

Modeling of Electric Field created by Electronic Optical System

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Introduction

Over the last thirty years, the finite element method has been established as a powerful and widely employed numerical technique for solving electromagnetic problems. A very vigorous activity has been recorded in the area of applying the finite element method [1-3] for various 3-D electromagnetic field computations promoting this method as the most powerful and versatile numerical technique not only for electromagnetic analysis, but also for applications which span wide range of different engineering disciplines.

Electromagnetic devices have their behavior governed by the electromagnetic fields which flow in them. These fields obey Maxwell's equations, therefore, in order to be able to predict performance characteristics, it is necessary, in the course of design of these devices to solve the Maxwell equations describing the field. Differential form of the Maxwell equations has made electromagnetic field computations a heavily mathematically oriented discipline.

Fortunately, with the advent of the computers and the subsequent advances in computing power, storage devices, as well as developments in numerical techniques, it is now possible to use simple numerical approximation schemes to solve large-scale problems within reasonable time limits. In the real world, involving complex geometries and numerous electromagnetic configurations, numerical schemes yield by far more accurate solutions than their classical analysis counterparts. Nowadays, modern trends in electromagnetic field computations are almost entirely based on these numerical schemes.

Real numerical methods can be broadly divided into three separate groups: integral methods, differential methods, and variational methods. The most important and widely employed variational method today is the finite element method. Today, the finite element method is widely established procedure for analysis, optimization and design of electromagnetic devices and a large portion of modern CAD/CAM/CAE modules or expert system are partially or entirely based on this method.

Creation of EOS construction model

ANSYS/Emag 3D (ANSYS Inc.) software package, based on finite element method, was selected to simulate electric field of EOS. EOS modeling process consists of following stages: creation of libraries of electrode models

and presumable electron trajectory models; overall EOS model assembly; marking of zones with different number of finite elements and creation of finite element mesh; setting electrode potentials; electric field calculation and saving results to data files.

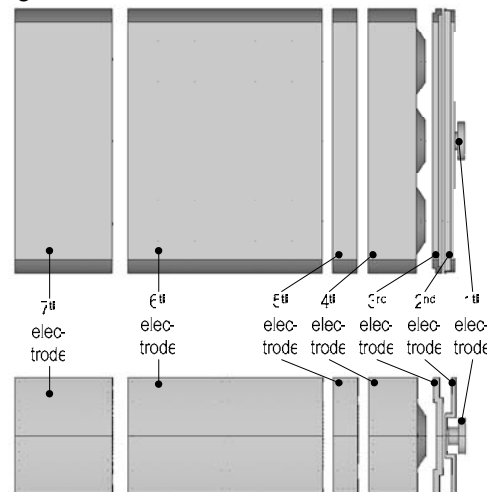


Fig. 1. EOS construction model

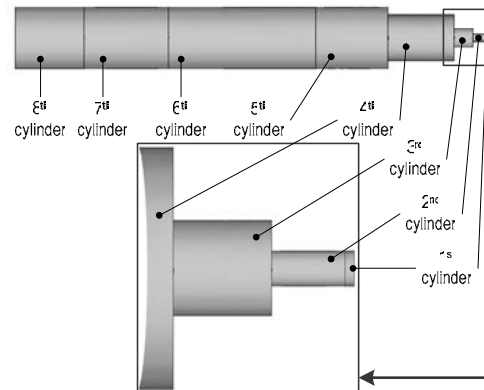


Fig. 2. Presumable electron trajectory approximated using eight cylinders

EOS construction model consists of several separate electrodes. In this case, EOS is composed of seven electrodes – cathode, modulator, first accelerating electrode, first focusing electrode, second accelerating electrode, second focusing electrode and anode. Such EOS is shown in Fig. 1 and Fig. 2.

