THE ENERGY BALANCE STRUCTURE ON THE CATHODE SURFACE OF THE METAL VAPOUR ARC

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ABSTRACT

The paper presents computational results for composition of the energy flow on the cathode spot surface. It is determined regions where dominate energy loses due to an evaporation and electron emission cooling, or heating by ion and electron flows from the near cathode plasma.

1. INTRODUCTION

There are remarkable differences in behaviour and characteristics of the cathode spot of the vacuum arc in quasi-stationary and non-stationary modes /1/. Theoretical models /2/ also represents the gap in parameters of these modes. But they are essentially linked: initiation of quasi-stationary spot occurs on the place previously heated by non-stationary spot, and regeneration of the explosive-type (ecton) spot suppose so called ionic stage.

Developed ecton theory shows new perspective for description of cathode spot fragments behaviour /3/, taking into account the electron backflow to cathode surface from the near cathode plasma sheath. Some improvements are possible and for the quasi-stationary spot models of the metal vapour arc.

2. EQUATIONS

Models of the cathode spot /1/,/2/ mostly based on description of the processes: (i) generation of neutral atoms on the cathode surface, (ii) formation of particle flows to/from the near cathode plasma, (iii) formation of space charge sheath near the cathode, (iv) electron emission, (v) ionization within the near-cathode plasma layer, (vi) energy balance for the electrons and heavy atomic particles.

The self-consistent calculation of the near cathode plasma layer gives the boundary conditions for cathode spot modeling taking into account processes within the cathode bulk, mainly the heat transition. So one of the main boundary condition is the energy balance on the cathode surface. In addition to results /4/, below presented structure of the energy flow on the surface.

The total energy flow $Q_s = -Q_v - Q_{em} + Q_{ip} + Q_{ep}$ through the metal surface is given by: (i) Q_v – the energy loss due to the evaporation of atoms; (ii) Q_{em} – the energy exchange due to electron emission, including Nottingham effect; (iii) Q_{ip} –

the energy gain by accommodation of ions coming back to the surface; (iv) Q_{ep} – the energy gain of returning plasma electrons. The components were described by the next equations:

$$Q_v = I_{v0}\cdot(1-\beta)\cdot(E_v + 2kT_c),$$

$$Q_{em} = J_{ec}\cdot(\varphi_{FT}+\varphi) + \sum_z \frac{J_{iz}}{z}\gamma^z_{IFT}\left(\varphi^z_{IFT}+\varphi\right),$$

$$Q_{ip} = \sum_z \frac{J_{iz}}{z}\left((U'_c - \Delta\varphi_S)\cdot z + \sum_{p=1}^{z}(U_{ip}-\varphi) + 2kT_0/e + \tfrac{1}{2e}\tilde{Z}kT_e\right)$$

$$Q_{ep} = \alpha\cdot J_{ep}\cdot\left(\varphi - \Delta\varphi_S + 2kT_e/e\right)$$

Here: I_{v0} is the flow of evaporated atoms moving away from the surface at the temperature T_c, $\cdot\beta$ is the back flow to the surface in a kind of atom or ion, E_v is the evaporation energy, J_{ec}.– density of the electron thermo–field emission current; J_{iz} is the ion current with charge z: $J_i=\sum J_{iz}$; φ and $\Delta\varphi_s$ – are the work function and Schottky correction, respectively; φ_{FT}, $\varphi^{\tilde{z}}_{IFT}$ – overage energy of emitted electrons (F–T and I–F–T emissions /5/) for calculation of the Nottingham effect; $\gamma^{\tilde{z}}_{IFT}$ – number of emitted electrons per one ion striking the cathode (top index z means the multiplicity of ionization of the ion); α is the accommodation coefficient of the returned from plasma electrons on the cathode; $U_c = U'_c + \Delta U_c$, $\Delta U'_c = \frac{1}{2e}\tilde{Z}kT_e$, U_c is the total cathode potential fall including $\Delta U'_c$ on plasma presheath; U_{ip} – ionization potential at (p-1–>p) transition, $\tilde{z}$ is the effective charge of the plasma ions near the cathode; T_e is the temperature of the plasma electrons.

The current density in the cathode spot: $J_c = J_{ec} + J_i - J_{ep}$, where the flows of charged particles are: emitted electrons J_{ec} , plasma electrons J_{ep} and ions J_i .

3. RESULTS

On Fig.1 are presented results of calculations for copper electrode in a kind of parameter isolevels (equal values of calculated parameter) in coordinates (T_c,U_c) – the near cathode fall U_c and the surface temperature T_c.

Fig.1*a,b* shows the energy balance at the surface by plotting sign(Q_s)·log(|Q_s|) as a function of U_c and T_c. For |Q_s|>1 we have log(|Q_s|)>0. For example, Q_s= 1×10^8 W/cm^2 corresponds to 8; Q_s= –1×10^5 W/cm^2 corresponds to –5 and Q_s= ±1 W/cm^2 – to the point 0.

