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Influence of the Thermal EOS Deformations on the Modulation Characteristics

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Introduction

The actual technical parameters of all of the real electron optical systems (EOS) are dependant on the geometry of their elements, which, being influenced by the thermal fields, are deforming, altering the distribution of the electric fields. This is why the simulation of the electric fields commonly with the influence of the thermal fields on the geometry and spatial orientation of the EOS elements may explain certain disagreements between the experimental results and the results of simulations. Therefore, the adequate method for the calculation of the parameters of the actual EOS has to incorporate the evaluation of the thermal fields.

Finite elements method and the tool, which implements this method (*ANSYS*) was selected to evaluate the influence of thermal fields. Thus the EOS model was made of cathodes, modulator, accelerating electrode and these elements were fixed in the glass ceramics. [1]. It was determined by modelling, that cathodes tend to deform towards the modulator, the surface of the modulator is also slightly approaching the cathodes, and the distance between the accelerating electrode and the modulator is also decreasing. In the working regime the decrease of the distances are as follows: between cathodes and modulator more than 30 µm; between modulator and accelerating electrode up to 30 µm. The elements of EOS are also moving to the x and y directions and these deformations also have influence on the EOS modulation characteristics. Therefore, after calculating the temperature induced deformations of EOS electrodes, the influence of them to the modulation characteristics was evaluated. Consequently the experimental research [2] and the calculation of modulation characteristics were done.

Distribution of the electric field near the cathode

The emission current I_K, passing the cathode, can be calculated by Childs–Langmuir law, if the potential distribution near the cathode is known [3]:

$$I_K = S\cdot\frac{4\varepsilon_0\sqrt{2e/m}}{9d^2}(V-V_0)^{3/2}; \qquad (1)$$

here S – area of the cathode emitting surface, ε_0 – dielectric permeability of vacuum, e ir m – charge and mass of the electron, V – potential of the plane, being at the distance d from the cathode, V_0 – potential of electrons in the cathode surface plane.

Distribution of the electric field near the emitting surface of cathodes was calculated by the finite elements method. It was determined, that the influence of electrodes distributed after accelerating electrode is minor to the cathodes emitting current. Therefore, the model for evaluation of potential distribution consists only of cathodes, modulator and accelerating electrode. The space, close to the cathodes, was approximated by the plates with the regular grid of the finite elements (Fig. 1).

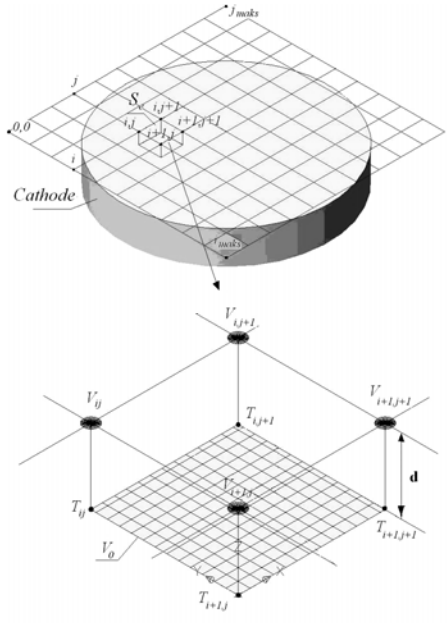


Fig. 1. The grid of finite elements near the cathode emitting surface

Vacuum is a linear medium for electric field, so if one electrode potential is increased by *n* times, electric field, created by this electrode, changes in the same way. Therefore it is enough to calculate the influence functions of the each electrode. So, this simplification was taken into account and the values of the influence functions of cathodes $\varphi_{K,ij}$ and accelerating electrode $\varphi_{G,ij}$ were written as the data files [4]. 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: $U(z,r)=\sum_{i=1}^{n}\varphi_i(z,r)U_i$; where φ_i and U_i – the influence function and the potential of the *i* electrode.