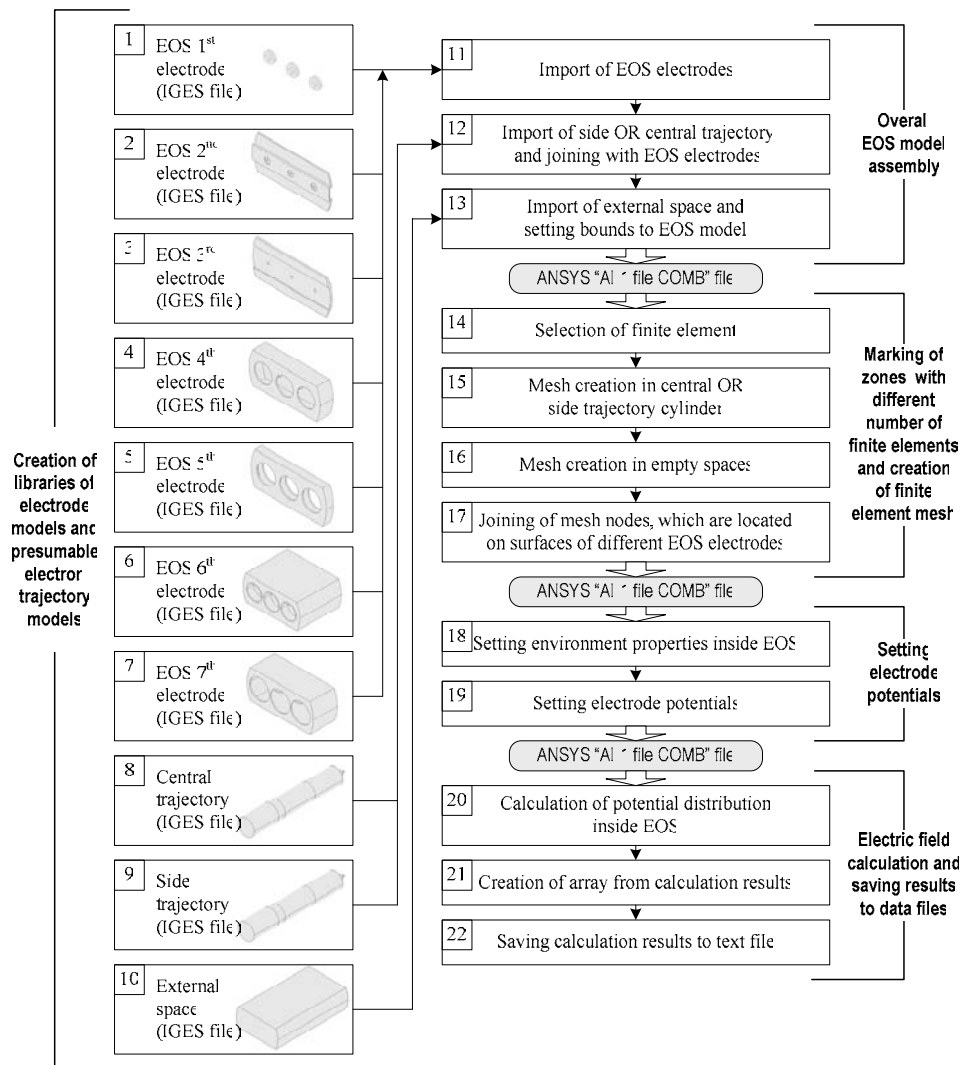


Fig. 3. EOS modeling algorithm

EOS electrodes during finite element method modeling are approximated using basic geometrical shapes (cylinders, rectangles, cones, etc.) with the help of logical operations. Then resulting overall electrode construction is saved to *IGES* file (Fig. 3). This format is widely used to describe dimensional structures in automated design systems (*AutoCAD*, *SolidWorks*, etc.).

Presumable electron trajectory zones were selected in order to reduce the calculation span. It is obvious, that electron trajectories exist only in electrode aperture regions. Thus presumable electron trajectory zones (central and side) are approximated using eight connected cylinders (Fig. 2, Fig. 4, Fig. 5). Parameters of cylinders, used to describe presumable electron trajectory, are shown in Table 1. Joint cylinder structure (Fig. 2) is saved to *IGES* file. Thus EOS separate electrode and presumable electron trajectory zone libraries are created. This library can be modified and complemented at any time.

Joint EOS model is designed by placing needed electrodes and presumable electron trajectory zones into appropriate dimensional coordinate system. Therefore there is a possibility to model any asymmetry of EOS, for example, electrodes can be shifted or rotated in respect of

x , y , z axes. Asymmetric EOS construction model, when modulator is shifted $\Delta x=0.035\text{mm}$ and $\Delta y=0.035\text{mm}$ is shown in Fig. 6.

