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Analysis of Finite Element Mesh Spacing Influence on Modeling Results

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Introduction

The finite element analysis of any problem involves basically four steps [1, 2]: discretizing the solution region into a finite number of subregions or elements; deriving governing equations for a typical element; assembling of all elements in the solution region; solving the system of equations obtained.

During modeling of electronic devices by finite element technique much of the time is consumed for finite element mesh generation. It is important to select proper finite element shape (tetrahedral, hexahedral, etc.) and their size in different model areas. The precision of modeled electronic device construction description depends on the shape of the finite elements and their size. Number of finite elements (number of finite element mesh nodes) determine how long it will take to form the system of equations and to solve it. A problem of generation of optimal mesh (according to various criterions) emerges when solving various modeling tasks, for example, during modeling of electronic optical system (EOS) of colour picture tubes.

EOS construction model

Modeling of EOS (Fig. 1) is performed by finite element analysis software package ANSYS/Emag (ANSYS Inc.) [3–6].
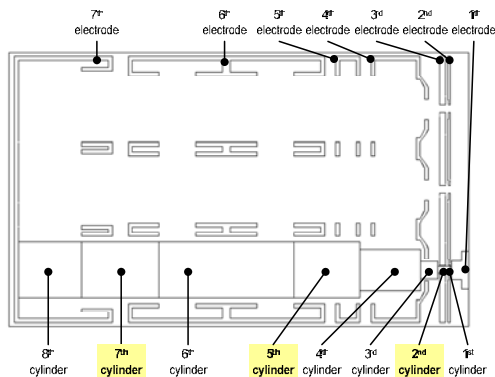

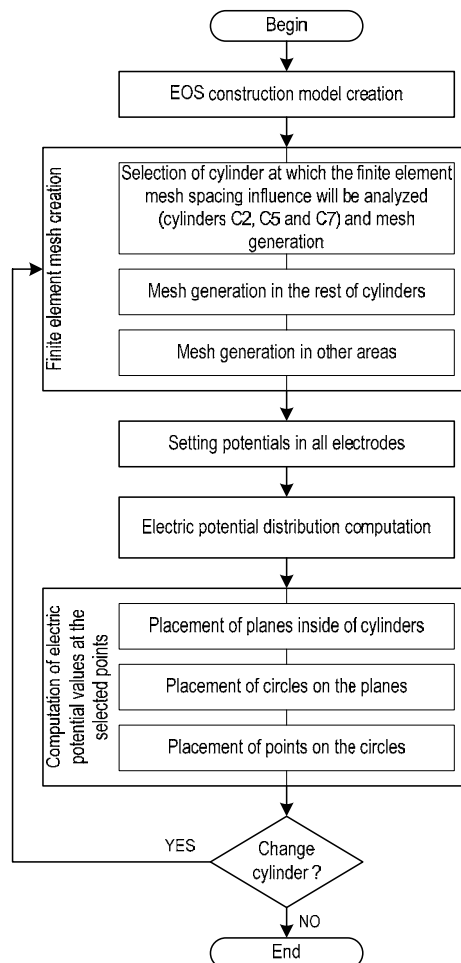**Fig 1.** Colour TV-tube EOS construction model (section *x*=0 mm)

Fig 2. Analysis of finite element mesh spacing influence in presumable electron trajectory cylinders *C2, C5* and *C7*

Modeled EOS consists of seven electrodes; presumable electron trajectory geometrical model, consisting of eight cylinders, is placed along the centers of the electrode holes. [3, 4]. General modeling algorithm of such EOS is shown in Fig. 2. Algorithm is slightly modified for analysis of finite element mesh spacing influence on precision of modeling results.

Finite element mesh generation

Finite element mesh is created using finite tetrahedral element *SOLID123* [3, 4]. In order to increase calculation speed different finite element mesh spacing is set in different model zones. "Dense" mesh is formed in presumable electron trajectory cylinders (Fig 1), and mesh spacing is set as large as possible in the rest space of the model. Mesh is not created in electrodes.

