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Analysis of Electrode Temperature Influence on EOS Parameters

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Introduction

Variation of electronic optical system (EOS) parameters varies these important parameters of the kinescopes, monitors or electronic microscopes, as resolution, image brightness, contrast and other. Therefore, the parameters of EOS – geometry, voltage and position of electrodes, have to be optimized first of all. Generally the influence of temperature is not taken in to account during computation of EOS parameters. But on some of them it has a great effect.

Instability of cut–off voltage is the one of the main reasons of kinescope reject. The cut-off voltage by accelerating electrode U_{g2} of the EOS is dependant on the several dimensions of the modulator: the diameter of the hole D_M, thickness of the modulator at the place of the hole δ, distance between the corresponding surfaces of the cathode and modulator d_{CM} and the effective distance between the modulator and the accelerating electrode d_{MA}. It can be approximately calculated by the following M. Heine equation [1]:

$$U_{g2} \approx U_{CM}\ d_{CM}\, d_{MA} / 0.034 \left(D_M - \delta\right)^2 ; \qquad (1)$$

where U_{CM} – potential difference between the cathode and modulator. As we see from equation (1), the value of cut–off voltage depends on distances between the cathode and electrodes. Therefore during the assembly of the EOS the cathodes have to be fixed in respect of the modulator electrode in such a way, that all the individual cut-off voltages would have right and the same value.

Reasons of EOS cut–off voltage instability

The electronic optical system (Fig. 1) consisting of three cathodes *C*, modulator *G1*, accelerating electrode *G2*, focusing electrode *G3* and anode *G4* was analysed.

Nine, rejected for cut–off voltage instability kinescopes were taken for analysis. During the measurement of cut–off voltage the voltage of the cathodes heaters was 5.7 V. The potential of the cathodes was 0 V. -150 V potential was applied to the modulator and the potential of the focusing electrode (*G3*) and the anode (*G4*) was 1000 V. During the variation of the accelerating electrode voltage U_{g2} the current of each cathode I_C was measured. We say, that the cathode is cut–off, when I_C = 2μA. The theoretical EOS parameters of all nine kinescopes were the same, so the cut–off voltages, calculated by equation (1), were the same for all of them, too (Table 1). But the measured cut–off voltages by accelerating electrode for the each cathode of the each kinescope were given very different (Fig. 2).

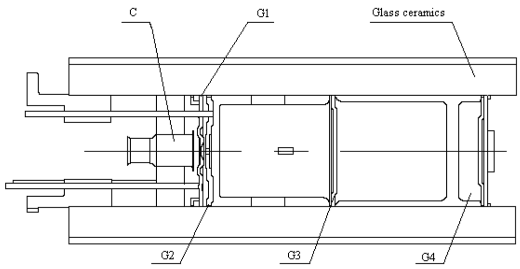

Fig. 1. Kinescope EOS construction

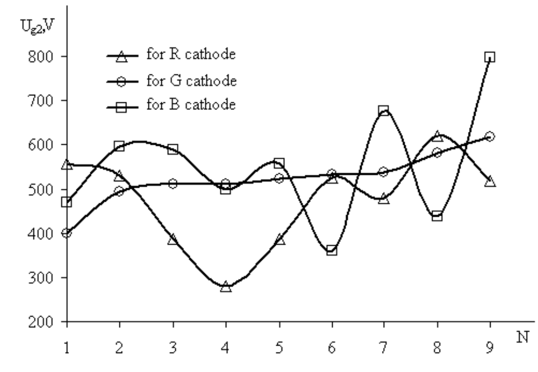

Fig. 2. Measured values of the EOS cut–off voltage by accelerating electrode, where *R cathode* – the cathode, which beam illuminates red phosphors; *G cathode* – the cathode, which beam illuminates green phosphors; *B cathode* – the cathode, which beam illuminates blue phosphors; *N* – kinescope No.

