

WINSAM AND WINMAG – NEW PROGRAM PACKAGES FOR SIMULATION OF ELECTRON-OPTICAL SYSTEMS

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Abstract

In BINP new program packages WinSAM and WinMAG have been developed. The main goal of WinSAM program is the simulation of axially symmetric electron optical systems with space charge consideration. This program is the further development of SAM code with greatly improved interface and enhanced scope of considered tasks. WinMAG is developed to solve 3D non-linear magnetostatic tasks, direct integral method is used in this code. Several types of coils including user-defined coils can be entered, magnetic volumes can be described by several basic volumes.

INTRUCTION

Over the years, software packages for modeling electron-optical systems are developed in BINP SB RAS. These software packages, along with well-known commercial programs such as COMSOL Multiphysics or OPERA, are widely used in the Institute for the development of various elements of accelerators and other physical installations. Especially intensively these programs are applied at development of electron coolers. The peculiarity of some of these software packages, considered below, is the use of integral methods of calculation, allowing to maintain accuracy with relatively small number of mesh cells, which leads to a significant reduction in the calculation time.

The first of the programs considered in the article is the SAM complex, which is designed for simulation of axially symmetric electron optical systems with space charge consideration [1, 2]. These systems can include electrodes, dielectrics, coils, permanent magnets, linear ferromagnetics. Tasks with space charge can also be simulated with help of SAM program, that allows calculation of electron guns and collectors. Another program under consideration is the MAG3D complex for solving problems of nonlinear 3D magnetostatics [3].

Despite the wide application of these programs, there was a need for their further serious modernization. The most serious problem is their outdated interface. This makes it difficult for existing users to work with these programs, and prevents the attraction of new users. In addition, a confusing interface can lead to errors when specifying the geometry of the problem and the choice of calculation parameters. It is especially necessary to have a simple and intuitive interface in the program MAG3D, performing three-dimensional calculations. Updating the interface is also required for the efficient operation of the postprocessor, facilitating the output of the results of calculations. In addition, the accumulated experience with these programs allowed us to identify those areas of the computational part that need further development to improve the accuracy of calculations.

WINSAM

Basic Calculation Methods

The SAM software package is based on the method of boundary integral equations. This method uses a general solution of the Poisson equation to solve electrostatics problems:

$$\phi(\vec{r}_0) = \int_{S_e+S_d} \frac{\sigma(\vec{r}) dS}{|\vec{r}_0 - \vec{r}|} + \int_{V_b} \frac{\rho(\vec{r}) dV}{|\vec{r}_0 - \vec{r}|},$$

where S_e and S_d – surfaces of electrodes and dielectrics, V_b – volume occupied by beam space charge. Substituting this solution into boundary conditions on the surface of electrodes and dielectrics results in a system of integral equations for an unknown surface charge distribution:

$$\begin{aligned} \int_{S_e+S_d} \sigma(\vec{r}) \frac{1}{|\vec{r}_e - \vec{r}|} dS &= \varphi_e - \int_{V_b} \frac{\rho(\vec{r}) dV}{|\vec{r}_e - \vec{r}|}, \\ 2\pi \frac{\varepsilon_2 + \varepsilon_1}{\varepsilon_2 - \varepsilon_1} \sigma(\vec{r}_d) - \int_{S_e+S_d} \sigma(\vec{r}) \frac{\partial}{\partial n_d} \left(\frac{1}{|\vec{r}_d - \vec{r}|} \right) dS &= \\ = \int_{V_b} \rho(\vec{r}) \frac{\partial}{\partial n_d} \left(\frac{1}{|\vec{r}_d - \vec{r}|} \right) dV \end{aligned},$$

where \vec{r}_e and \vec{r}_d – points on the surfaces of electrodes and demarcation boundaries of dielectrics respectively. If an axially symmetric problem is considered, these equations must be integrated with respect to the angle, and the integral over the surface becomes the integral over the contours of the electrodes and dielectrics. Consideration of the problem of linear magnetostatics leads to an integral equation, similar to the second of the above, with respect to the surface density of effective magnetic charges, which describe the field induced by magnetized magnetic materials.

To solve these integral equations a collocation method with spline interpolation of the solution is used in the SAM package. A set of points is placed on the surface of the elements under consideration, the surface charge density is described by linear spline interpolation from the density values at these points. The requirement is put forward – the integral equations must be exactly fulfilled at these points. Due to these conditions, the integral equations are transformed into a system of linear algebraic equations that can be easily solved.

When calculating electron guns and collectors, the right parts of the integral equations describing the effect of the space charge are unknown in advance. In this case, a complete solution of the self-consistent problem is required, which is performed by an iterative method. At

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the beginning of the iterative process, some simple initial volume charge distribution is assumed. Integral equations are solved, surface charges are found, and it is possible to calculate the electric field at any point in space by numerical calculation of the corresponding integrals. The emission density is calculated in accordance with the given model, the trajectory analysis of the beam macroparticles is carried out. Based on the results of this trajectory analysis, the volume charge distribution is refined and a new iteration begins.

