RESEARCHING OF RUNNING-IN, STARTING, TRANSITION THERMAL PROCESSES OF SELF-HEATED HOLLOW CATHODE IN ELECTRIC CURRENT RANGE FROM 5 UP TO 25 A

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Abstract

Thermal state of self-heated hollow cathode has very significant topic. We can see it by help of influence fact to emitter cooling condition and geometry. So existence of heating shield provides decreasing of arcing voltage to several volt, and using of more optimal construction will decrease it more (fig.1). More over it is well known that in stationary regime of operating, start erosion has heating character and that is why knowledge of heating state allows to estimate the recourse of a cathode.

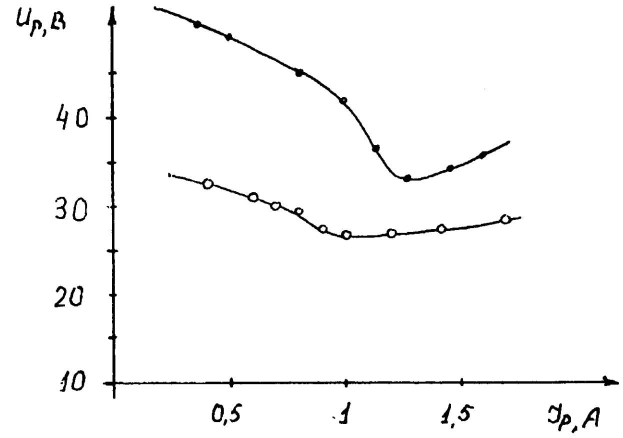

Fig. 1 Volt-ampere characteristics of a cathode.
-•- without of heating shield; -o- with 3 heating shield.

Thermal computation for non-stationary problem of emitter heating to stationary operating temperature is feature task. It is well known that start erosion could reach $10^{-8} - 10^{-9}$ kg/K, that at about in 3 times more than in stationary regime. Start erosion can be so significant to destroy of a cathode.

Mathematics model

Stationary regime of operating is the main regime, so almost all theoretical researching were carried out for stationary problem of heat-conduction. But there are no any data for calculation of emitter heating in electric arcing problem data in a public media. In condition of self-heating start, the process of heating runs self-consistently from a gas arcing. That is why solving of heating problem will provide the estimation of some factors influence to emitter thermal regime changing in start time. This allows to have minimum of start erosion and time of self-heated hollow cathode (SHC) arc ignition.

Basic equation of non-stationary heat-conduction is:

$$c \cdot \rho \cdot \frac{\partial T}{\partial \tau} = div(\lambda gradT) + q_V \qquad (1)$$

where c, ρ, λ - physic parameters of a material;

q_V - specific heat-evolution.

Difficulty of constructive making of a cathodes and diversity of processes which takes place in it will provide very big number of equations in the mathematical model. There are many variation coefficients and partial derivatives in it. So algebraic solving of the model could be made for only some cases. So numerical methods now era almost only way to model solving.

One from possible methods of computing is the elementary balance method. Idea of this method is

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of small-framed volumes. Researched object is divided to multi numbers of elementary geometric forms, in which frames changing rules is linear.

SHC construction,(in majority cases) is axes-symmetry one, so changing of temperature in angle is not changed. So emitter division is necessary make to cylinder layers with radius r, r+Δr and height Δz. Taking into account that $R_{em} \ll l_{em}$ we have that elementary volume has radius R_{em} and height Δz (fig.2).

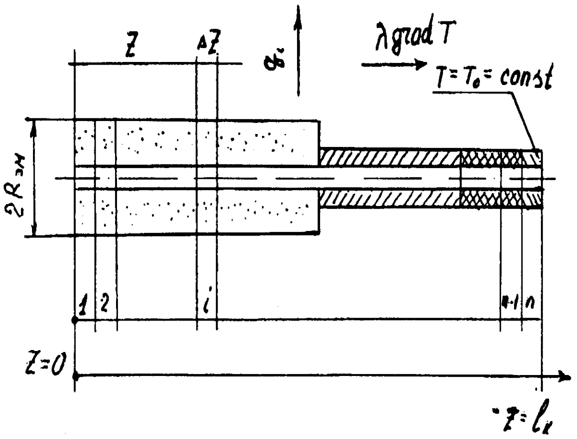

Fig. 2. Cathodes heating dynamics computing scheme.