Emission current

In the equation (1) the initial velocities of electrons are underrated. But in real EOS the emitting surfaces of the cathodes were supposed to be heated initially, therefore giving some initial temperature dependant velocity to the electrons. Thus the potential difference ΔU_0, corresponding to the initial velocity of the electrons was estimated. For this purpose the temperature maps $T_{K,xy}$ of the emitting surfaces were extracted from the calculated distribution in EOS temperature data. They were interpolated and the values of the temperature $T_{K,i,j}$ in the nodes of the regular grid over the front surfaces of the cathodes. With all this data, the cathode current I_K was calculated as the arithmetical sum of the elementary cathode currents $I_{K,e,ij}$ (Fig. 2) in each of the elementary areas S_e of the grid:

$$I_K = \sum_{i=0}^{i_{\max}-1}\sum_{j=0}^{j_{\max}-1} I_{K,e,ij} \;. \qquad (2)$$

The average temperature and potential of each elementary area was calculated as follows:

$$T_{K,e,ij} = 0.25\left(T_{K,ij} + T_{K,i+1,j} + T_{K,i,j+1} + T_{K,i+1,j+1}\right), \quad (3)$$

$$V_{e,ij} = 0.25\left(V_{ij} + V_{i+1,j} + V_{i,j+1} + V_{i+1,j+1}\right); \qquad (4)$$

here $V_{ij} = U_K\varphi_{K,ij} + U_g\varphi_{G,ij}$ (U_K, U_g – voltage of cathode and accelerating electrode). When the potential distribution near the surface of the cathode is evaluated through the calculation of the influence functions of the electrodes, the emission current for the elementary area of the cathode can be calculated as follows:

$$I_{K,e,ij} = S_e \cdot \frac{4\varepsilon_0\sqrt{2|e|/m}}{9} E_{K,e,ij}^{3/2}\left(\varphi'_{K,e,ij}\right)^{1/2}; \qquad (5)$$

here $\varphi'_{K,e,ij}$ – average value of the fluxion of the function of the influence of the elementary cathode area, $E_{K,e,ij}$ – average value of the electric field strength near the surface of the cathode, can be calculated by the equation:

$$\begin{cases} E_{K,e,ij} = \dfrac{V_0 - V_{e,ij} + \Delta U_{0,e,ij}}{d}, \\ \Delta U_{0,e,ij} = \dfrac{k_B T_{K,e,ij}}{e}; \end{cases} \qquad (6)$$

here k_B – Boltzmann constant.

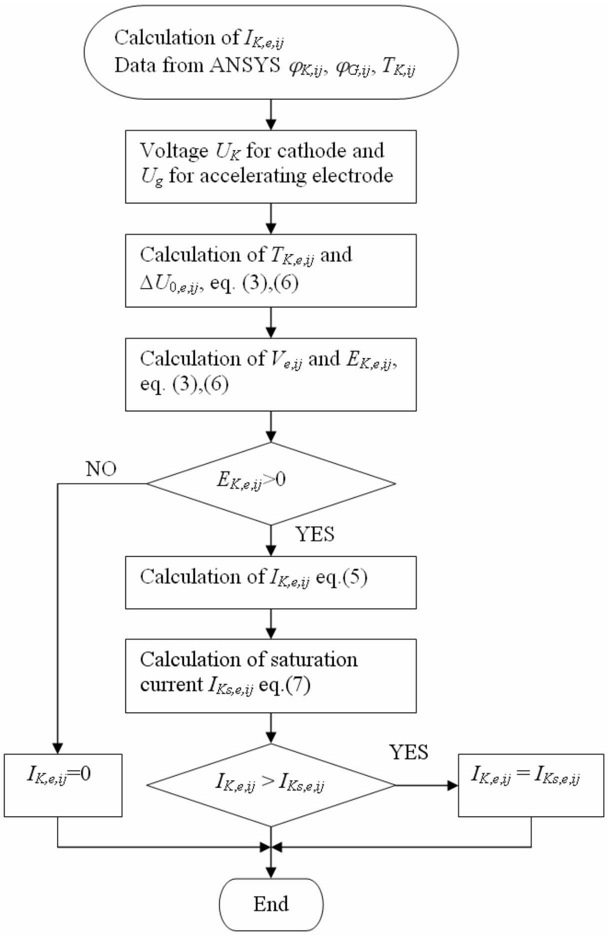
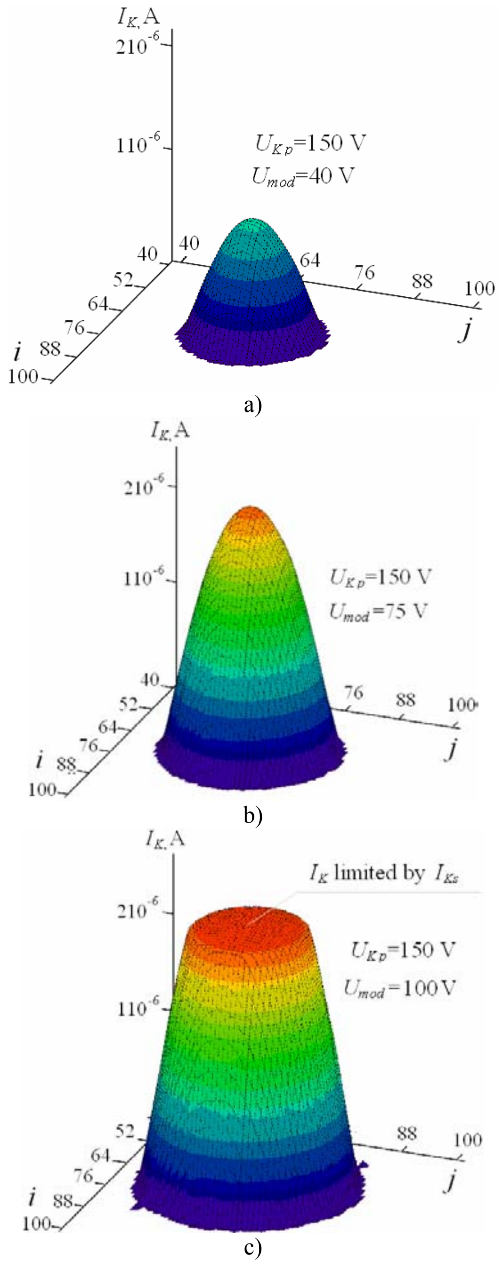


