ANNOTATION

for dissertation work of the PhD Student in

6D071900 – «Radio engineering, electronics and telecommunications»

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on the topic «Investigation of the properties of immersion electron lenses with two planes of symmetry»

General description of work. The main elements of the electronic optics are the electronic lenses. Lenses can be classified according to different points of view. The main types of electronic lens are the immersion lenses and single lenses. The immersion electron lens can be called a lens in which the potentials to the right and left of the lens are constant, but not equal. If the potentials to the right and left of the lens are constant and equal to each other, then such lenses are called single.

The combination of the immersion lens with the source of electrons - a cathode is called an immersion objective, can also be called a cathode lens or an emulsion immersion lens. The present work is devoted to the theoretical and practical investigation of the properties of new emission immersion electron lenses with two symmetry planes. New emission electron-optical elements of vacuum electronics with improved focusing characteristics are proposed.

In the first chapter, a review of scientific works on the study of electronic lenses is performed.

The modeling of fields and the calculation of the potential distribution of the electrostatic lenses with two symmetry planes are considered in the second chapter of the thesis.

In the third chapter, algorithms and software for numerical studies of emission elements with two symmetry planes in Delphi programming language are developed. A technique for calculating paraxial parameters with a focusing condition in the region of a given point of space is considered. Numerical studies of paraxial parameters are carried out.

The fourth chapter compares the focusing parameters of a box-shaped lens with a square cross-section and an axisymmetric lens. In this chapter it is shown that for the box emulsion immersion lens under consideration, a number of aberration coefficients, along the x axis, have noticeably lower values compared to aberrations of the other direction. In this case, the aberrations of the «y» direction are approximately equal to the aberrations of axisymmetric emission lenses. Thus, it is shown that emission lenses with two symmetry planes allow the construction of sources of charged particles with improved focusing characteristics.

Relevance of the research topic. Electron-optical elements of vacuum electronics are currently widely used for the construction of various electronic devices and process units. For example, such elements are used in electron microscopes, mass spectrometric devices, microwave electronics devices, as well as in electron-lithographic and ion-lithographic installations of nano and micro electronic technologies.

The most important elements of most devices are the immersion lenses. The technical characteristics of electron-optical and ion-beam instruments and devices mainly depend on the quality of focusing of the immersion lenses, since it is carried out the start of process of the formation of a beam of charged particles.

Classical methods for the research on the electronic lenses are not suitable for the development of the theory of immersion lenses because they do not take into account the specificity of their initial conditions. The creation of an effective theory of immersion objectives has for a long time been hampered by difficulties of a mathematical nature associated with the vanishing of the potential on the cathode surface, as well as with large slopes of trajectories in the vicinity of a surface with zero potential.

On the basis of an analysis of the current state and problems of improving electronic devices, it can be concluded that in vacuum electronics, the development of new types of immersion lenses is very relevant. At the same time, the improvement of the focusing properties of electron-optical elements makes it possible to obtain improved technical and operational characteristics in electron-optical and ion-beam devices and technological devices. Therefore, the investigation on the electron-optical parameters and characteristics of new elements of vacuum electronics are an actual task of electronic instrumentation.

Objective. The purpose of this work is the investigation and development of new emission electron-optical elements of vacuum electronics with improved focusing characteristics.

Tasks of the research:

1. To develop models and calculate electrostatic fields of focusing immersion elements with two symmetry planes;
2. To develop algorithms and programs for performing numerical studies of the paraxial parameters of emission elements with two symmetry planes;
3. To create an automated working environment for the calculation of the complex of focusing parameters for immersion electron lenses with two symmetry planes;
4. To carry out numerical studies of the focusing parameters of immersion lenses with two symmetry planes using the developed program;
5. To calculate the aberration coefficients of a box emission lens.
6. To perform a comparative analysis of the paraxial and aberrational parameters of the immersion lenses considered.

Object of study. The object of the study are the emission immersion lenses, which are one of the most important elements of vacuum electronics.

Subject of study. The subjects of the study are the electron-optical parameters of the emission immersion lenses with two symmetry planes. Complex analysis of these parameters allows us to develop new electronic emission lenses that provide high quality of focusing.

Method of research. When designing new types of immersion lenses with two symmetry planes, an important task is modeling the trajectories of charged particles, developing programs for calculating fields and determining the distribution of potentials in the lenses under investigation. When modelling the trajectories of charged particles, a method was used which helps to eliminate the division by zero in the cathode region of the emission lens. For the analysis of trajectories, the three-dimensional Laplace equation with given boundary conditions is solved, that is, the Dirichlet problem for an emission lens with two symmetry planes is solved.

For the numerical studies of a complex of focusing parameters of immersion electron lenses with two planes of symmetry, as it is known that algorithms and programs must be developed. For the development of the program, theories of numerical methods for analyzing differential and integral equations were used. The developed program is written in Delphi programming language.

The main provisions to be defended.

- Mathematical methodology and programs used to solve the three-dimensional Dirichlet problem in calculating electrostatic potential distributions in immersion emission lenses with two symmetry planes;
- Results of calculations of electrostatic potential distributions and their derivatives for emission lenses with specific boundary conditions;
- Mathematical model and software used to calculate the paraxial properties of emission lenses with two symmetry planes;
- Results of calculating the trajectories of charged particles in emission immersion lenses with two symmetry planes for different values of the potentials supplied and the dimensions of the electrodes;
- Results of calculations of parameters of the paraxial equation with the condition of focusing of charged particles in the region of a given point of space $|wy| = 0$;
- Mathematical formulas and software for numerical studies of aberration characteristics;
- Results of a comparative analysis of the aberration coefficients of axisymmetric and box emission lenses;
- Conclusion on the possibility of reducing aberration coefficients, at least in one direction, by using an emulsion immersion lens with two symmetry planes.