For a cathode that consisted from elementary volumes Vi next equation is right:

$$c_i \cdot \rho_i \cdot V_i \cdot \frac{\partial T_i}{\partial \tau} = \sum_{i=1}^{n} Q_{si} + q_{vi} \qquad (2)$$

Algebraic sum of heat fluxes Q_{si} through all surfaces, framed the object go to change it's enthalpy, q_{vi} - heat-evolution in the volume. So if ε - blackness ratio, for any i layer (i≠1, i≠,n) we have:

$$\frac{dT_i}{d\tau} = \left[\frac{\lambda S_{i,i+1}}{\Delta z} (T_{i-1} - 2T_i + T_{i+1}) - \varepsilon \sigma S_\delta (T_i^4 - T_m^4) \right] \frac{1}{c_i \rho_i V_i} \qquad (3)$$

For (2) system it possible to write the boundary conditions of a composite type. The heat flux is put on emitter surface of a cathode (z=0, i=1), which depend on electric discharge parameters. And the cathode temperature after ceramic isolator is equal to environment temperature. Let see elements of energy balance:

The ions input energy:

$$q_a = J_i \left[\alpha_i \left(V_k + \frac{2kT_i}{e} \right) + \alpha \left(E_i - \varphi_{ef} \right) \right] \qquad (4)$$

J_i, T_i - ions current and temperature;

α_i - ions accommodation coefficient;

Vk – near-electrode decreasing of voltage;

Ei – ionization potential;

φ_{ef} - effective output energy;

α - atom neutralization coefficient.

The electrons back-current energy:

$$q_e = J_e \alpha_e \left(\frac{2kT_e}{e} + \varphi_{ef} \right) \qquad (5)$$

The gas convection energy is:

$$q_a = \frac{n}{4} \cdot \langle v_a \rangle \cdot m_a \cdot c_v \cdot (T_a - T) \qquad (6)$$

$n, \langle v_a \rangle, m_a, c_v, T_a$ - the atoms concentration, speed, mass, heat-conduction, temperature.

Plasma radiant energy is:

$$q_r = \frac{\varepsilon_{pl}}{2} \left(L + R - \sqrt{L^2 + R^2} \right) \qquad (7)$$

where ε_{pl} - volume plasma radiant coefficient;

L, R – length and radius of a arc column.

Emitter emission cooling energy:

$$q^c{}_e = j_e^{em} \cdot \left(\frac{2kT}{2} + \varphi_{ef} \right) \qquad (8)$$

T – the cathode temperature.

Emitter radiant energy:

$$q^c{}_r = \varepsilon \cdot \sigma_0 \cdot \left(T^4 - T_{en}^4 \right) \qquad (9)$$

T en –the temperature of environment.

The energy outputted in a cathode body (because of heat-conduction):

$$q = \lambda \left(\frac{dT}{dz} \right) \qquad (10)$$

Energy of evaporate material:

$$q\ ev = h \cdot \dot{m} \qquad (11)$$

where h, $\dot{m}$ - heating and speed of a cathode material evaporation.

The connection between specific velocity of evaporation and material temperature:

$$\lg v_{ev} = c - 0{,}5 \cdot \lg T - \frac{B}{T} \qquad (11)$$

v_{ev} – specific velocity of evaporation;

c, B – empirical const.

But so boundary condition requires solution of self-consistently problem of discharge evolution. That is why we have used the integral variant, which has been based in dependence of anode heat-evaluation from electric current. This idea was described in details in [1]. So Heating flux on work surface of a emitter was approximated by expression: $Q = Ud \cdot Jd \cdot K(Jd)$, where Ud, Jd – are voltage and current of a discharge, K(Jd) – coefficient of power transition in to a cathode.

