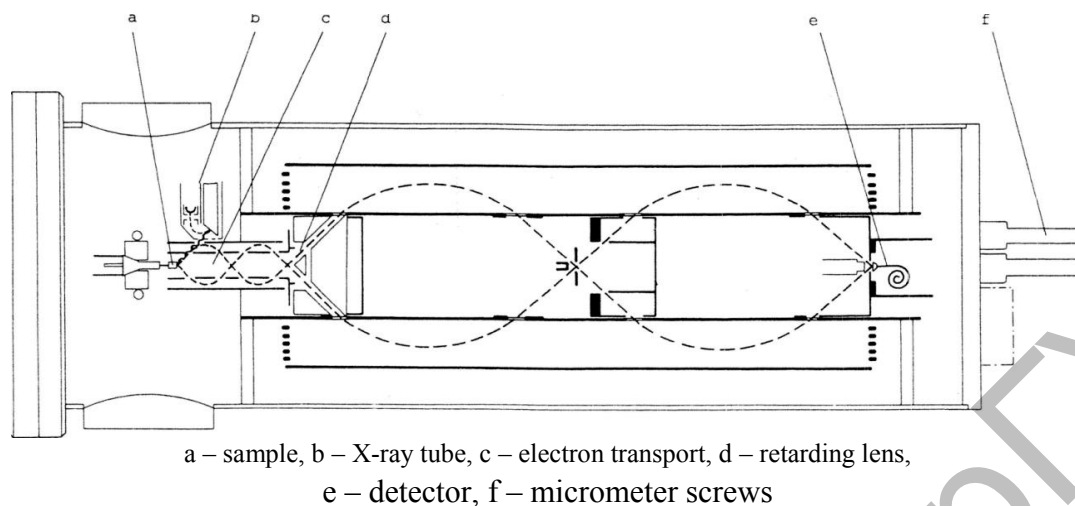


Fig.1. Schematic cross section of the ESA-12 electron spectrometer

Fig. 2 shows the appearance of the ESA-12 electron spectrometer of double pass cylindrical mirror type (a) and an extended radioactive disc-shaped source with the diameter of 8 mm (b).



Fig. 2. The appearance of the ESA-12 electron spectrometer (a) and a radioactive disc-shaped source with the diameter of 8 mm (b).

The transfer of the electron spectrometer of double pass cylindrical mirror type into the mode of a spectrograph is caused by the problem of the focal line straightening and the determination of optimal conditions for the convergence to the detector surface. Only on the basis of these data it is possible to predict the efficiency of the transfer of an energy analyzer into a spectrograph mode. The focal line of an analyzer is the geometric place of foci of charged particle beams with different energies. It is known that in a simple cylindrical mirror analyzer, a focal line is a complex curve and it is difficult to implement the spectrograph mode. However, a *multicascade cylindrical mirror* analyzer makes it possible to straighten this line, and thus to use the device as a spectrograph.

This principle was established and numerically proved by V.V. Zashkvara et al. [3]. As a criterion for focal line straightening, the slope angle of the tangent to the focal line equal to zero is taken that leads to the condition $d\Delta/d\varepsilon=0$, where ε is the spread of kinetic energy in the beam. This condition should be considered simultaneously with the condition of the angular focusing of a charged particle beams. The problem of the straightening of the focal line in a double pass cylindrical mirror can be solved by introducing a *third additional coaxial cylindrical electrode*.

On the basis of a combination of two areas with different cylindrical symmetric electrostatic field energy, an analyzer with a third order focusing can be constructed [4]. The required field configuration is achieved by adding a third cylindrical electrode, located between the outer and inner cylinders. The third order focusing occurs at the value of the entrance angle of $\alpha=39.98^\circ$, when the value of the optimal ratio of the radii of inner cylinders is equal to 1.4754 and the value of the ratio of the field strength on the inner surface of the intermediate cylinder to the strength on the outer surface of the same cylinder is equal to 1.0889. The resulting focal length along the analyzer axis is $5.7764 \cdot r_1$, where r_1 is the radius of the inner cylindrical electrode. For the range of entrance angles $\Delta\alpha=9.34^\circ$ the resolution $\Delta E/E$ of the analyzer reaches 0.3%.