Table 1. Parameters of side presumable electron trajectory cylinders

Trajectory cylinder parameters	Trajectory cylinder		
	C2	C5	C7
Beginning of Z coordinate in the global coordinate system Z ($C?\_Z$), mm	0,000	7,475	23,875
Radius ($C?\_R$), mm	0,3675	2,2750	2,2750
Length ($C?\_LENGTH$), mm	0,870	5,400	6,300
Divided ($C?\_MESH\_PARTS$), number of parts	19	15	25
Mesh spacing ($C?\_MESH$), mm	0,0512	0,3600	0,4200
Number of planes in cylinder ($C?\_SECTIONS$), units	10	8	13
Number of circles in the plane ($C?\_CIRCLES$), units	5	5	5
Number of points in the circle ($C?\_POINTS$), units	12	12	12

Finite element mesh parameters for cylinders of presumable electron trajectory are described in ASCII format text files and presented in Table 1. In these files parameter $C?\_MESH\_PARTS$ is set for each cylinder (it is presented in Table 1 for cylinders *C2*, *C5* and *C7*), and this parameter indicates into how many segments cylinder will be divided along longitudinal axis when creating finite element mesh. Number of segments must always be uneven. Finite element mesh spacing is calculated in this manner: $C?\_MESH=C?\_LENGTH/C?\_MESH\_PARTS$. In the rest space of calculating model a default *ANSYS/Emag* finite element mesh spacing is formed. At first mesh is created in cylinders of presumable electron trajectory, and then in the remaining space. Optimal mesh spacing was determined after completing a series of experiments [3, 4].

Calculation of electrical potential in trajectory cylinders

After generation of finite element mesh, respective electrode electric potential values are set (Table 2). Electric potential values are calculated at points, which are located inside trajectory cylinders. Planes are placed inside of trajectory cylinders perpendicularly to longitudinal axis of cylinders (Fig. 2). Circles are formed on the planes, on which points are placed (Fig. 3). Number of planes, circles and points can be freely changed by user. These numbers for cylinders C2, C5 and C7 are presented in Table 1.

Table 2. Values of electric potential in electrodes

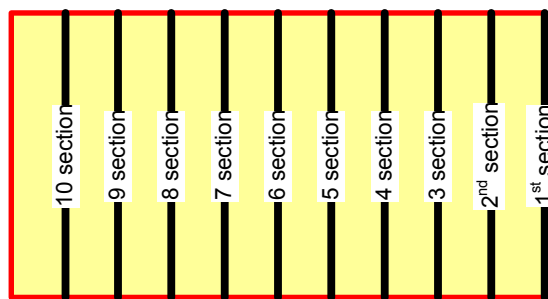| Elektrodas	E1	E2	E3	E4	E5	E6	E7
Potencialas, V	40	0	400	8000	400	8000	25000

Fig. 3. Section placement in the presumable electron trajectory cylinder *C2* (section *x*=6.604 mm)
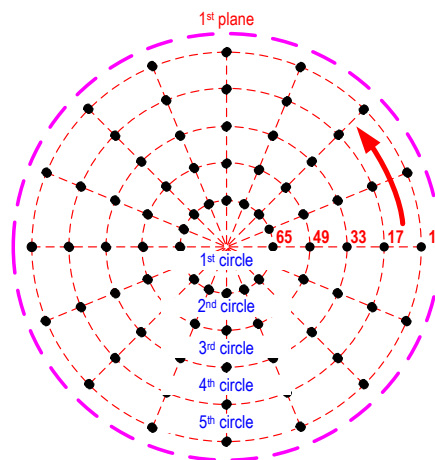

Fig. 4. Placement of circles and points, at which electric potential values are calculated

Parameters of points, at which electric potential values are calculated, are defined in ASCII format text files. Values which are set in file (Table 1): $C?\_SECTIONS$ – number of planes in the cylinder; $C?\_CIRCLES$ – number of circles on the plane; $C?\_POINTS$ – number of points on the circle; $C?\_CIRCLES\_R\_COEFFICIENT$ – circle radius decrement factor. Circle radius must be shorter than radius of the corresponding trajectory cylinder ($C?\_CIRCLES\_R\_COEFFICIENT$ value can not be higher than 0,98).

```
C1_SECTIONS=(C1_MESH_PARTS+1)/2
*DIM,Z,ARRAY,C1_SECTIONS,0,0, , ,
C1_MESH=C1_LENGTH/C1_MESH_PARTS
TEMP=C1_MESH
*do,i,1,C1_SECTIONS,1
    Z(i)=C1_Z+TEMP
    TEMP=TEMP+2*C1_MESH
*enddo
```