In fig.3 You can see curves of a emitter working surface temperature changing with different number of vacuum isolation shields (VIS). It possible to mark 2 part of a emitter heating. First is existing before 1000 K without of any significant changing, second one after 1000 K. In second part of heating we can see significant differences because of VIS existence or absence. Obviously that in increasing of VIS number, the operating temperature of a emitter is increasing to. But in same time the period of 95%Tmax reaching increases. So increasing of VIS number provides the increasing of thermal erosion time.

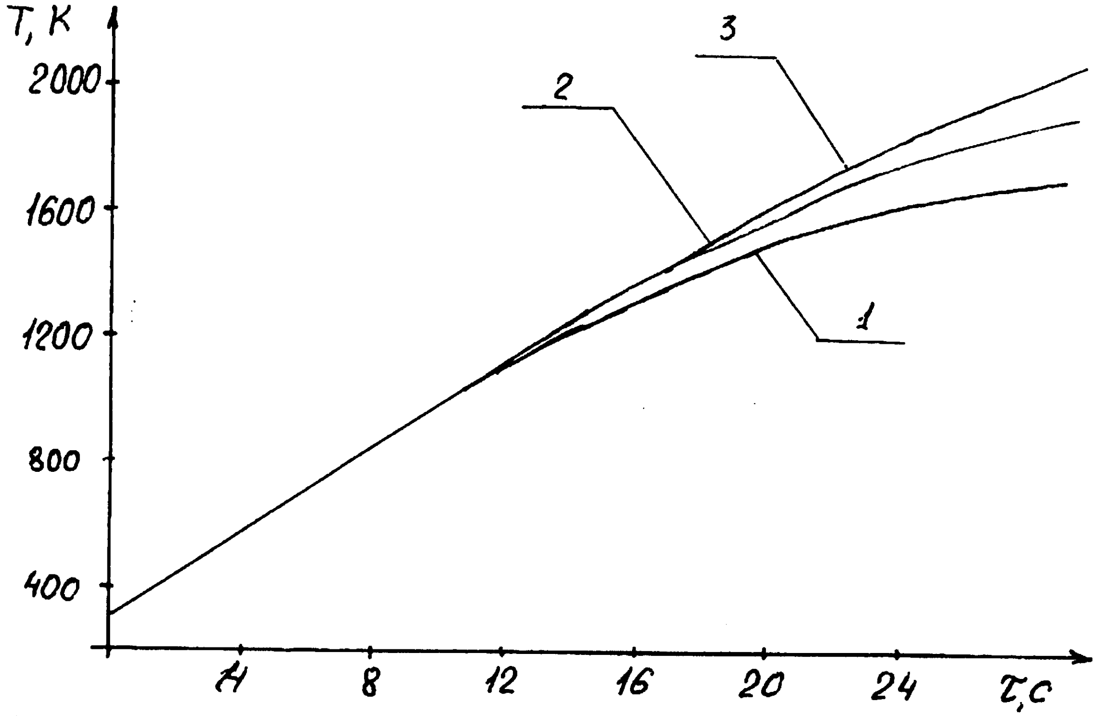

fig. 3. The emitter working surface temperature changing with different number of vacuum isolation shields. 1- without of VIS; 2- with 1 VIS; 3- with 3 VIS.

So we can conclude that:

1. In first period of heating the erosion, which is depended by only erosion thermal conditions does not depend from VIS number.
2. Start heating velocity is quasi-constant and depended only by emitter mass-clearance characteristics.
3. In emitter heating more than 1000 K with VIS number increasing the operating temperature and temperature 95%Tmax reaching time of emitter is increased.

Facility and experiments results

For experiments the vacuum chamber V=1,5 m^3 was used. 2 turbo-molecular pumps made vacuum without-oil. Common working capacity 5000 l/s. Temperature measurements were carried out by colibrated thermocouple W/Re on the cathode body.

Signal was sent in digital device with galvanic isolation from thermocouples. Complex operating time was 40 ms, that enough for temperature measurements.

The dependencies of emitter operation temperature reaching time from electric current are presented in fig. 4. Absence of any significant differentials between theoretical and experimental data is obviously.