Fig. 2. The algorithm of calculation of the elementary cathode area current

If the cathode temperature is not changing, the cathode current is able to reach some saturation value, which can be slightly increased, if an electric field applied to the electrodes. This current is calculated by the Richardson-Dushman equation with the Shottky effect. It can be written for the any elementary area as follows:

$$I_{Ks,e,ij} = S_e \cdot A^* T_{K,e,ij}^2 \mathrm{e}^{\frac{-e\left(\phi_0 - \Delta\phi_{e,ij}\right)}{k_B T_{K,e,ij}}}; \qquad (7)$$

here A^* – Richardson constant, theoretically equal for every metal, but in fact is dependant on the cathode material ($A^* = 0{,}85\cdot10^6$ A/m²K² for oxide cathodes), ϕ_0 – work of exit of electrons ($\phi_0 = 1{,}5$ eV for oxide cathodes). Shottky effect in each area S_e: $\Delta\phi_{e,ij} = \sqrt{\frac{e^3 E_{K,e,ij}}{4\pi\varepsilon_0}}$. So, calculated value of the elementary area current $I_{K,e,ij}$ by the eq. (5) has not to overcome the saturation current $I_{Ks,e,ij}$.. The results of calculation of the cathode emission current are given in Fig. 3: in a) and b) figures the current is not limited by saturation current and calculated by eq. (5); in c) figure in some elementary areas the value of the current $I_{K,e,ij}$ overcomes the value of saturation current $I_{Ks,e,ij}$. In these areas the current is equal to saturation current calculated by eq. (7).



a)

b)

c)

Fig. 3. Alternation of the cathode emission current dependant on the modulation voltage

During the experimental research the initial voltage U_{Kp} was applied to the cathode (voltage of modulator was 0 V) and the voltage of accelerating electrode U_g was changed until the appropriate colour beam was opened. This voltage of accelerating electrode was fixed. Than the voltage of cathode U_K was lowered until zero and the cathode current I_K was fixed. The modulation voltage U_{mod} was calculated: $U_{mod} = U_{Kp} - U_K$. The experiments were done at two initial cathode voltages $U_{Kp} = 100\,\text{V}$ and $U_{Kp} = 150\,\text{V}$. So, the calculations of emission current were done in the same way. First of all, holding the initial voltage U_{Kp}, the voltage of accelerating electrode, at which the cathode is open ($I_K \approx 1\,\mu\text{A}$), was adjusted. The algorithm of adjustment of accelerating electrode voltage is given in Fig. 4. Then, changing the voltage of the cathode, the emission current I_K was evaluated.