New Interface

The SAM package was originally DOS-based program. To edit the geometry of the considered task or its calculation parameters, user must make changes by outer text editor in special text file with complex structure, and then start SAM preprocessor to read this file. The calculated geometry and obtained results are shown in small fixed-sized window. All this make difficult the work with SAM program and provokes the user to make mistakes.

It was decided to create a new package with a completely changed interface, which would be similar to the interfaces of modern CAD programs. This program package was named WinSAM. The window of this program with the entered geometry of the electron gun, the calculated trajectories of the beam particles and the parameters of the formed beam at the exit of the gun are shown in Fig. 1.

In the WinSAM program, the entire workspace is divided into two windows, the left window shows the main elements of the problem geometry, the right window shows the geometry itself and the calculation results. One can create new geometry elements and edit existing ones

using the structure in the left window or directly in the right one.

The possibilities for the output of the calculation results are expanded – all the obtained data are recorded in a text file, and the resulting image can be saved in a vector format.

It is now possible to export task geometry from files of various CAD formats, as well as import the entered geometry into such files.

Increase of Accuracy of Calculations

Our experience in using SAM software has allowed us to identify areas that significantly affect the accuracy of calculations. First, it is a description of thermal emission in the presence of a strong magnetic field. In the WinSAM complex, the effect of this field has been refined.

The second problem is the insufficient accuracy of the biquadratic interpolation of the eigenfield of the beam in the mesh cells. This leads to an erroneous increase in the current density at the edges of the beam. To eliminate this effect, the approximation of the beam field on the mesh cells occupied by the beam boundary was developed.

WINMAG

Basic Calculation Methods

To solve 3D non-linear magnetostatic problems, another integral equation must be used. To obtain this equation, it is necessary to divide the magnetic field into the field of currents and the field induced by magnetized magnetic materials:

$$\vec{H} = \vec{H}_c + \vec{H}_m.$$

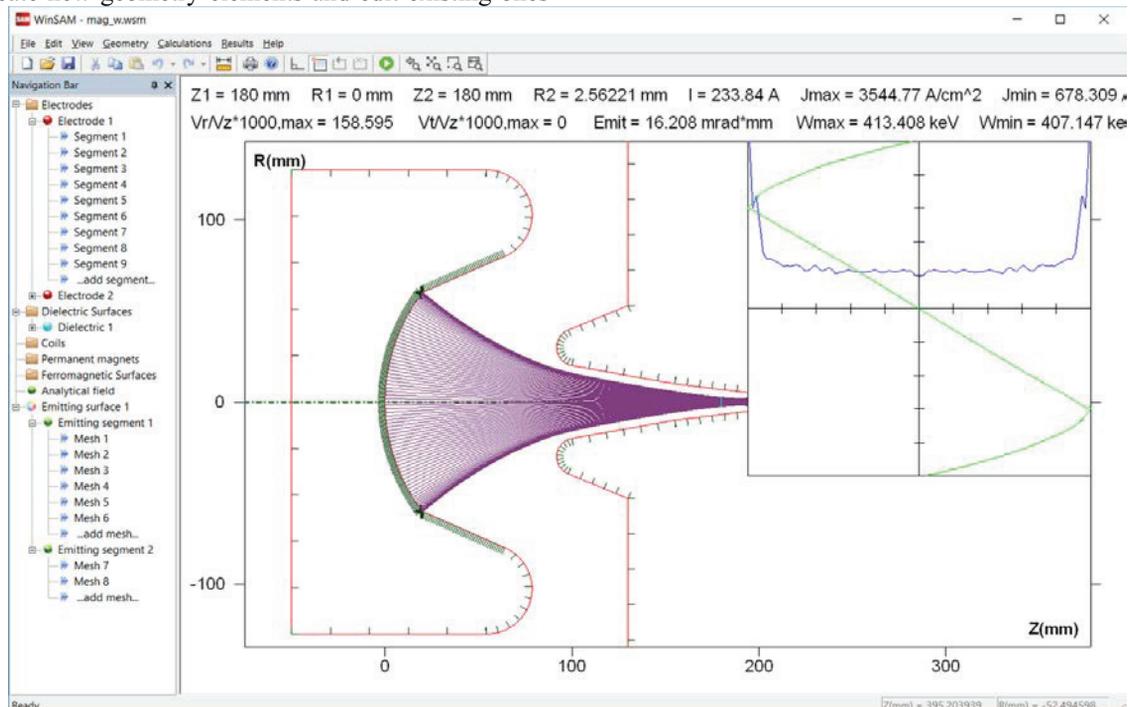


Figure 1: Example of the electron gun simulation in WinSAM. Geometry of electrodes, trajectories of particles and beam parameters are shown.