Table 1. Parameters of side presumable electron trajectory

Presumable electron trajectory cylinders	Beginning of cylinder Z, mm	Cylinder radius, mm	Cylinder length, mm	Mesh spacing, mm
1 cylinder	5,495	0,254	0,125	0,0179
2 cylinder	5,620	0,254	0,870	0,0512
3 cylinder	6,490	0,672	1,220	0,0938
4 cylinder	7,710	1,700	5,260	0,3507
5 cylinder	12,970	2,275	5,400	0,3600
6 cylinder	18,370	2,275	11,000	1,2222
7 cylinder	29,370	2,275	6,300	0,2520
8 cylinder	35,670	2,275	5,180	0,3453

Macro commands were written using *ANSYS APDL* programming language in order to speed up model creation. Complete EOS model is written to a specific "*All 1 file COMB*" file (Fig. 3).

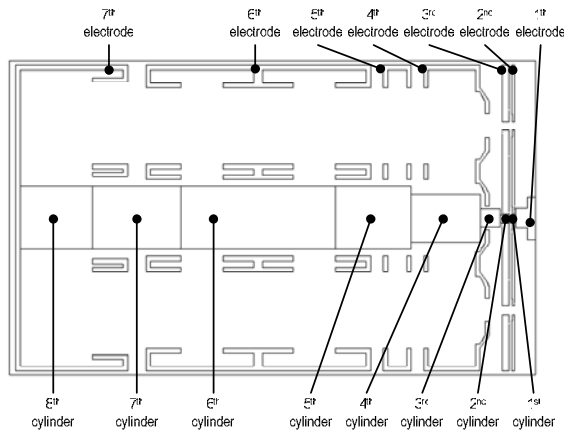


Fig. 4. EOS central electron trajectory model (section $y=0$)

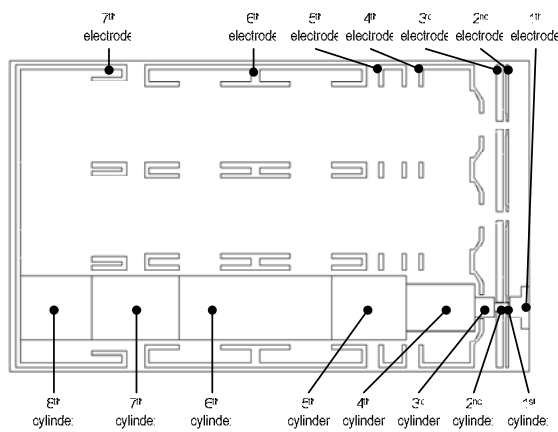


Fig. 5. EOS side electron trajectory model (section $y=0$)

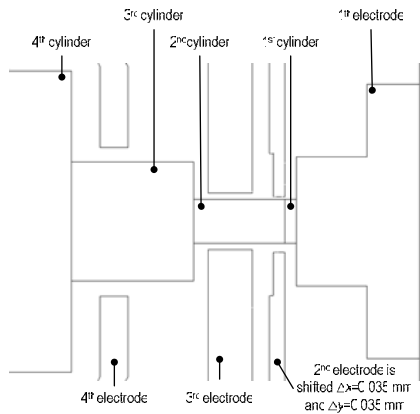


Fig. 6. Asymmetric EOS side electron trajectory model

Creation of finite element mesh

Finite element mesh was created using tetrahedral finite element *SOLID123* [4]. Finite element mesh spacing was determined for each zone individually in order to speed-up calculations. Main reason for such choice was the lack of computer resources (calculations were performed using computer with 1.5GB of random access memory and 3.0GHz processor). Small mesh spacing is defined in cylinders, which approximate presumable electron trajectories. Spacing for zone it is selected according to

Table 1 and created mesh is shown in Fig. 7. In other regions of EOS model mesh spacing is defined as large as possible (possible size is determined by *ANSYS* finite element mesh generator). Mesh is not created in EOS electrodes.

