THERMAL EFFECTS AND BEAM PARAMETER VARIATIONS IN ELECTRON GUNS

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The paper describes results of research on influence of electrode temperatures and manufacturing tolerance of an electron gun on parameters of an output beam. The Pierce's gun that provides an electron beam with a current of 1.2 A and energy of 25 keV for the S-band technological linac is considered as an example. Numerically calculated parameters of the beam and the temperature distribution in electrodes are presented. It is shown that the acceptable error in a position of electrodes is ±0.1 mm. This value does not fall outside the limit of thermal deformations and technical abilities for manufacturing guns in a laboratory. The scaling to the area of injectors for compact X-band linacs leads to the tolerance of ±0.01 mm that requires introducing fixing and adjustment elements reducing a thermal insulation of the cathode. However, the calculation and experiment showed that such reducing is negligible even for the modern low temperature thermionic cathodes due to a dominant role of the radiation in the heat transfer. This circumstance permits to create the precision intensive compact thermionic electron sources with replacing cathode for the compact linacs.

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1 INTRODUCTION

Vacuum failures during operation of power electron linacs reduce the lifetime of dispenser cathodes of the electron guns. Obviously, the design of the gun with an easy replaced cathode is rational in this case. The simplification of a replacement operation requires a research on the problem of a cathode installation tolerance. This problem has significance under development of a X-band linacs for radiation applications. It is possible to show by simple scaling [1] that a transition to the compact X-band linac will require the reducing of geometric deviations proportionally to a frequency. Therefore, an investigation of influence of gun geometry errors on deviations of output beam parameters is important.

Deviations from optimal geometry can arise at cathode replacement as well as during heating of electrodes. It may be a reason of known dependence [2] of a perveance and geometric beam parameters on voltage. It is known that the form and mutual dispositions of the cathode, anode and focusing electrode have the greatest influences on electron trajectories.

2 METHOD OF SIMULATION

Geometry of electrodes is shown in Fig. 1. The error Δ_1 arises during a cathode installation in a longitudinal position and heating it.

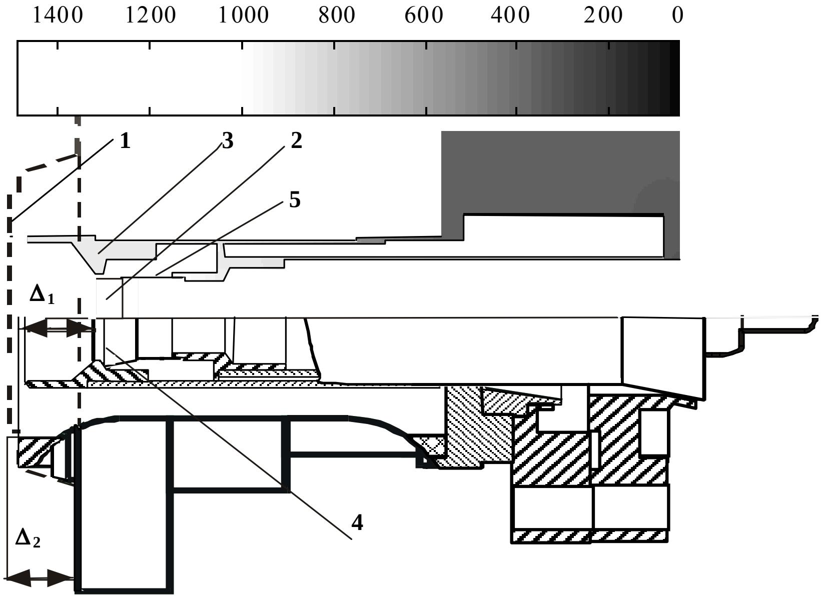

Fig. 1. Gun with the replacing cathode and the temperature distribution in electrodes.
1 – anode (injector body), 2 – cathode, 3 – focusing electrode 4 – adjusting element, 5 – springing holders.
Above is the simulation model and temperature scale in K.

The error Δ_2 is connected with a gun installation on the accelerator since the anode usually is the injector body (see Fig. 1). This error arises also during the reducing of the anode–cathode gap that is sometimes used for the extension of the cathode lifetime.

The beam parameters simulation was made with the EGUN code [3] with an account of electrons thermal velocities. A criterion of simulation validity was the independence of the beam parameters on voltage and on emission properties of the cathode.

A thermal problem was solved using the numerical method. For the account of a radiation heat transfer, the area of the problem was divided into segments. The heat transfer equation with a boundary temperature or radiation flux was solved in each segment. The radiation heat transfer was accounted only between two nearby fields using the known dependence [4]:

$$q_i = \sum_j \varphi_{i,j} \varepsilon^*_{i,j} \sigma (T_i^4 - T_j^4),$$

Where q_i is the radiation flux density on the i segment with the surface area F_i, $\sigma = 5.67\cdot10^{-8}$ W/m^{2}K, $\varphi_{i,j}$ -angular factors [3]:

$$\varphi_{i,j} = \frac{\cos\theta_i \cos\theta_j F_j}{\rho_{i,j}},$$

θ_i, θ_j - angles contained by $\boldsymbol{\rho}_{i,j}$ vector and normal vectors $\mathbf{n}_i$, $\mathbf{n}_j$ respectively.