The field of currents can be directly found according to Biot-Savart law, the other field can be represented as a gradient of scalar potential, that can be found according to following expression:

$$\vec{H}_c(\vec{r}) = \frac{1}{c} \sum_{n=1}^{N_c} \int_{V_{cn}} \frac{[\vec{j}(\vec{r}') \times (\vec{r} - \vec{r}')] }{|\vec{r} - \vec{r}'|^3} dV',$$

$$\vec{H}_m(\vec{r}) = -\nabla \psi(\vec{r}), \quad \psi(\vec{r}) = \frac{1}{4\pi} \int_{V_m} \frac{\vec{M}(\vec{r}') \cdot (\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3} dV',$$

$$\vec{M} = \chi(H) \cdot \vec{H}.$$

Combining these two fields, we obtain the following integral equation for unknown magnetic field:

$$\vec{H}(\vec{r}) + \frac{1}{4\pi} \nabla \int_{V_m} \chi(H(\vec{r}')) \frac{\vec{H}(\vec{r}') \cdot (\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3} dV' = \vec{H}_c(\vec{r}).$$

In the MAG3D program the entire volume occupied by magnetic materials is divided into triangular prisms (see Fig. 2). The magnetization within each prism is assumed to be constant. The integral equation obtained above is written at the central points of these prisms. Thus, integral equation turns to a system of nonlinear algebraic equations, that can be solved. Following types of coils are implemented: a round solenoid, an O-type coil and a user-defined coil made up of straight and curved sections. Examples of these coils are shown in Fig. 3.

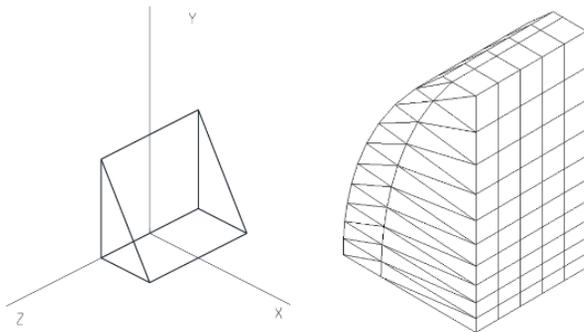


Figure 2: Basic triangular prism and division of iron volume into basic prisms.

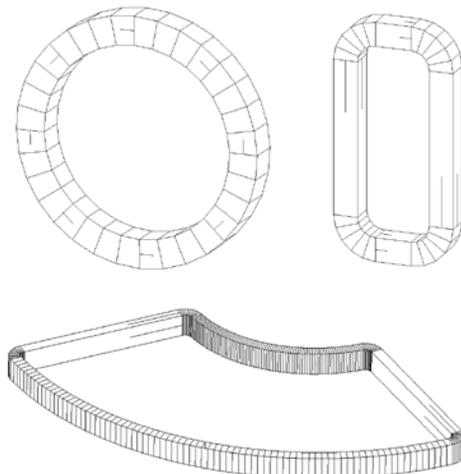


Figure 3: Types of coils implemented in MAG3D package.

New Interface

As in the WinSAM program, in the WinMAG program the entire workspace is divided into two windows, the left window shows the main elements of the problem geometry, the right window shows the geometry itself and the calculation results. One can create new geometry elements and edit existing ones using the structure in the left window or directly in the right one. The geometry of the bending magnet for an ion beam source, entered in the WinMAG program, is shown in Fig. 4.

While working with the WinMAG program all the obtained data are recorded in a text file, and the resulting image can be saved in a vector format.

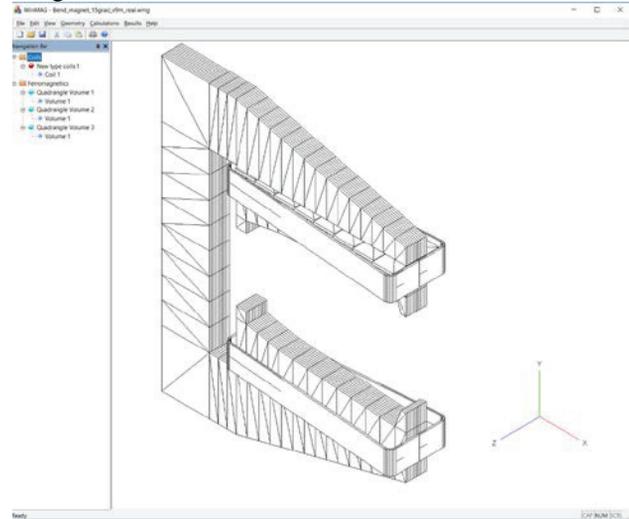


Figure 4: The geometry of the bending magnet in the WinMAG program.

CONCLUSION

In BINP for calculation of electron-optical systems on the basis of integrated methods the programs WinSAM and WinMAG were developed. These programs are based on previously created programs – SAM and MAG3D respectively. The main point of development is a qualitatively new interface, similar to the interface of modern CAD programs. In addition, the accuracy of calculations was improved and the range of tasks was expanded. New programs have been successfully applied in the development of electron coolers in the Institute [4].

REFERENCES

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