In ref. [5] the characteristics of a three cylindrical mirror analyzer (TCMA) for the general case are described, when the electron-optical source and the image are rings which coaxially with the cylinder. It is shown that in TCMA the fourth order focusing is reached, and at the third order focusing it is possible to choose designs with any entrance angle of the main beam trajectory. At the second order focusing a design with a variable focal length specified by the potentials of the electrodes is only possible.

By means of the analytical method developed in ref. [6], the possibility of achieving the fourth order axis-ring type focusing of the general form in TCMA is shown. On the basis of theoretical calculations, it was found more than a ten-fold improvement in energy resolution compared to conventional CM.

In [7] the electron-optical characteristics of a modified cylindrical mirror analyzer based on three coaxial cylindrical electrodes obtained with numerical calculations are presented. It is shown, that the image of a point source of electrons located on the analyzer symmetry axis in the form circle which does not depend on the entrance angle of electrons into the analyzer within the range of angles $\alpha = 30^\circ-40^\circ$.

According to the modified scheme (Fig. 3), the analyzer consists of three coaxial cylindrical electrodes: the outer, intermediate and inner (with radii r_1 , r_0 and r_2); the inner and outer electrodes are applied by deflecting potentials U and U_1 . The intermediate cylindrical electrode is grounded. A charged particles beam emitting at the α angle from the source S, located on the symmetry axis of the energy analyzer, is twice reflected from the outer cylinder 1 and once from the inner cylinder 3, four times penetrating the intermediate cylinder 2. Then it is focused, forming a point image on the symmetry axis z . Thus, the analyzer operates at the "axis-axis" focusing. In the scheme, the trajectory of the basic energy particles W_0 is shown by the solid line while dashed lines represent the axial trajectories of particles with energies different from W_0 by $\pm 10\%$.

The expression for the length of the trajectory projection from the source to its image is determined by the sum of the projections trajectories in the cascades of a cylindrical mirror analyzer [3]:

$$l = [\Delta + 4(nP_1\theta_1 + mP_2\theta_2)] \cot \alpha \quad (1)$$

Where

$$P_1 = \sqrt{\frac{W}{qU}} \ln \frac{r_1}{r_0} \sin \alpha \quad \theta_1 = \exp(p_1^2) \int_0^{p_1} \exp(-x^2) dx$$

$$P_2 = \sqrt{\frac{W}{qU_1}} \ln \frac{r_0}{r_2} \sin \alpha \quad \theta_2 = \exp(-p_2^2) \int_0^{p_2} \exp(x^2) dx \quad (2)$$

– are reflection parameters characterizing a cylindrical mirror analyzer, q and W – are the charge and kinetic energy of particles, $\Delta = \Delta_1 + \Delta_2$ – are the total distance of the source and the images from

the surface of the intermediate electrode, n and m – are number of cascades of inner and outer reflections, respectively.