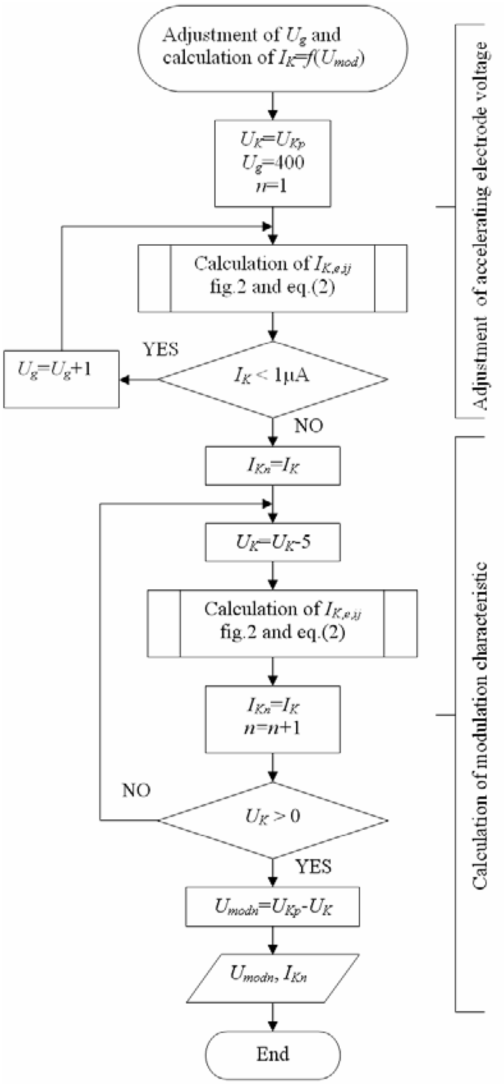


Fig. 4. The algorithm of adjustment of accelerating electrode voltage and calculation of modulation characteristics

In the way described above the calculations for the cold and deformed by the heat EOS were performed. In the first case the electrode influence functions near the surfaces of the cathodes were calculated for the optics, drawn regarding to the technical drawings of the assembly. In the second case the calculated temperature induced deformations u_{xyz} were transferred to the cathodes and electrodes of EOS. After forming the new geometry of EOS the influence functions values were calculated again. The currents of the each cathode and the resulting modulation characteristics were calculated for each case for comparison (Fig. 5a). The calculations were performed with the distance d = 1 µm between the emitting surface of the cathode and the regular grid with the 5 μm step of the grid. The experimental and calculated results of deformed EOS were compared too. (Fig. 5 b).

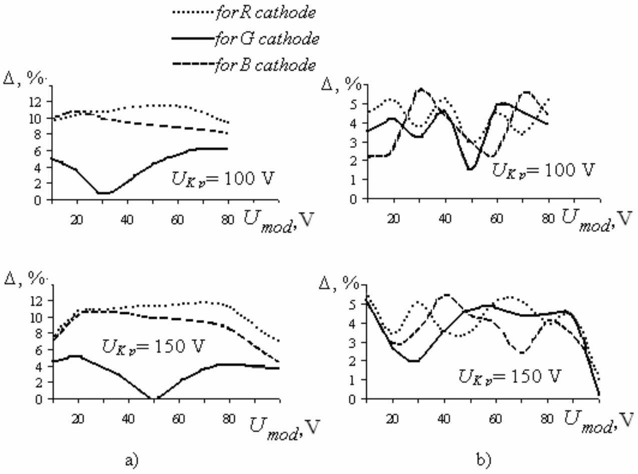


Fig. 5. Deviations of EOS modulation characteristics: a) comparison of calculation results; b) comparison of calculation and experimental results.