As can be seen in this figure, the positive values of the energy flow on the cathode surface (and the spot existence region corresponded to it) has a big variation in dependence on included or not in consideration the energy delivered by backflow of plasma electrons. Especially remarkable changes in Q_s occurs for the region T_c>3800 K and U_c>13 V, where energy flow change the sign and differs on order of magnitude. Values of Q_s within the existence region of the quasi-stationary spot (3000 K< T_c <4000 K , U_c>15 V) also changes up to one order of magnitude, so the calculated in different models spot radii might differs in orders of magnitude

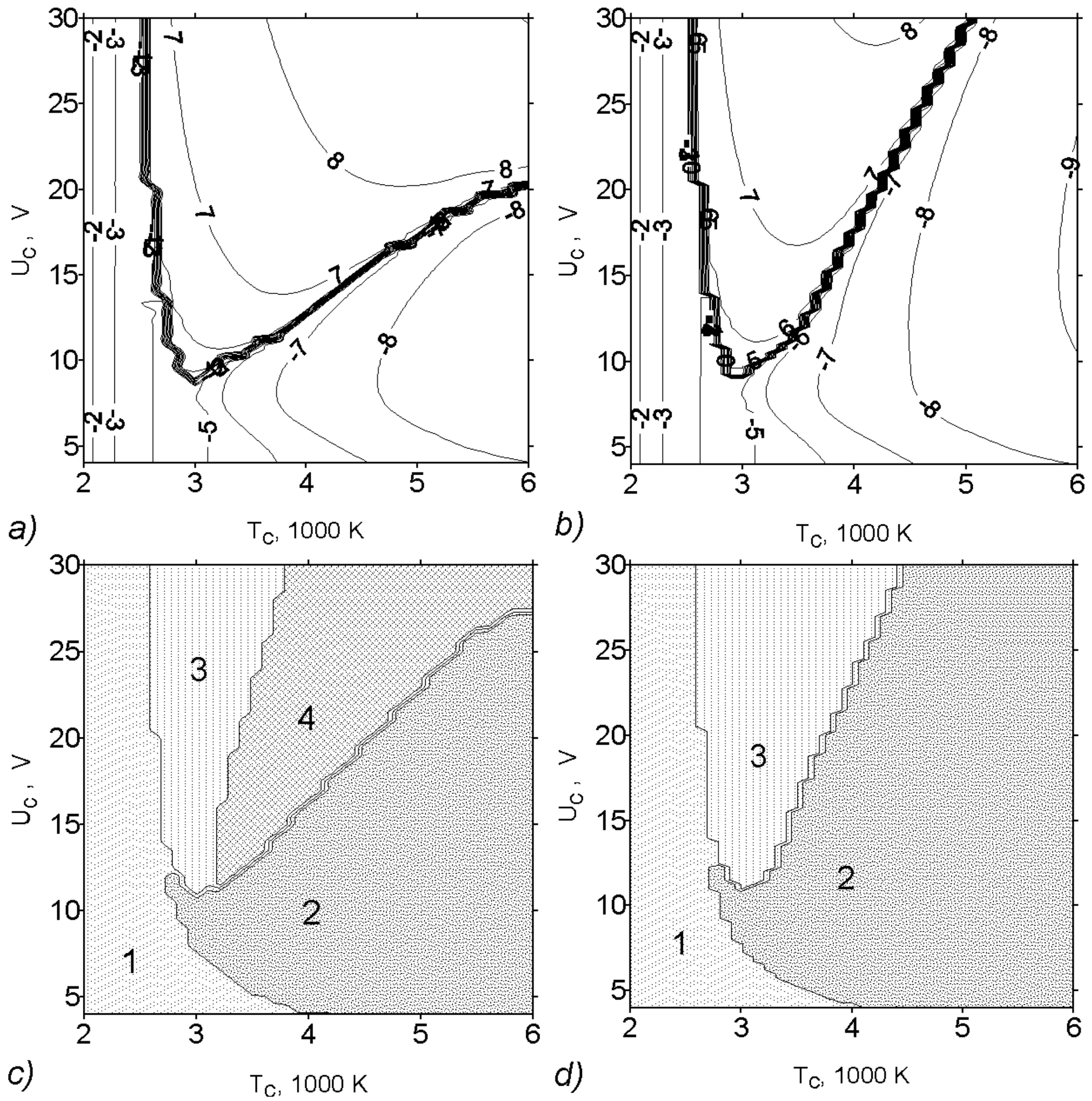

***Fig.1**. The energy balance on the cathode surface as a function* $\mathrm{sign}(Q_s)\cdot\log(|Q_s|)$ *(for*$|Q_s|>1$*)*(a,b). *Contours of* $\max\{|Q_v|,|Q_{em}|,|Q_{ip}|,|Q_{ep}|\}$: 1– *evaporation loses,* 2– *electron emission cooling,* 3– *heating by the plasma ion bombardment,* 4– *heating due to a backflow of plasma electrons.*(c,d)
The accommodation coefficient of plasma electrons: *a,c*– α=1, *b,d*– α=0.

Fig.1*c,d* shows the dominated component of the energy balance on the surface. It is interesting to note in Fig 1*c* the expansion of the spot existence on the gap between the regions of stationary – non-stationary spot operation (in terms of E–diagrams – modes (0)–(1), respectively /2/). On presented in Fig.1 results Joule heating within the cathode bulk do not taken into account.

The calculations shows that the ratio $J_i/J_{ec}<0.04$ for $T_e>3$ eV. The ratio J_{ep}/J_{ec} is approximately 1/10 when the surface temperature $T_c>3500$ K. Figs.1 shows, that relatively small backflow of plasma electrons might be the energy source for convergence of non-stationary and quasi-stationary spot modes.

It was shown in /6/ that the stable cathode spot operation corresponds to decreasing of positive Q_s with increasing of T_c. Formally, it gives possibility to control the spot operation by changing it mode to stable/unstable in dependence on local surface temperature and near-cathode potential fall using, for example, external energy supply for plasma electrons.

4. CONCLUSIONS

The vacuum arc cathode spot modeling with consideration of the energy realized on the surface by the plasma electron backflow will cover gap between quasi-stationary and non-stationary modes of the spot functioning.

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