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CALCULATION OF THE ELECTRON BEAM FOCUSING SYSTEM IN THE ION SOURCE OF MASS SPECTROMETER WITH ELECTRON IMPACT IONIZATION

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It has been found the correlations for the parameters of electron movement and it has been determined the value for magnetic induction in the region of ionization chamber providing the electron beam passage through the space of ionization chamber without its broadening.

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Ion sources with ionization of gaseous substances by slow electrons are sufficiently widespread in mass-spectrometry. Ionization is realized by an electron beam of low energy (~ 100 eV) with the ion formation due to the collisions of electrons with molecules and atoms of the considered substance. Such sources form stable monoenergetic ion beams with the intensity of 10^{-8}-10^{-9} A and allow to easily control the ionizing electron current and ionization energy [1-3]. In those cases, when it is necessary to raise the ionization efficiency without growth of the ionizing electron current, magnetic field is used. Below we present the calculation technique of the electron beam focusing system in the ion source with electron impact ionization in the presence of magnetic field in the ionization chamber.

The typical scheme of ionizer by a slow electron beam is shown in Fig. 1. Electrons emitted by a hot cathode 1 are accelerated in the direction of the ionization chamber 2 under the action of the ionizing voltage applied between the cathode and the ionization chamber. A part of a beam passes through the collimating slit into the ionization chamber, and then through the symmetrical output slit it gets on the electron collector 3. Electron beam is additionally focused by the longitudinal magnetic field, which increases the electron free path due to the transverse component of their velocity and, consequently, increases the ionization probability. Ions formed in the region of the electron beam passage in the ionization chamber leave the chamber through the side slit and are formed into the ion beam by the ion gun (it is not shown in the figure). It is necessary that the electron beam passing the ionization chamber space does not touch its walls that can be achieved due to the corresponding choice of the longitudinal magnetic field, which focuses the electron beam. In this connection we determine the parameters of the electron trajectory and magnetic induction in the ionization chamber, at which the above mentioned requirement holds.

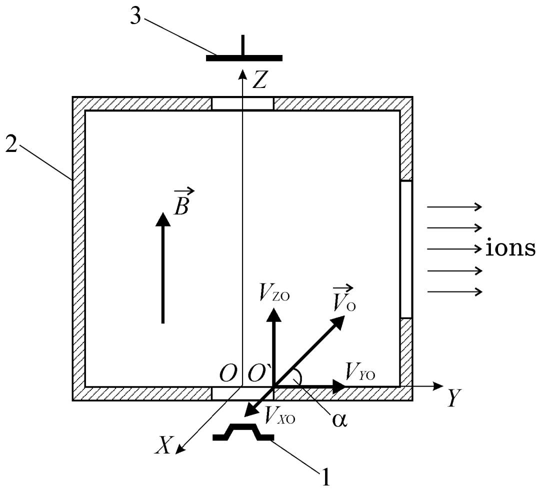

Fig. 1 *– The scheme of ionizer and disposition of the coordinate system*

Values of the geometrical and physical parameters of the electron gun are chosen to be those which are often used in mass-spectrometers [2, 3]: width of the ribbon cathode is 0,5 mm; distance from the cathode to the ionization chamber is 1 mm; sizes of the slit in the ionization chamber for the electron beam passage is 1 × 1 mm; value of the ionizing voltage is 70 V.

In order to solve the assigned problem we will use the equations of electron motion in the magnetic field since in the ionization chamber electric field is equal to zero. We will also use the rectangular coordinate system and choose the directions of its axes in such a way as it is shown in Fig. 1.

Equations of electron motion in the chosen coordinate system if its origin is placed in the point O are written as [4]

$$X-\frac{m}{eB}V_{YO}=-\frac{mV_{YO}}{eB}\cos\frac{eB}{m}t+\frac{mV_{XO}}{eB}\sin\frac{eB}{m}t\,, \tag{1}$$

$$Y+\frac{m}{eB}V_{XO}=\frac{mV_{YO}}{eB}\sin\frac{eB}{m}t+\frac{mV_{XO}}{eB}\cos\frac{eB}{m}t\,, \tag{2}$$

$$Z=V_{ZO}t, \tag{3}$$

where m and e are the electron mass and charge, respectively; B is the magnetic field induction in the ionization chamber; V_{XO}, V_{YO}, and V_{ZO} are the components of the electron velocity vector; t is electron travel time.