EOS construction has two symmetry planes (XOZ and YOZ), so electric field potential and strength is calculated only for two cases – for central and for one side electron trajectory traces. In first case, finite element mesh with small spacing is created in cylinders, which approximate presumable electron trajectories in the center of EOS (Fig. 4). In second case finite element mesh with small spacing is created in cylinders, which approximate presumable electron trajectory zones in one side of EOS (Fig. 5).

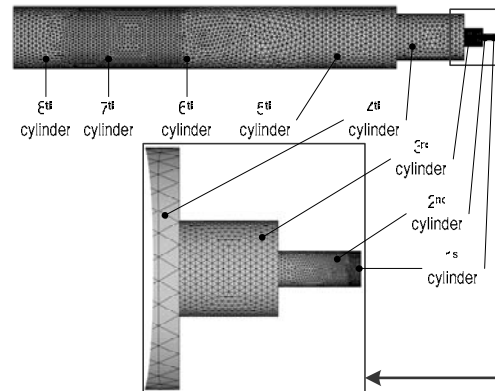


Fig. 7. Finite element mesh (view from above)

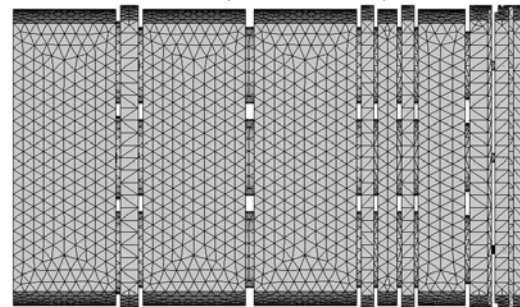


Fig. 8. Finite element mesh (view from above)

Completed finite element mesh is shown in Fig. 8. It is composed of 0.8 million tetrahedral finite elements. Completed mesh is saved to specific *ANSYS* “All 1 file COMB” file (Fig. 3).

Electric field calculation

Vacuum is a linear medium for electric field, i.e. if one electrode potential is increased by n times, electric field, created by this electrode, changes in the same way. Considering this factor we can greatly speed-up calculation of electric field if EOS construction is not modified and only electrode potentials are changed. In this case, EOS electrode partial electric field database is created. It is created in such way: potential of one electrode is chosen equal to 1V, while potentials of other electrodes are 0V and these potential values are saved to specific *ANSYS* “All 1 file COMB” file (Fig. 3). Later 1V potential is assigned to the second electrode, while potentials of other electrodes are 0V, and etc.

After performing electric field calculations results are saved to text file (Fig. 3). Such information is included in file: node numbers of finite element mesh, its coordinates x , y , z , electric field potential and electric field strength electrode E_x , E_y , E_z values of each node. In this way seven data files are created, which will be partial electric field files for particular EOS, irrespective to electrode potentials. These text files are transferred from *ANSYS/Emag* program to *MATLAB* program, for calculations of electron trajectories in electric or hybrid field and for solving electron focusing problems.

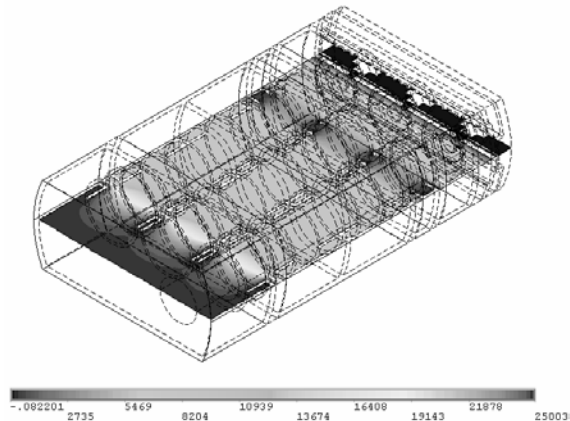


Fig. 9. Distribution of potential in section $y=0$

The value of real field at any point is found while multiplying partial electric field data by real voltage values and summing influence of all electrodes. Real potential distribution for side electron gun in horizontal ($y=0$) sections, calculated in this way, is shown Fig. 9.

Conclusions

In order to describe EOS construction, creation of electrode and presumable electron trajectory library in *IGES* format is advisable. After completing analysis of finite element mesh creation it was concluded, that finite element mesh spacing should be between 0.016mm and 1.225mm subject to presumable electron trajectory zone.