Table 1. Calculated values of cut–off voltage U_{g2}

Kinescope No. *N*	d_{CM}, µm			d_{MA}, µm	Calculated U_{g2}, V		
	R	G	B	RGB	R	G	B
1–9	115	125	110	340	602	655	576

For that reason the EOS were taken out of kinescopes and the exterior distances between electrodes *C–G2* and *G1–G2* were measured (Fig. 3). Thicknesses of the cathode bottom, modulator and accelerating electrode at the place of the hole were measured too.

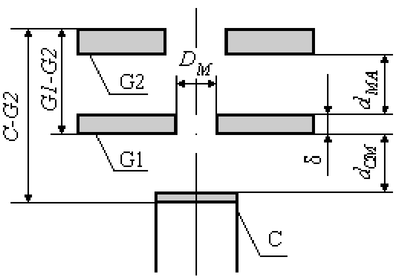

Fig. 3. Distances between EOS cathodes and electrodes

The interior distances d_{CM} and d_{MA} were calculated from these measurements and we got deviations (Fig. 4, 5) from the distances measured during the assembly (Table 1). Not only the deviations from the distances *C–G2* and *G1–G2* determine such scattering of d_{CM} and d_{MA} values, but also the deviations from the thicknesses of the cathodes bottoms, modulators and accelerating electrodes at the place of the holes have the influence on these parameters. Thicknesses of electrodes depend on quality of electrode steal and stamps, so it is difficult to take these parameters in to account. Consequently not the exterior, but interior distances have to be measured during the assembly of EOS, to avoid the influence of them [2].

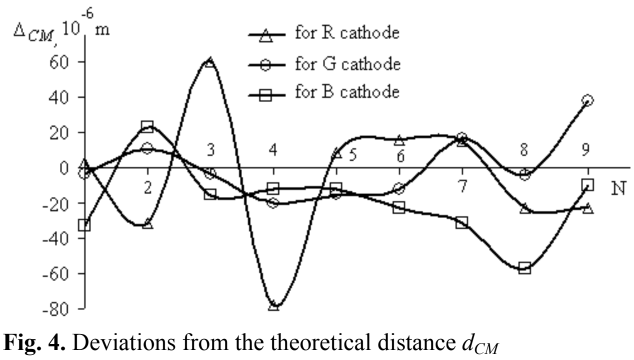

Fig. 4. Deviations from the theoretical distance d_{CM}

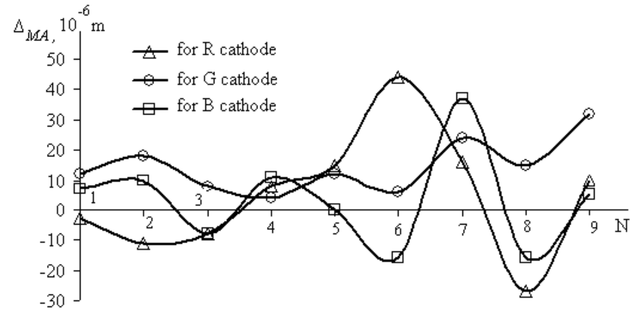

Fig. 5. Deviations from the theoretical distance d_{MA}

Deviations from distances influence on cut–off voltage

More accurate the cut–off voltage values can be calculated knowing the distribution of electrostatic field near the cathode. This distribution was obtained during the finite element modelling (*FEM*, *ANSYS*) [3, 4]. Vacuum is a uniform medium for electric field, so if one electrode potential is increased by *n* times, electric field, created by this electrode, varies in the same way. Therefore it is enough to calculate the functions of influence of the each electrode. They are calculated in such way: potential of one electrode is chosen equal to 1 V, while potentials of other electrodes are 0 V. Later 1 V potential is assigned to the second electrode, while potential of other electrodes are 0 V. 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 function of influence and the potential of the *i* electrode.

The influence of focusing electrode *G3* and anode *G4* on cut–off voltage U_{g2} was analysed, calculating the potential difference near the cathode and evaluating also an initial velocity of the electrons, corresponding to the potential difference: $\Delta U_0=\frac{kT}{e}$; where *k* – Boltzmann constant, *T* – the temperature of the cathode, *e* – electron charge. It was found, that the influence of *G3* and *G4* electrodes on cut–off voltage by accelerating electrode U_{g2} equal to 0,04% and these electrodes can be ignore in other calculations. So, the model of EOS construction becomes simpler.