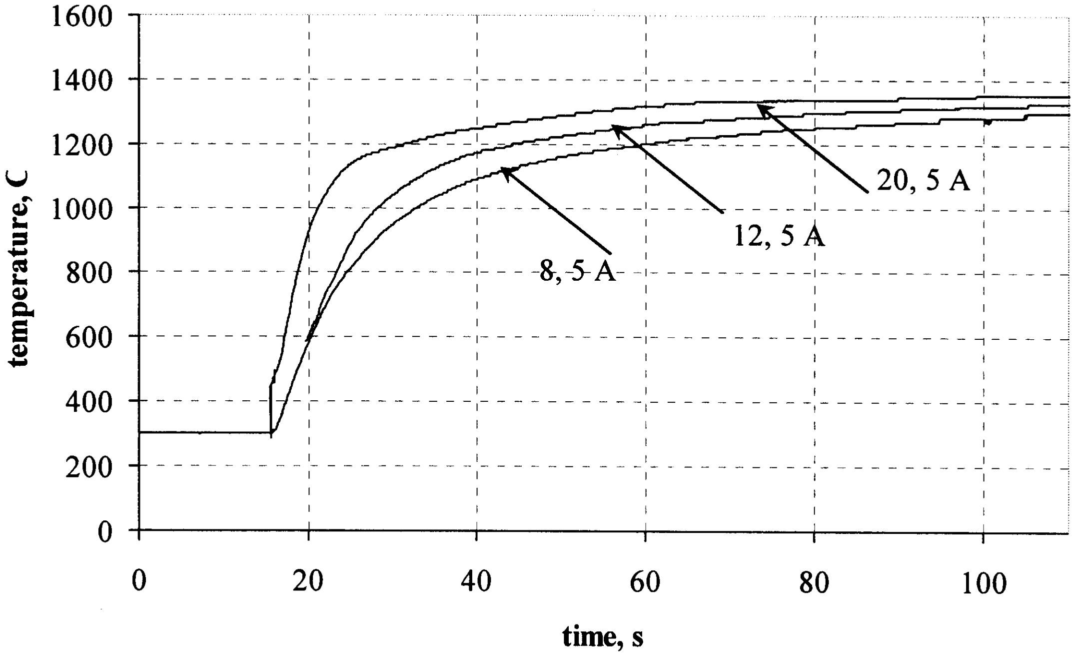

Fig. 4 Dependencies of emitter operation temperature reaching time from electric current.

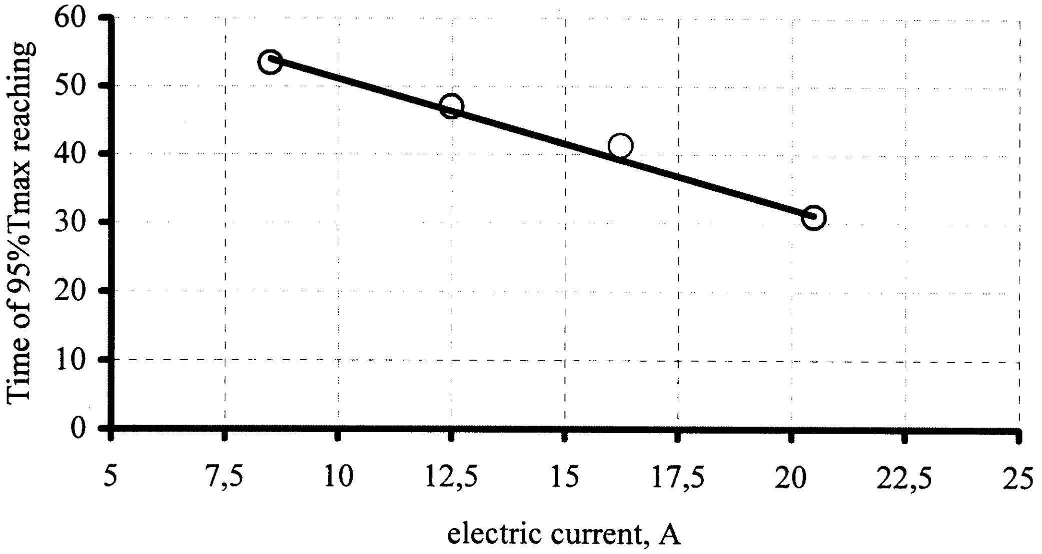

Fig. 5 Dependence of emitter heating times up to 95% of stationary temperature from electric current.

