APPLICATION OF SIMULATION TECHNOLOGIES TO THE INVESTIGATION OF THE BEAM GENERATING SYSTEMS

Ivan V. Barsuk, Alexandr V. Bondar, Gennadiy S. Vorobjov, Aleksey A. Drozdenko[*]

Sumy State University, R-Korsakov 2, 40007, Sumy, Ukraine

ABSTRACT

A series of numerical calculations of electron beam generation in the three-electrode electron-optical system has been performed with the help of the electromagnetic modeling FIT method both with the PBA technology. Effects of the initial blocking and ray laminarity failure have been modeled. Optimum electrode potentials have been obtained for generation of the low-energy intensive axial-symmetric electron beam with beam-crossover behind the last anode of electron gun.

Key words: beam crossover, electron-optical system, electron beams, FIT method, perveance.

INTRODUCTION

Electron beams (EB) of different intensity levels are widely used nowadays in the microwave devices and different technological units. Optimization of their electron-optical system (EOS) parameters is generally based on the EB characteristics. Due to the numerical methods progress nowadays programs of electromagnetic simulation are actively used to collect such information. Usually these programs allow to avoid providing effortful and very expensive experiments. High requirements are applied to modern EOS with a high current density (up to tens or hundreds A/m^2) and creation of the focusing EOS with a high EB compression level helps us to achieve such density level. This paper leads with the detecting of the optimal electrode potentials for the electronic gun of the task geometry to achieve the high levels of EB compression.
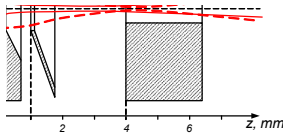
SYSTEM DESCRIPTION AND SIMULATION RESULTS

The investigation object is the electron beam, generated by the three-electrode axial-symmetric electron gun, which is widely used in devices of the type TWT [1]. EOS configuration and disposition layout view is shown in the *figure 1*.

Such type guns allows us to form EB with the crossover diameter about $0,05 - 0,5$ mm, beam current $5 - 30$ mA, acceleration potential nearly 6000 V.

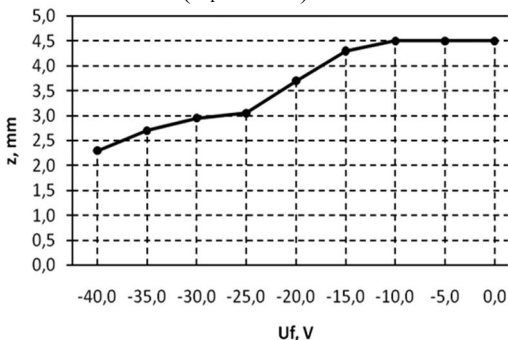[*] e-mail: aleksey.drozdenko@gmail.com, tel: +38(095)9193335

For the decision of the assigned task the complex simulation of the EOS has been made, electrostatic fields have been evaluated with the further tracking analysis. There are a lot of popular and widely used numerical algorithms of three-dimensional electromagnetic simulation (FDTD, FEM, MoM, integral equations method etc). We choose the method of finite integrals (well known as FIT – The Finite Integration Technique [2]), and realized it in the program CST Particle Studio.

Fig. 1 – Scheme of EOS of axially symmetric electron gun: 1 – hot cathode (U_k), 2 – focusing electrode (U_f), 3 – first anode (U_{a1}), 4 – second anode (U_{a2}).

This method is more multipurpose than the finite difference method, and it has some preferences in comparison with other methods: there are no restrictions on the element grid type (supports nonorthogonal cell shape) and this method can be realized both in time and frequency domain. Moreover, simultaneously with the Perfect Boundary Approximation (PBA) technology, this method allows us to avoid the staircase approximation of complex boundaries – the main disadvantage of the finite difference method. FIT method approval showed high level of correlation with experimental results [3], so this method is suitable for EOS optimization in the case of unconditioned geometry. Initial parameters of the electron gun is a combination of electrode potentials [4]: beam perveance $P = 0,045$ mkA/$V^{1,5}$, initial energy of electrons $E = 20$ eV.

After the numerical simulation of the electron gun operating conditions we have established, that the beam crossover is located in the area between first and second anodes, but not at the gun outlet, in the case of overestimate potentials of the focused electrode ($U_f \approx$ -40 V).


Fig. 2 – Influence of the focusing electrode potential U_f on EB crossover position

Decreasing of the U_f value reduces the beam crossover to the range of the drift channel of the second anode, as it is shown in the *figure 2*. Crossover beam diameter decreases and current propagation increases, when U_f changes from U_f=-10÷0 V to 100%. However, it is impossible to move the beam crossover beyond the second anode only with

the help of focusing electrode potential variation.