Including these simplifications, the cut–off voltage U_{g2} was calculated as a function of cathode–modulator distance d_{CM}. The values of potential difference between the cathode and modulator U_{CM} and the distance between the modulator and the accelerating electrode d_{MA} were kept to be unchanged. The results of calculations and simulation are presented at Fig. 6, together with the measured values of the kinescopes with the right cut–off voltages. Significant differences between the measured, simulated and calculated values can be observed from the diagram. We can see that the FEM results have significantly more adequacy, comparing it with the calculations by (1).

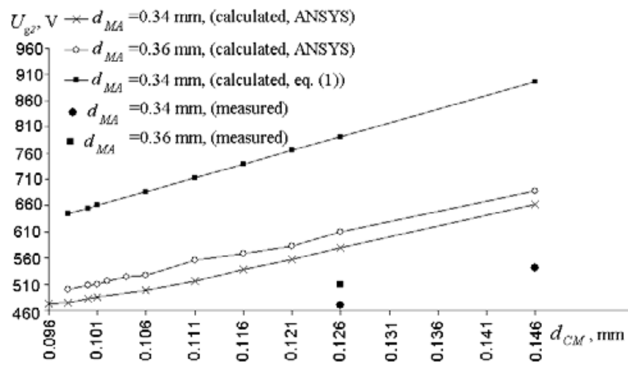

Fig. 6. The values of the voltage of accelerating electrode of EOS, at which *G cathode* is closed, as a function of the distances d_{CM} ir d_{MA}

We can conclude from the results of the calculations (Fig. 6), that variation of the distance between the cathode and the modulator by 1 μm is equal to variation of the cut–off voltage U_{g2} by 4 V. Similarly, the variation of distance between the modulator and the accelerating electrode by 1μm is equal to variation of the cut–off voltage U_{g2} by 3 V. Therefore, position of the cathodes within the ±1μm deviation from the optimum can be regarded as reasonable.

Evaluation of thermal deformations

Cathodes, like other electrodes of EOS, experience significant heating during the operation. Therefore the distances d_{CM} and d_{MA} become altered during operation due the heat induced deformations. To evaluate effects, caused by these deformations, we have chosen to solve the problem of temperature distribution by *FEM*, using the results as boundary conditions for structural problem afterwards [5].

In vacuum radiant energy exchange between neighboring surfaces of a region or between a region and its surroundings can produce large effects in the overall heat transfer problem, therefore we solve the problem of temperature distribution evaluating radiation effect. For more generalized radiation problems involving more then two surfaces we used radiation matrix method. The method involves generating a matrix of view factors between radiating surfaces and using the matrix as a *superelement MATRIX50* in the thermal analysis.

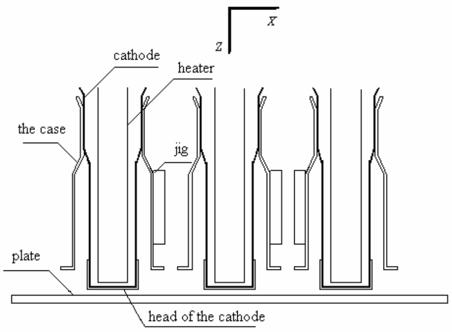

Fig. 7. The calculation model of the cathodes and their jigs in the section *y*=0

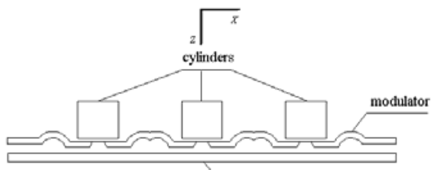

Fig. 8. The calculation model of EOS modulator in the section *y*=0

Generation of radiation matrix needs many computer resources. The construction of the cathodes and jigs, modulator and accelerating electrode is sophisticated, so we decided to divide the problem into three stages: 1) to compute the temperature distribution of the cathodes and their jigs, substituting the modulator and the accelerating electrode for simple plates (Fig. 7); 2) to compute the temperature distribution of the modulator (Fig. 8), substituting the cathodes for simple cylinders, with correspondent temperature, and the accelerating electrode for simple plate; 3) to compute the temperature distribution of the accelerating electrode (Fig. 9), substituting the accelerating and focusing electrodes for simple plates, and the cathodes for simple cylinders, with correspondent temperature.