Scientific novelty is determined by the fact that the paper considers the theoretical and practical issues of designing new immersion electron lenses with two symmetry planes, which provide a higher quality of focusing of charged particles, which in turn leads to the improvement in the technical characteristics of analytical instruments and process units.

Up to the present time, two-dimensional electron lenses have been considered, including cylindrical and axially symmetric immersion lenses. From the number of electronic lenses with two planes of symmetry, the transaxial immersion lenses were

considered. The other types of doubly-symmetric electronic immersion lenses have not mainly been investigated.

The scientific and practical significance of the results of the thesis is high because the new elements (immersion electron lenses) with small aberrations and increased possibilities for their correction selected with the results of performed investigation can be used in the design of modernized electron-ion-beam devices and devices.

The developed software package will allow to design and build mass-spectrometric devices, electron-optical converters and amplifiers, electron microscopes, installations for electronic and ion lithography, ion implantation installations and a number of other devices which are necessary for accelerated innovative development.

Sources of the research. The traditional apparatus of the theory of focusing, which is used in the investigation of ordinary single and immersion electron lenses, can not be effective in studying emission and reflecting lenses, since the conditions for the smallness of the slope angles of the particle trajectory in the cathode region are substantially violated in emission lenses.

At present time, there is a qualitative scientific reserve in Kazakhstan in the field of theories and methods of research of elements and assemblies of electron-optical and ion-beam systems. Scientists of Kazakhstan led by Kelman V.M. and Yakusheva E.M. have created an original method of transforming coordinates and time in the equations of motion, this allowed us to overcome the above difficulties for electronic mirrors. The effective theory of emission systems was developed by Ibraev A.T., this theory allows eliminating all difficulties in the investigation of cathode lenses. The theory developed by Ibraev A.T. has helped to obtain formulas for the calculation of the aberration characteristics of an emission immersion lens.

The author's personal contribution consists in the fact that all the algorithms and programs for conducting numerical studies have been developed and the results of a numerical study were obtained personally by the applicant. The setting of the problems and discussion of the results were carried out jointly with scientific advisers.

Reliability of the results. The reliability of the results obtained in the work is not in doubt, since the results obtained for axially symmetric lenses, which are special cases of lenses with two symmetry planes studied in this paper, coincide with the results of a number of published and put into practice papers.

Publications. 8 published works were published on the topic of the thesis, including 2 in international peer-reviewed scientific journals, 3 in publications recommended by the Education Control Committee and the Ministry of Education and Science of the Republic of Kazakhstan, 3 in international scientific and practical conferences.

Articles in international peer-reviewed scientific journals:

- A.T. Ibraev, A.B. Sagyndyk. Numerical investigation of the aberrational coefficients of a box shaped cathode lens. News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences. (Kazakhstan), ISSN: 2224-5278. Vol. 4, № 424. -2017. – pp. 108-114.

- V.R. Roganov, A.B. Sagyndyk, R.F. Akhtarieva, A.K. Beisenbayeva, S.I. Sannikova. Integrated organization of the system for forming the information support of aeronautical simulator**.** International Journal of Applied Engineering Research ISSN 0973-4562. Vol. 12, №15. -2017. pp. 5207-5213. Индекс Хирша 13, Импакт фактор 0,149.

Articles in publications recommended by the Committee for Control in Education and the Ministry of Education and Science of the Republic of Kazakhstan:

- А.Т. Ибраев, А.Б. Сагындык. Численное исследование параксиальных параметров коробчатой катодной линзы. Вестник ПГУ, Энергетическая серия. №1. -2017. С. 139-145.

- А.Т. Ибраев, А.А. Ибраев, А.Е. Куттыбаева, А. Сагындык, Д.Т. Джунусова. Параксиальные параметры и аберрации семиэлектродной осесимметричной катодной линзы. Вестник КазНИТУ. №1. -2016. С.146-152.

- А.Т. Ибраев, А.Е. Куттыбаева, А. Сагындык, В.И. Чернецов, М.В. Чернецов, П.Г. Михайлов. Инвариантное преобразование в информационно-измерительных системах с параметрическими датчиками. Вестник КазНИТУ. №2. -2017. С. 95-99.

International scientific-practical conferences:

- Ibraev A.T., Ibraev A.A., Kuttybayeva A.E., Sagyndyk A., Junussova D. Numerical Study of Focusing Parameters of a Five-Electrode Cathode Lens with the Rotational Symmetry of the Field. The 5th International Workshop on Computer Science and Engineering. -2015. pp. 424-430.

- Ибраев А.Т., Сагындык А. Решение задачи Дирихле для электростатических линз с двумя плоскостями симметрии. ТРУДЫ II Международной научно-практической конференции «Информационные и телекоммуникационные технологии: образование, наука, практика», Алматы, Казакстан. II том. – 2015. С.155-159.

- Ibraev A. T., Sagyndyk A.B. Numerical investigation of the distribution of electrostatic potential and paraxial parameters of a box shaped cathode lens. Proceedings of the 14th European Conference on Innovations in Technical and Natural Sciences. «East West» Association for Advanced Studies and Higher Education. GmbH. Vienna. -2017. pp. 61-66.

The volume and structure of the dissertation. The thesis is set out on 109 pages of typewritten text, consists of an introduction, 4 chapters, conclusion, list of literature, including 104 titles. The work is illustrated by 2 tables and 101 drawings.