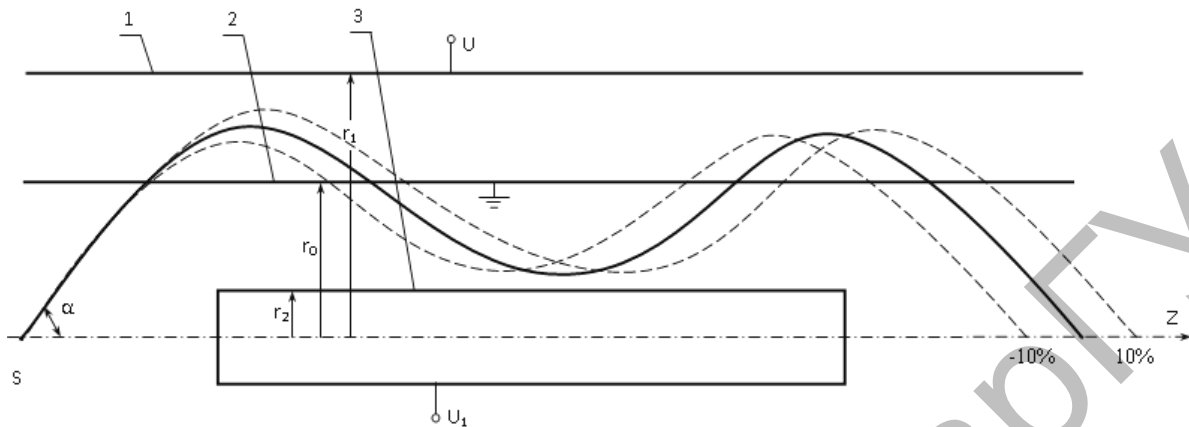


Fig.3. The modified scheme of the cylindrical mirror analyzer (the "axis-axis" focusing of general form):
1 – the outer cylinder, 2 – the intermediate cylinder, 3 – the inner cylinder

The radii of the working surfaces of the intermediate and outer electrodes remain constant and are as follows: $r_0 = 53,3\text{mm}$, $r_1 = 102\text{mm}$, as we assume a minimal modification of the device. The value of the radius of the surface of the inner cylindrical electrode r_2 was chosen basing on the requirement that the deflecting potentials U and U_1 in cascades should be equal that leads to the relation:

$$\frac{\ln r_0'/r_2}{\ln r_1/r_0} = \left(\frac{P_2}{P_1} \right)^2 \quad (3)$$

where $r_0' = 51\text{mm}$ is the radius of the inner cylindrical surface of the intermediate electrode. In this case, according to Eq. (3), the radius of the additional inner electrode is $r_2 = 16,33\text{mm}$.

Further the paper considers the modeling of an electron-optical scheme of the modified energy analyzer, based on three coaxial cylindrical electrodes by means of a numerical program "Focus" for simulating axial-symmetrical systems of corpuscular optics with arbitrary geometry of electrodes.

The "Focus" program consists of several modules that exchange information between them by using data files. The program enables us to graphically enter and carry out design modifications, to calculate the potential distribution in the selected area and to analyze the trajectory of the system. The module of the graphics editor enables us to create a radial section of the electrode system with applied proper potential for them. The module for calculating the potential distribution function implements the boundary element method (BEM) with advanced methods of calculating singular and quasi-singular integrals. On the basis of BEM the external Dirichlet problem is solved that, in contrast to the interior Dirichlet problem, enables us to simulate the electron-optical systems, which structures are as realistic as possible. The module makes it possible to compute an array of values of normal derivative of the potential on an area boundary, which is then used to calculate particle trajectories in an electrostatic field. The module simulating trajectories of charged particles in an electrostatic field enables us to calculate a set of trajectories of positively charged particles with initial energy emitted by either point or extended source in a range of initial angles. If the specified number of calculated trajectories is more than 5, then the conditions of the high order angular

focusing are determined. In addition, the module implements the possibility of construction the transmission function of the initial energy of charged particles (instrumental function) [8].

Fig. 4 represents the process of trajectories of charged particles with different kinetic energies of 1 – $E/V = 1.458$, 2 – $E/V = 1.62$, 3 – $E/V = 1.782$ in a modified electron-optical scheme of the energy analyzer in case of a point source. The point source is located on the symmetry axis of the energy analyzer. The range of initial angles of $40.85^\circ \pm 1^\circ$, and the position of the source ($x=3.034$ mm, $y=0$), the width of the entrance slit remained constant. The scheme of the modified design is built in a scale of 1:10.