Fig. 5. $Z(i)$ coordinate array formation for planes, which are located inside trajectory cylinder *C1*

Plane coordinate *z* array $Z(i)$ formation procedure is shown in Fig. 5, where $C1\_SECTIONS$ – number of planes in trajectory cylinder *C1*; $C1\_MESH\_PARTS$ – number of cylinder divisions, *C1*; $C1\_LENGTH$ – length of the cylinder *C1*; $C1\_MESH$ – finite element mesh spacing, mm; $C1\_Z$ – the beginning of the cylinder C1; *TEMP* – coordinate Z variation step. Arrays $Z(i)$ for other cylinders are created in the same manner.

```
C1_CIRCLES=CIRCLES
C1_R_STEP=C1_R*C1_CIRCLES_R_COEFFICIENT/
/(C1_CIRCLES-1)
C1_R_PATH_CHANGE=0
*DIM,R,ARRAY,C1_CIRCLES,0,0, , ,
*do,i,1,C1_CIRCLES,1
    R(i)=C1_R*C1_CIRCLES_R_COEFFICIENT-
    -C1_R_PATH_CHANGE+0.001
    C1_R_PATH_CHANGE=C1_R_PATH_CHANGE+
    +C1_R_STEP
*enddo
```

Fig. 6. Radius $R(i)$ array formation for circles, which are placed on planes

Circle radius array $R(i)$ formation procedure is shown in Fig. 6, where: *C1_CIRCLES* – number of circles on the planes of cylinder C1; *C1_R_STEP* – circle radius variation step, mm. Arrays $R(i)$ for other planes are created also in the same manner.

Electric potential values calculated at these points are saved to ASCII format text file. In the real modeling these files from *ANSYS/Emag* program are transferred to *MATLAB* program, in which they are used to calculate electron trajectories in electric or hybrid field and to solve electron focusing problems. In the considered case these files are used for the research of finite element mesh spacing influence on modeling results.

Analysis of mesh spacing influence

The investigation of influence of mesh spacing on the modeling results is performed in trajectory cylinders *C2*, *C5* and *C7*. These cylinders are selected because they are located at the zones of EOS at which the biggest change of electric potential is observed (Fig. 1, Table 2).

Table 3. Parameters for trajectory cylinder *C2*

Variant	C2_MESH_PARTS	C2_MESH
1	5	0.174000
2	7	0.124286
3	9	0.096667
4	11	0.079091
5	13	0.066923
6	15	0.058000
7	17	0.051176
8	19	0.045789

Table 4. Parameters for trajectory cylinder *C5*

Variant	C5_MESH_PARTS	C5_MESH
1	5	1.080000
2	7	0.771429
3	9	0.600000
4	11	0.490909
5	13	0.415385
6	15	0.360000

Table 5. Parameters for trajectory cylinder *C7*

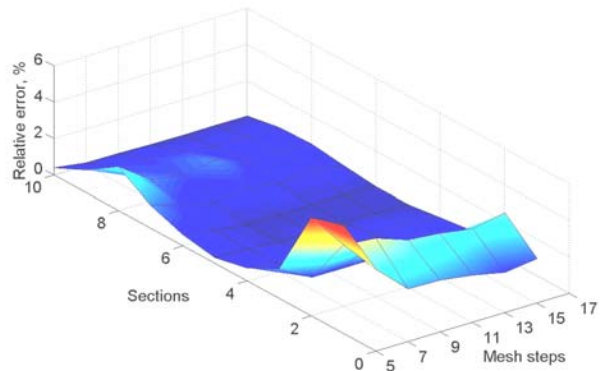| Variant	C7_MESH_PARTS	C7_MESH
1	5	1.260000
2	9	0.700000
3	13	0.484615
4	17	0.370588
5	21	0.300000
6	25	0.252000