Emitter heating times up to 95% of stationary temperature are shown in fig. 5. So we can see linear dependence of that characteristic:

- For 8,5 A time was in level 53,5 sek;
- For 12,5 A time was in level 47 sek;
- For 8,5 A time was in level 39 sek;

In range of electric current from 5 up to 25 A we think this characteristic to be linear.

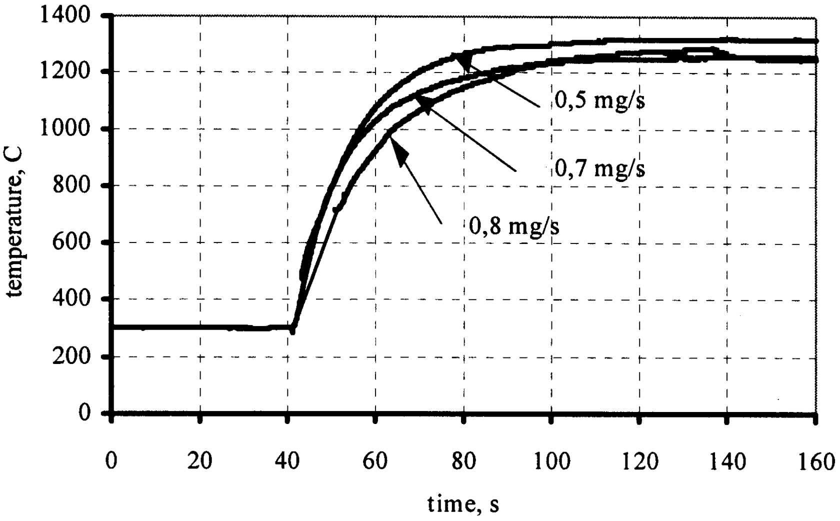

Fig. 6. Dependencies of emitter operation temperature reaching time from gas consumption.

There are emitter heating dependence from gas consumption in a fig.6. You could see that we have not very significant dependence. Obviously in gas consumption increasing, the cathode temperature is decreased and vice-versa. This fact could be explained by physics of activators and gas heating flux. But time of cathode temperature transition up to operating maximum temperature has linear dependence from gas consumption (GC)(fig. 7) For GC=0,8 mg/s time was at about 50 s. For GC=0,7 time was 48,5 s. And for GC=0,5 time was in 40 s level.

It is very important to understand causes of different between experimental and theoretical data.

Main causes are:

- Accuracy of heating flux to emitter surface approximation;
- Errors which were connected with definition of emitter and capsule properties.

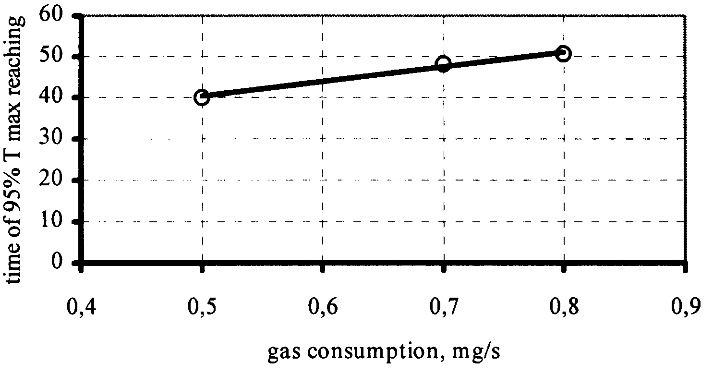

Fig. 7 Dependence of emitter heating times up to 95% of stationary temperature from gas consumption.

Conclusions

In the paper the mathematical model of cathode emitter start heating from “cold” state is presented. Approximation of heating flux on to emitter flux was proposed and the numerical analyze was carried out. Experimental results were described. It was shown that mathematical model adequate describes the real physics heating process. Possible causes of any differential was made.

References

[1]“Источники и ускорители плазмы”. *Межвузовкий тематический сборник научных трудов*, Харьков, 1984.