It was managed to reduce significantly calculation span with the help of EOS electrode partial field database. After performing electric field calculations with real potential values and also with $0V$ and $1V$ potentials, it was concluded, that calculation precision had not decreased.

Macro commands were written in order to assemble construction model from separate electrodes and presumable electron trajectories, to create finite element mesh, to set potentials in electrodes, to calculate electric field and to save results.

References

1. **Monk P.** Finite Element Methods for Maxwell's Equations. – Oxford: Oxford University Press, 2003. – 336 p.
2. **Jin J.** The Finite Element Method in Electromagnetics. – New York: J. Wiley & Sons, 2002. – 753 p.
3. **Backstrom, G.** Fields of Physics on the PC by Finite Element Analysis. – Lund: Studentlitteratur, 1994. – 312 p.
4. **P. Tarvydas, V. Markevičius, A. Noreika.** Elektroninės optinės sistemos modeliavimas baigtinių elementų metodu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2003. – Nr.5(47). – P. 52–55.

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P. Tarvydas, V. Markevičius, A. Noreika, E. Pačėsaitė. Elektroninės optinės sistemos sukuriama elektrinio lauko modeliavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr. 1(57). – P. 20–23.

Sukurta metodika elektrinei optinei sistemai modeliuoti baigtinių elementų metodu. Sudarytos elektroninės optinės sistemos elektrodų ir tikėtinų elektronų trajektorijų zonų bibliotekos. Atlikta baigtinių elementų tinklelio sudarymo analizė ir nustatytas baigtinių elementų tinklelio žingsnis tikėtinų elektronų trajektorijų zonose. Sudarytas tetraedrinis baigtinių elementų tinklelis. Apskaičiuoti daliniai elektriniai laukai bei elektrinis laukas esant realiems elektrodų potencialams. Parašytos bendrojo konstrukcijos modelio surinkimo, baigtinių elementų tinklelio sudarymo, elektrinio lauko skaičiavimo ir gautų rezultatų įrašymo į failus makrokomandos. Šie failai vėliau bus naudojami programoje *MATLAB* elektronų trajektorijoms skaičiuoti ir elektronų fokusuotės klausimams spręsti. Il. 9, bibl. 4 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

P. Tarvydas, V. Markevičius, A. Noreika, E. Pačėsaitė. Modeling of Electric Field created by Electronic Optical System // Electronics and Electrical Engineering- Kaunas: Technologija, 2005. – No. 1(57). – P. 20–23.

Created electronic optical system model is based on finite element method. Libraries of electronic optical system electrodes and presumable electron trajectories were made. Analysis of finite element mesh creation was completed and finite element mesh spacing was determined in the zones of presumable electron trajectories. Tetrahedral mesh was created. Partial electrical field calculations and electrical field calculations with real potential values were performed. Macrocommands for overall electronic optical system construction assembly from separate electrodes and for writing electrode potential and electric field strength values to files were created. These files will be later used in *MATLAB* program for calculation of electron trajectories in electric field and for solving electron focusing problems. Ill. 9, bibl. 4 (in English; summaries in Lithuanian, English and Russian).

П. Тарвидас, В. Марквичюс, А. Норейка, Э. Пачесайте. Моделирование электрического поля, созданного электронной оптической системой // Электроника и электротехника. - Каунас: Технология, 2005. – № 1(57). – С. 20–23.

Применяя метод конечных элементов, создана модель электронной оптической системы. Созданы библиотеки электродов и возможных электронных траекторий электронной оптической системы. Выполнен анализ создания сетки конечных элементов и определен шаг сетки конечных элементов в зонах с предвиденными траекториями электронов. Создана тетраэдральная сетка. Выполнены расчеты частных электрических полей и электрического поля при заданных реальных потенциалах. Написаны макрокоманды для создания модели электронной оптической системы из отдельных компонентов, для сохранения значений потенциала и силы электрического поля электродов на файлы. Эти файлы будут позже использоваться в программе *MATLAB* для расчета траекторий электронов в электрическом поле и для решения вопросов фокусирования. Ил. 9, библи. 4 (на английском языке; рефераты на литовском, английском и русском яз.).