$\varepsilon^*_{i,j}$ is generalized emissivity factor of a radiation:

$$\varepsilon^*_{i,j} = \frac{1}{1 + \varphi_{i,j}(1/\varepsilon_i - 1) + \varphi_{j,i}(1/\varepsilon_j - 1)},$$

Here ε_i,ε_j are emissivity factors of mutually irradiated surfaces.

The temperature T_j was updated by the method of iterations. The error of the calculation is evaluated by magnitude ± 5 %. Such there was an average correction to T_j after 4-5 iterations. The refinement of this result can be reached by the increasing of a number of iterations that however is deprived of a sense because of large indeterminations in the emissivity factor of surfaces.

3 RESULTS AND DISCUSSIONS

As can been seen from Fig. 1, the difference between the cathode and enclosing electrode temperatures is about 500 K. With account of the divergence between expansion coefficients of various constructional materials used in guns ($\Delta\lambda \sim 7\cdot10^{-6}$ K^{-1} between molybdenum and stainless steels) and scale of details sizes (~ 10 mm) it is possible to say that the temperature deformations leading to a deviation from optimal geometry are less than 0.05 mm.

Obviously the indicated error may be considerably reduced by the choice of material and by the design of electrodes. It is necessary to mark, that the necessary increasing of a emission density in going to small-sized guns is satisfied usually by increasing of emission properties of the cathode instead of temperature ones. Therefore relative temperature deformations will not been increasing, that increases a role of the installation tolerance of electrodes. To estimate the acceptable tolerance it is necessary to find criterions of beam parameters deviations.

The calculated values of perveance and emittance of the beam for various positions of the anode and cathode relatively to the focusing electrode are represented in Fig. 2 and Fig. 3.

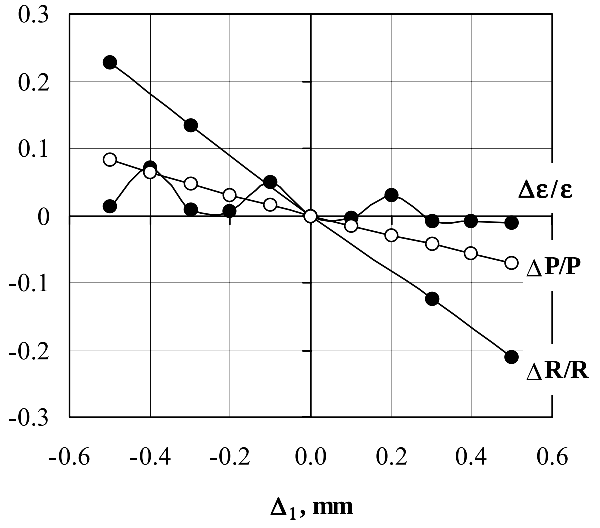

Fig. 2. Relative variations of emittance – $\Delta\varepsilon/\varepsilon$, perveance – $\Delta P/P$ and the beam radius–$\Delta R/R$ vs the anode displacement Δ_1.
ε=30.3π·mm·mrad, μP=0.54, R=3mm.

The greatest deviations at small Δ_1, Δ_2, as can be seen, are observed for the emittance. Let's consider that the emittance of technological accelerators is limited by the acceptance of a transport system only. In this case [5]: $\varepsilon = A$ and $A = (2\pi^2/\lambda)a^2$, where λ is a focussing period, a is radius of the aperture, A – acceptance. The parameter λ is connected with a disposition of focusing elements, therefore, λ = *const*. In this case the permissible emittance oscillations are determined by the aperture only. Then

$$\Delta\varepsilon/\varepsilon = 2\Delta a/a > 0.1\text{-}0.2,$$

where $\Delta a = a\cdot(0.05 \div 0.1)$ is halo size of a beam.

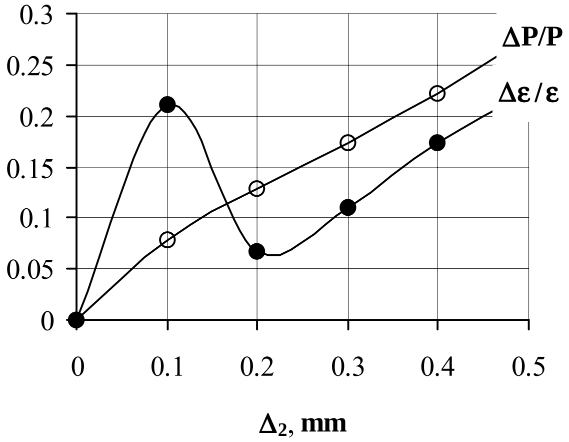

Fig. 3. Relative deviations of the emittance – $\Delta\varepsilon/\varepsilon$ and perveance – $\Delta P/P$ vs the cathode displacement – Δ_2.