Squaring both sides of the equations (1) and (2) and adding them, we obtain the equations of electron motion in the form

$$\left(X-\frac{m}{eB}V_{YO}\right)^2+\left(Y+\frac{m}{eB}V_{XO}\right)^2=R^2\,, \tag{4}$$

where $R = m\sqrt{V_{XO}^2 + V_{YO}^2}/eB$. Therefore, in the ionization chamber electron moves uniformly in a circular orbit, the center of which moves with the constant velocity V_{ZO} parallel to the OZ-axis, i.e. parallel to the direction of magnetic field lines. Consequently, electron trajectory represents helix with constant step, which is situated on the straight circular cylinder whose axis is parallel to the OZ-axis. Projection of the trajectory on the XY-axis is the circumference with the radius

$$R = \frac{mV}{eB}, \tag{5}$$

where $V = \sqrt{V_{XO}^2 + V_{YO}^2}$ is the projection of electron velocity on the plane, which is perpendicular to the vector $\vec{B}$ (in the given case, on the XOY-plane). The value of eB/m in equation (1) is the electron angular velocity. Therefore, time T of one revolution of electron or time of one coil of helix is determined from the following condition:

$$\frac{eB}{m}T = 2\pi, \tag{6}$$

i.e. $T = 2\pi m/eB$. The electron path along the direction of magnetic field lines during one revolution (helix step) is written as

$$\Delta Z = L = V_{ZO}T = \frac{2\pi m V_{ZO}}{eB} = \frac{2\pi m V_O \sin\alpha}{eB}. \tag{7}$$

In order to find the magnetic field induction providing the electron beam passage without its broadening, we will use relation (5), which defines the dependence of the circle radius of the electron trajectory projection on the plane on the value of the magnetic field induction. Since in our case we have $V_{XO} = 0$, then $V = \sqrt{V_{YO}^2} = V_{YO} = V_O \cos\alpha$, and relation (5) takes the form

$$B = \frac{mV_O \cos\alpha}{eR}. \tag{8}$$

If U is the potential difference passed by an electron from the cathode to the ionization chamber input, then

$$\tfrac{1}{2} mV_O^2 = eU \tag{9}$$

or

$$V_O = \sqrt{2eU/m}. \tag{10}$$

Then, substituting the velocity value from (10) into relation (8), we obtain

$$R = \sqrt{\frac{2mU}{eB^2}} \cos\alpha \tag{11}$$

or

$$B = \sqrt{\frac{2mU}{eR^2}} \cos\alpha \,. \tag{12}$$

As seen from (11), the circle radius R decreases with the magnetic field induction B. Taking into account that the value of R should not exceed the half-width of the ionization chamber slit and $\cos\alpha = 0{,}45$ (starting from the chosen ionizer geometry), we obtain the following formula for the determination of the magnetic field induction inside the ionization chamber:

$$B = 0{,}45\sqrt{\frac{2mU}{e \cdot 0{,}25 \cdot 10^{-6}}} \,. \tag{13}$$

As calculations show, it follows from relation (13) that diameter of the electron beam (with the energy of 70 eV) will not exceed the width of the ionization chamber slit in that case if magnetic field induction inside this chamber will be not less than 0,0253 T. Obtained value of the magnetic field induction allows to choose a rational design of electromagnet for the electron beam focusing in the ion source of modern mass-spectrometers with electron impact ionization [5, 6]. If magnetic field in the ion source is generated by constant magnets and energy of ionizing electrons during operation of the mass-spectrometer is changed, one should to take into account the possible change in the instrument sensitivity conditioned by violation of conditions of the electron beam focusing.

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