In addition, the focusing electrode placing in the neighborhood of the cathode causes the effect of the partial blocking appears. In this case the kinetic energy of outgoing electrons is too low to overcome the potential barrier and it decreases the degree of the current propagation and breaks the EB laminarity. For example, results of simulation of the electrons emission and starting moment of the beam creation are shown in the *figure 3*. It should be noted, that we have used only 50 particles for the best performance of the results. It is obvious, that particles majority is able to come back to the cathode, but the rest of the particles highly disturb the laminarity, especially the extreme ones.
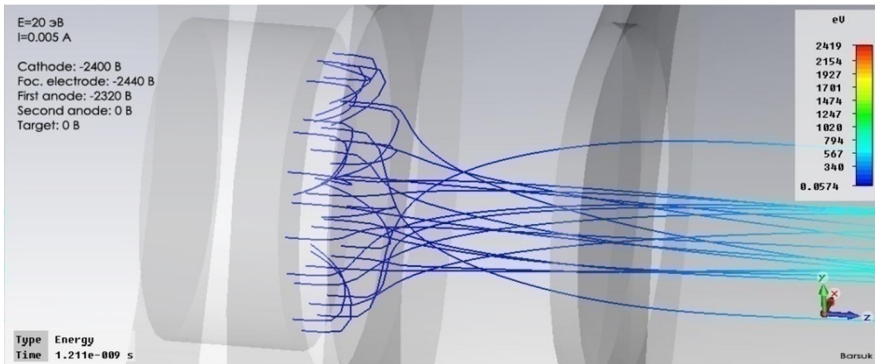

Fig. 3 – Blocking effect and beam laminarity disturbance

Then the particles lifetime has been explored in the observable system. The particles amount per time dependence is shown in the *figure 4*. From the plot on the figure 4 we can say, that about 28% of particles moved back to the cathode (first falloff 1000-720 particles), the rest particles have reached the collector (720-0 particles).
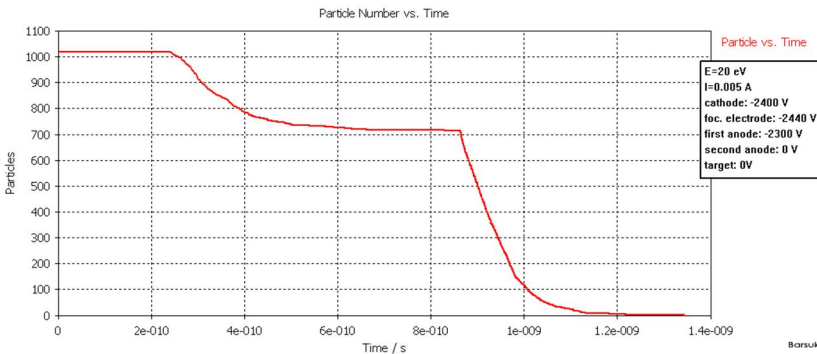
Fig. 4 – Amount of particles/time

Flat second falloff indicates that particles have reached the cathode not at the same time. It is obvious from detailed investigations that particles of the central part of the beam secure the collector much faster than the particles of the outer part of the beam. We consider the laminarity disturbance at the starting moment leads to this energy dispersion in the EB.
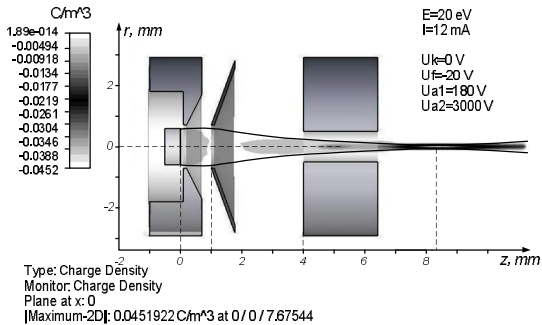
Fig. 5 – EB configuration, which was obtained after the electron gun mode optimization

Then a system of numerical experiments have been carried out to find the optimal operation modes of the electron gun (fig. 1), with the help of varying of electrodes potential values U_f, U_{a1}, U_{a2}, which helped to create the EB of the optimal geometry, as it is shown in the *figure 5*.

The beam crossover is located behind the second anode of the electron gun at the distance 8,4 mm, the beam diameter is 0,1 mm, it corresponds to the compression coefficient 150 (on area) and beam energy 3 keV.

CONCLUSIONS

Series of numerical experiments of creating the axially symmetric EB have been described in the paper. Basic method of numerical investigation is FIT method, which has been realized in the program CST Particle Studio. Optimal operation modes of the three-electrode electron gun has been determined in the case of low-energy electron beam creating.

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