As one can see from the indicated figures, the condition $\Delta\varepsilon/\varepsilon < 0.2$ corresponds to the tolerance Δ_1, $\Delta_2 \leq \pm 0.1$ mm.

For X – band guns according to the scaling theory [1] Δ_1, $\Delta_2 \leq \pm 0.01$ mm is necessary that is difficult to realise in conditions of usual laboratories. The constructions of the gun with an adjustment insertion 4 (see Fig. 1) are interesting for overcoming these difficulties. In connection with a problem of a high electric power transfer to small-sized cathodes, arise a question of a heat leak via such insertions.

As shown by numerical simulations and experimentally, the operation temperature 1500K of the BaNi-cathode in the design in Fig. 1 requires a heat power of about 50 W, 30 W of them is dispersed by radiation. The dominant role of radiation in the heat transfer allows using such insertions for the reaching the cathode tolerance installation $\Delta_2 \leq \pm 0.01$ mm without significant losses of heat.

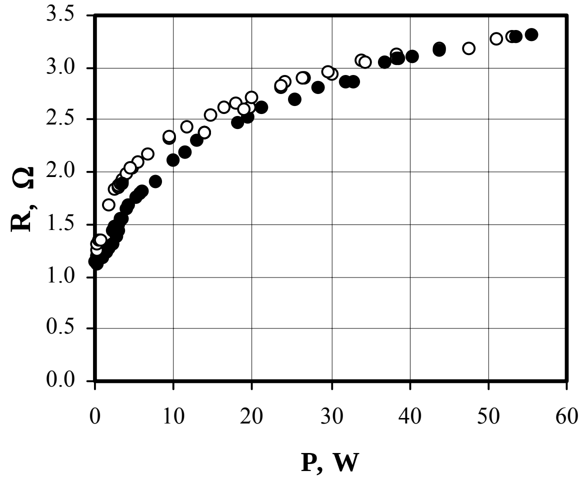

Fig. 4. A resistance of a heat wire of the BaNi-cathode vs the input electric power.
o – gun without insertion (4), • – with insertion.

For the heat transfer process studies two guns were tried. One of them, having an adjusting insertion (4), shown in Fig. 1. Such insertion with thickness of 0.3 mm was made of a stainless steel and with a roughly surface for the reducing of the heat transfer via the end face contacting with a focusing electrode (3). The resistance of heating wire in the dependence on the cathode temperature is shown in Fig. 4. One can see that temperature of the cathode without the insertion is higher in the field of low powers only, i.e. for low temperatures when predominates a kinetic heat transfer instead of radiation one. Both curves coincide in the field of high temperatures. The dependence for the cathode with an insertion has even the smaller derivation that apparently is connected with a shielding from irradiation of a focusing electrode by the insertion.

Going to compact high intensive electron sources requires operating it nearby current saturation. A source of beam parameter instabilities in this regime may be the loss of emission as shown in Fig. 5.

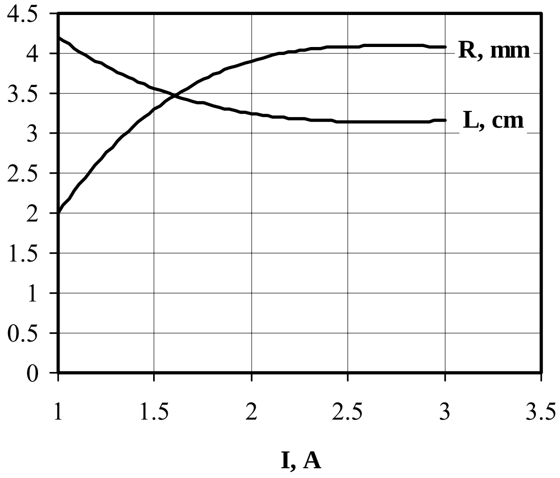

Fig. 5. Position of crossover L and beam radius in the crossover vs emission ability of cathode I.

Here I is the current of saturation for cathode with the 1.54 cm^2 emission area in the gun presented in Fig. 1. As can be seen, for the emission abilities more then 2.7 A indicated parameters are stable.

4 CONCLUSION

Thus, obtained results showed a possibility to create the precision intensive thermionic electron sources with replacing the cathode for the compact technological linacs. Such sources must be supplied with the cathode having an enough reserve of emission for conservation of beam parameters unvaried in long time.

5 ACKNOWLEDGMENTS

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