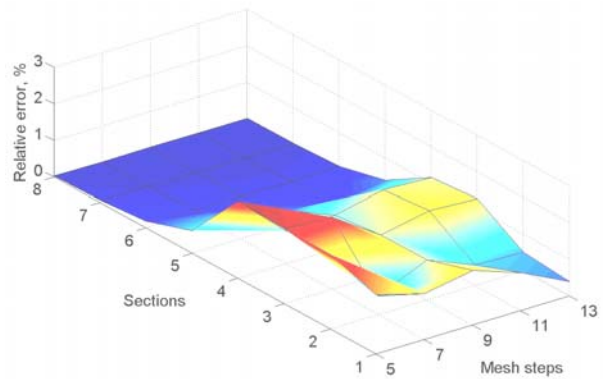**Fig. 7.** The dependence of relative error on mesh spacing in cylinder *C2*

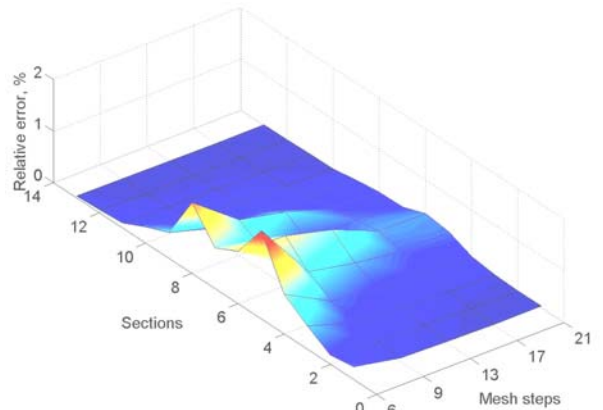**Fig. 8.** The dependence of relative error on mesh spacing in cylinder *C5*

Fig. 9. The dependence of relative error on mesh spacing in cylinder *C7*
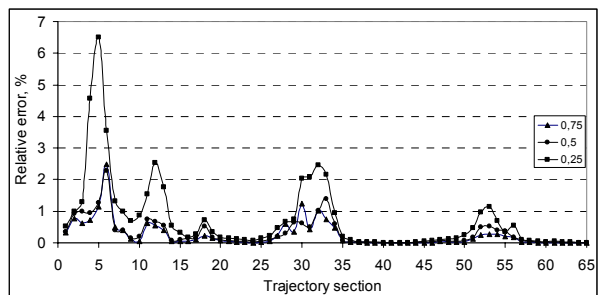

Fig. 10. The dependence of relative error on mesh spacing in entire trajectory zone

During investigation of mesh spacing influence on modeling results the number of planes, circles and points located on them remains constant and for cylinders *C2*, *C5* and *C7* is selected according to the Table 1.

Finite element mesh spacing in trajectory cylinders *C2*, *C5* and *C7* is calculated on the base of data which is presented in tables 1, 3–5 and formula *C?_MESH=C?_LENGTH/C?_MESH_PARTS*.

Eight mesh spacing influence investigation variants are calculated in the case of cylinder *C2*, and six variants in the case of cylinders *C5* and *C7* (Tables 3–5). Modeling algorithm is presented in Fig. 1. Received modeling results were processed statistically.

Conclusions

After statistical processing of modeling results it was found, that highest modeling errors were received at those model zones, where highest change of defined potentials is observed.

Highest error of trajectory cylinder *C2* is 6.0 % (when cylinder is divided into 5 planes); in *C5* – 2.1 % (when cylinder is divided into 5 planes); in *C7* – 1.7 % (when cylinder is divided into 5 planes).

When mesh spacing is proportionally increased in all trajectory cylinders, the following highest errors are received: when mesh spacing is increased by 1/4 the relative error is 2.3 % (cylinder *C2*, plane 1, circle 1, point 1); 2/4 – 2.5 % (cylinder *C2*, plane 2, circle 1, point 9); 3/4 – 6.5 % (cylinder *C2*, plane 2, circle 1, point 11).

Created mesh spacing influence assessment technique and algorithms can be applied not only in case of EOS modeling, but also when modeling other electronic devices.