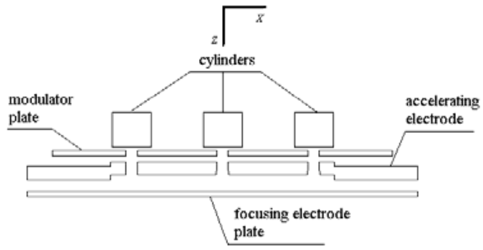

Fig. 9. The calculation model of EOS accelerating electrode in the section *y*=0

The simulation was performed altering the voltage of the cathodes heaters U_h from 5.1 to 6.6 V with the step of 0.3 V. The results were the values of alterations of corresponding distances Δd_{CM} and Δd_{MA} for each cathode as functions of the heater voltage (Fig. 10, 11).

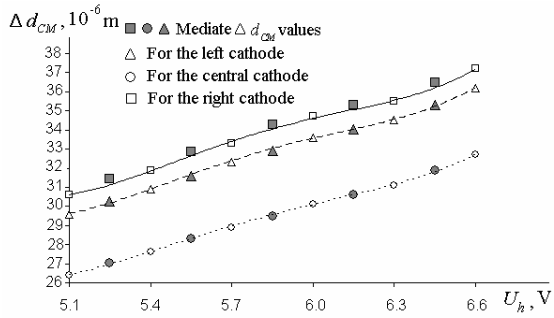

Fig. 10. Δd_{CM} as a function of the cathode heater voltage, fitted to the polynomial curves of 4-th order with interpolated values

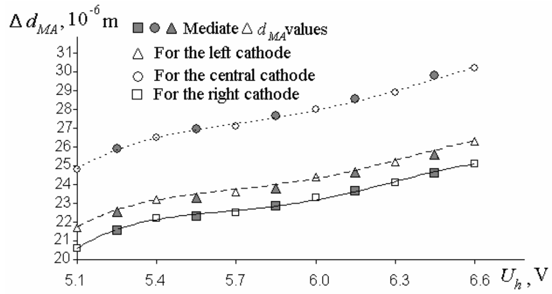

Fig. 11. Data of Δd_{MA}, fitted to the 4-th order polynomial, together with the intermediate interpolated values

The simulated data were best fitted to the polynomial curves of 4-th order with the maximal deviations from the data: $|\Delta_{CM\,max}|$ = 0.1032 μm for Δd_{CM} (evaluated as ±1.56 % uncertainty interval) and $|\Delta_{MA\,max}|$ = 0.119 μm for Δd_{MA} (evaluated as ±2.64 % uncertainty interval).

To evaluate the correctness of this approximation, the intermediate values of the distances Δd_{CM} and Δd_{MA} were interpolated with following maximum deviations: $|\Delta_{CM\,max}|$ = 0.1248 μm and $|\Delta_{MA\,max}|$ = 0.1173, which can be assumed as ±1.87% and ± 2.54 % uncertainty intervals, correspondingly. Therefore, the assumption about correctness of fitting the data to the 4-th order polynomial curve is valid within the above mentioned uncertainty range.

After the evaluation of the alterations Δd_{CM} and Δd_{MG} of the distances d_{CM} and d_{MG}, an equation (1) can be rewritten as follows:

$$U_{g2} = \frac{U_{CM}}{0.034} \cdot \frac{\left(d_{CM} - \Delta d_{CM}\right) \cdot \left(d_{MA} - \Delta d_{MA}\right)}{\left(D_M - \delta\right)^2}; \quad (2)$$

where $\Delta d_{CM} = \sum_{i=0}^{n} a_i U_h^i$, $\Delta d_{MA} = \sum_{i=0}^{n} b_i U_h^i$, ($a_i$ and b_i – the coefficients of polynomial, individual for different EOS constructions).