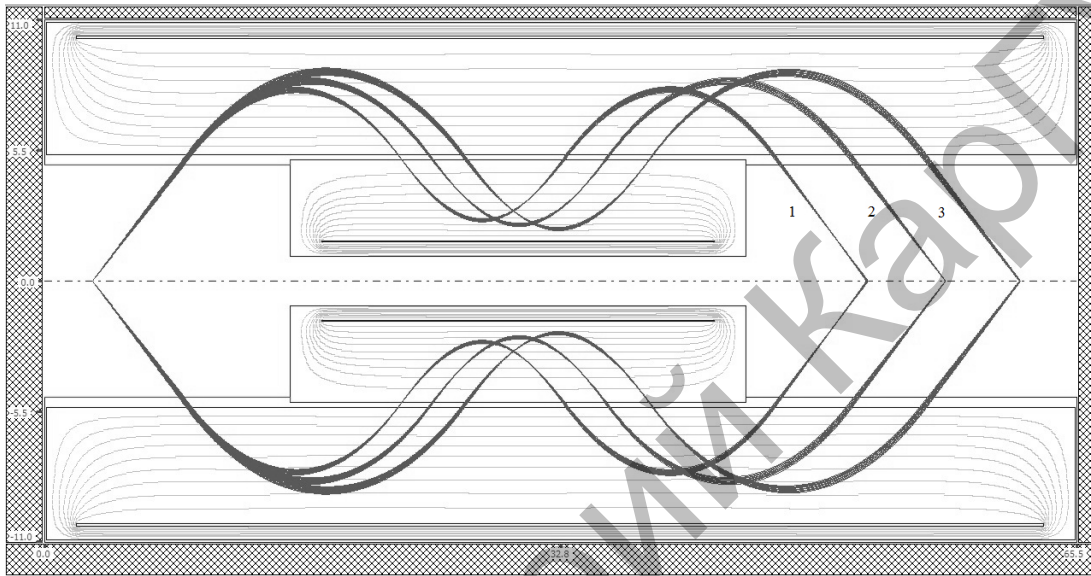


Fig. 4. The angular focusing of charged particles with different kinetic energies in case of a point source: 1 – $E/V = 1.458$, 2 – $E/V = 1.62$, 2 – $E/V = 1.782$. All dimensions are in conventional units

Table 1. Values of aberrational smearing of the image on the focal line at the angular divergence of $\pm 1^\circ$:

$\Delta\alpha$, degree	Δl
$\varepsilon = 0.1$	
1	0.015882
0	0.0
-1	0.059849
$\varepsilon = 0.05$	
1	0.005043
0	0
-1	0.045632
$\varepsilon = 0.0$	
1	0.020125
0	0.0
-1	0.017901
$\varepsilon = -0.05$	
1	0.027912
0	0.0
-1	0.007437
$\varepsilon = -0.1$	
1	0.076733
0	0.0
-1	0.083656

As one can see in Fig. 4, the charged particles fly from a point source to the intersection with an intermediate cylindrical electrode in a fieldless space. Further, the particles come to the field of the outer cylinder, and then they are deflected back into the area of the inner cylinder field, repel each other, pass another cascade in the outer cylinder field and going back to fieldless space, are focused in a point image.

The axial distance of the particles, i.e. the length of the trajectory projection from the source to its image is $L = 9.86r_0$, is roughly approximate to its original value in case of a double pass mirror $L = 10.04 r_0$, it means the preservation of lengths of the cylinders, and thus it provides a minimal modification of the spectrometer. Table 1 shows the values that characterize the aberrational smearing of the image on the focal line of $\Delta l = l(\varepsilon, \Delta\alpha) - l(\varepsilon, 0)$ at the angular divergence of $\pm 1^\circ$. The table shows that Δl strongly depends on the magnitude and character of sign ε , on the signs of the cubic dependence of Δl on α .

Fig. 5 represents the trajectories of charged particles with different kinetic energies in case of an extended disc-shaped source of diameter $d = 8$ mm: 1 – $E/V = 1.458$, 2 – $E/V = 1.62$, 3 – $E/V = 1.782$. In case of an extended disc-shaped source $d = 8$ mm the charged particles emitted by the source will pass the entrance slit, and only get into the field in the range of initial angles of $40.85^\circ \pm 3,5^\circ$.