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3. **Tarvydas P., Markevičius V., Noreika A.** Modeling of Electronic Optical System for TV Tube using Finite Element Method // Rigas Tehniskas universitates zinatniskie raksti. 7.Serija: Telekomunikacijas un elektronika. – Riga, 2003, Sejums 3. – P. 55–58.
4. **Tarvydas P., Markevičius V., Noreika A.** Elektroninės optinės sistemos modeliavimas baigtinių elementų metodu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2003. – Nr.5(47). – P. 52–55.
5. **Tarvydas P., Markevičius V., Noreika A.** Modeling of Asymmetric Electronic Optical System // BEC 2004. Proceedings. – Tallinn, 2004. – P. 67–70.
6. **Tarvydas P., Markevičius V., Noreika A., Pačėsaitė E.** Modeling of Electric Field created by Electronic Optical System // Electronics and Electrical Engineering- Kaunas: Technologija, 2005. – No.1(57). – P. 26–29.

P. Tarvydas, A. Noreika. Analysis of Finite Element Mesh Spacing Influence on Modeling Results // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. – No. 5(69). – P. 91–94.

A technique for analysis of finite element mesh spacing influence on modeling results was created. Colour picture tube electronic optical system was used for modeling purposes. Modeling was performed by finite element analysis software package *ANSYS/Emag*. Modeling algorithm and macro commands were designed. Tetrahedral finite elements *SOLID123* were used during mesh generation. Mesh spacing influence was analyzed in those zones of electronic optical system where biggest electric potential change is observed, so it is advisable to assess that when selecting mesh spacing. Created mesh spacing influence assessment technique and algorithms can be applied not only to model electronic optical system, but also to solve other modeling problems. Ill. 10, bibl. 6 (in English; summaries in English, Russian and Lithuanian).

П. Тарвидас, А. Норейка. Анализ влияния интервала петли конечных элементов на результаты моделирования // Электроника и электротехника. – Каунас: Технология, 2006. – № 5(69). – C. 91–94.

Создана методика для анализа влияния интервала петли конечных элементов на результаты моделирования. Для моделирования использовалась электронная оптическая система цветовых кинескопов. Моделирование было выполнено пакетом программ анализа конечных элементов *ANSYS/Emag*. Разработан алгоритм моделирования и макрокоманды. Конечные элементы формы тетраэдра SOLID123 использовались для генерации петли. Влияние интервала петли было проанализировано в тех зонах электронной оптической системы, где существует самое большое изменение электрического потенциала. Поэтому, выбирая интервал петли желательно это оценить. С помощью созданной техники и алгоритмов оценки влияния интервала петли возможно применять не только для моделирования электронной оптической системы, но и для решения других задач моделирования. Ил. 10, библ. 6 (на английском языке; рефераты на английском, русском и литовском яз.).

P. Tarvydas, A. Noreika. Baigtinių elementų tinklelio žingsnio įtakos modeliavimo rezultatams analizė // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. – Nr. 5(69). – P. 91–94.

Sukurta metodika baigtinių elementų tinklelio žingsnio įtakai modeliavimo rezultatams tirti. Modeliavimui naudota spalvotųjų kineskopų elektroninė optinė sistema. Modeliavimas atliktas baigtinių elementų analizės programa *ANSYS/Emag*. Sudarytas modeliavimo algoritmas ir makrokomandos. Tinkleliui sudaryti naudoti tetraedro formos baigtiniai elementai *SOLID123*. Žingsnio įtaka tirta tose elektroninės optinės sistemos srityse, kuriose yra didžiausias potencialo pokytis. Atlikus gautų rezultatų analizę nustatyta, kad, didinant baigtinių elementų tinklelio žingsnį, modeliavimo paklaida labiausiai padidėja didžiausio potencialo pokyčio srityse, todėl, parenkant tinklelio žingsnį, reikia į tai atsižvelgti. Sukurtus tinklelio žingsnio įtakos įvertinimo algoritmus ir metodiką galima taikyti ne tik elektroninės optinės sistemos, bet ir kitiems modeliavimo uždaviniams spręsti. Il.10, bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).