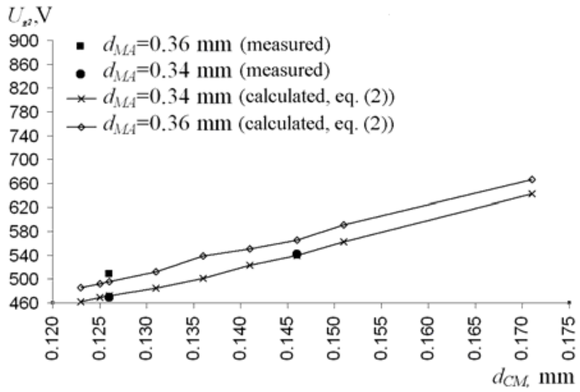

Fig. 12. Voltage of accelerating electrode, at which the *G cathode* is closed, as a function of distances d_{CM} and d_{MA} , after evaluation of thermal deformations

Taking into account conditions at which the EOS operates, it can be stated that distance d_{CM} can alter 36 to 27 µm (depending on the heating voltage), from the cold state value, and the distance d_{MA} – 29 to 21 µm, correspondingly. These values have to be taken in to account when the desired position of the cathode in cold system is calculated.

Conclusions

To equalize the cut-off voltages in the multiple beam EOS, cathodes have to be fixed with deviation not worse than ±1 µm in respect of the calculated positions. They can be adequately calculated only if thermal deformations during the operation of EOS are taken in to account.

Not the exterior, but interior distances have to be measured during the assembly of EOS, to avoid the influence of deviations from thicknesses of electrodes.

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Instability of cut–off voltage is the one of the main reasons of kinescope reject. After the analysis of kinescopes, rejected for cut–off voltage instability, we made the conclusions: first, not the exterior, but interior distances have to be measured during the assembly of EOS, to avoid the influence of deviations from thicknesses of electrodes and the second, that to equalize the cut-off voltages in the multiple beam EOS, cathodes have to be fixed with deviation not worse than ±1 µm in respect of the calculated positions. They can be adequately calculated only if thermal deformations during the operation of EOS are taken in to account. Ill. 12, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

В. Синкявичюс, Л. Шумскене, Ю. А. Вирбалис. Анализ влияния температуры электродов на параметры ЭОС // Электроника и электротехника. – Каунас: Технология, 2006. – № 6(70). – С. 41–44.

Причиной брака большинства кинескопов является нестабильность напряжения отсечки. В результате анализа бракованных кинескопов из-за нестабильности напряжения отсечки было установлено, что причиной является большой разброс требуемых расстояний между электродами. Было вычислено, что изменение расстояния между катодом и модулятором на 1 мкм вызывает изменение напряжения отсечки ЭОС по ускоряющему электроду на 4 В, а такое самое изменение расстояния между модулятором и ускоряющим электродом – на 3 В. Вычислив температурные деформации электродов, был сделан вывод, что для получения одинаковых напряжений по каждому катоду, точное расстояние каждого катода должно вычисляется с учетом термических деформаций. Ил. 12, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Sinkevičius, L. Šumskienė, J. A. Virbalis. Elektrodų temperatūros įtakos EOS parametrams tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2006. –Nr. 6(70). – P. 41–44.

Daugumos kineskopų brokuojamų dėl EOS kaltės priežastis yra užtvarinės įtampos nestabilumas. Atlikus dėl užtvarinės įtampos nestabilumo brokuotų kineskopų analizę, nustatyta, kad gamybos metu atsiranda didelių nuokrypių nuo reikiamų atstumų tarp elektrodų. Atstumui tarp katodo ir moduliatoriaus pakitus 1µm, EOS užtvarinė įtampa, apskaičiuota greitinančiajam elektrodui, pakinta apie 4 V, o tiek pat pakitus atstumui tarp moduliatoriaus ir greitinančiojo elektrodo, – apie 3 V. Apskaičiavus elektrodų deformacijas nuo temperatūros, padaryta išvada, jog norint, kad visų trijų EOS katodų užtvarinės įtampos tarpusavyje būtų vienodos ir reikiamo dydžio, tikslią katodų padėtį galima apskaičiuoti tik įvertinus šias deformacijas. Il. 12, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).