Conclusions

From the presented results one can conclude that in the case of the deformed optics the emission current is larger than in the case of full correspondence to the technical drawings. The currents of the *R* and *B* cathodes are larger for approximately 12%, and the current of the *G* cathode – up to the 5 %. This is because the temperature induced deformations of the modulator and the accelerating electrode in the area of *G* cathode are minimal. The calculation results for the deformed optics are much closer to the experimental ones (only up to 5% deviations). Therefore it can be stated that evaluation of the temperature induced deformations give significant accuracy potential to the results of calculation of the cathodes currents.

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The actual technical parameters of all of the real electron optical systems (EOS) are dependant on the geometry of their elements, which, being influenced by the thermal fields, are deforming, altering the distribution of the electric fields. Finite element method and the tool, which implements this method (*ANSYS*), was selected to evaluate the influence of thermal fields. The evaluation of temperature induced deformations of EOS electrodes was done and the influence of them on the modulation characteristics was checked. It was found, that in the case of the deformed optics the emission current is larger than in the case of full correspondence to the technical drawings. The currents of the *R* and *B* cathodes are larger for approximately 12%, and the current of the *G* cathode – up to the 5 %. This is because the temperature induced deformations of the modulator and the accelerating electrode in the area of *G* cathode are minimal. The calculation results for the deformed optics are much closer to the experimental ones (only up to 5% deviations). Therefore it can be stated that evaluation of the temperature induced deformations give significant accuracy potential to the results of calculation of the cathodes currents. Ill 5, bibl. 4 (in English; Summaries in English, Russian and Lithuanian).

Л. Якучёнис, В. Синкявичюс, Л. Шумскене. Влияние температурных деформаций ЭОС на модуляционную характеристику // Электроника и электротехника. – Каунас: Технология, 2006 – № 1(73). – С. 17–20.

Параметры всех реальных электронных оптических систем (ЭОС) зависят от геометрии их элементов, на которую в рабочем состоянии воздействуют тепловые поля и так изменяют распределение электрических полей. Для исследования влияния тепловых полей был выбран метод конечных элементов и программный пакет ANSYS. Произведены расчёты деформации электродов ЭОС и проверено их влияние на модуляционную характеристику ЭОС. Установлено, что ток эмиссии в деформированной ЭОС больше по сравнению с ЭОС, которая соответствует сборочному чертежу. Ток катодов *R* и *B* больше на 12 %, а для *G* катода – до 5 %. Для *G* катода из за температурных деформаций изменения расстояний между катодом и модулятором, а также между модулятором и ускоряющим электродом в области отверстия для этого катода получились наименьшие. Вычисленные и экспериментально измеренные токи катодов различаются только до 5 %. Таким образом можно утверждать, что при расчёте токов ЭОС катодов обязательно нужно учитывать температурные деформации катодов и электродов ЭОС. Ил. 5, библ. 4 (на английском языке, рефераты на английском, русском и литовском яз.).

L.Jakučionis, V. Sinkevičius, L. Šumskienė. Temperatūrinių EOS deformacijų įtaka moduliacinei charakteristikai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006 – Nr. 1(73). – P. 17–20.

Visų realių elektroninių optinių sistemų (EOS) parametrai priklauso nuo jų elementų geometrijos, kuri darbo metu veikiama šiluminių laukų, deformuojasi ir taip pakeičia elektrinių laukų pasiskirstymą. Šiluminių laukų įtakai nustatyti buvo pasirinktas baigtinių elementų metodas ir juo paremtas programų paketas ANSYS. Atlikti EOS elektrodų deformacijų nuo temperatūros skaičiavimai ir patikrinta jų įtaka EOS moduliacinei charakteristikai. Nustatyta, kad deformuotoje EOS emisijos srovė gaunama didesnė nei EOS, kuri atitinka surinkimo brėžinį. *R* ir *B* katodų srovės didesnės apie 12 %, o *G* katodo – iki 5 %. *G* katodui dėl temperatūrinių deformacijų atsiradę atstumų tarp elektrodų pokyčiai yra mažiausi. Apskaičiuotos ir gautos eksperimentinių tyrimų metu katodų srovės skiriasi tik apie 5 %. Todėl galima teigti, kad, skaičiuojant EOS katodų sroves, reikia atsižvelgti į temperatūrines EOS katodų ir elektrodų deformacijas. Il. 5, bibl. 4 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).