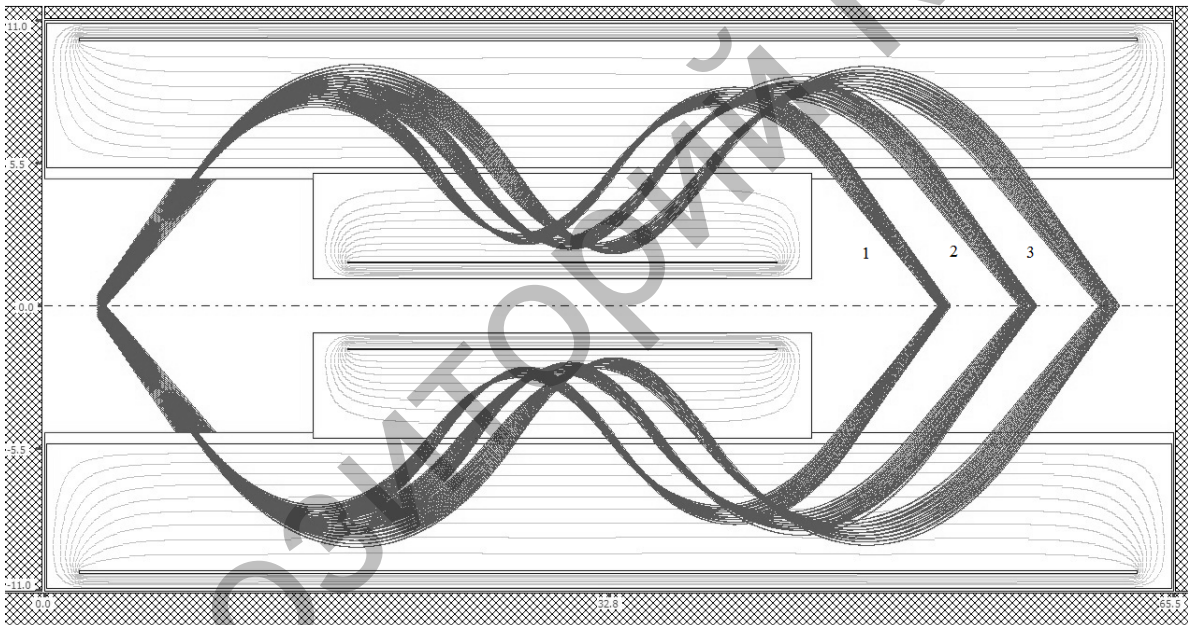


Fig.5. The trajectories of charged particles with different kinetic energies in case of an extended disc-shaped source $d = 8$ mm: 1 – $E/V = 1.458$, 2 – $E/V = 1.62$, 3 – $E/V = 1.782$. All dimensions are in conventional units

For the source size (in the emission area) of 8 mm and the length of a microchannel plate of 110 mm, the number of simultaneously resolute energy lines on the microchannel plate is 7. Within the energy range of 20% energy resolution in the microchannel plate varies slightly and is $R \approx 2.5\%$. Improvement of the resolution of the scheme can be achieved by reducing the size of the emission area.

The disadvantage of the numerical calculations of the charged particles trajectories in case of an extended source is that the emission area of charged particles is not taken into account.

Conclusions

Thus, the possibility of transfer of an electron spectrometer of double pass cylindrical mirror type into the spectrograph mode by introducing the additional third cylinder is investigated. The choice of its optimal design is justified. The obtained scheme is a modernized design with triple cascades and the "axis-axis" general form focusing. Since the electrodes in TCMA have the form of cylinders, its design is slightly complicated. The modernized energy analyzer is able to provide highly accurate and express research of angular and energy distributions of charged particles by means of a microchannel plate.

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