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In developed cathode arc spots on clean metal surfaces ("type 2" spots according to Rakhovsky /1/) two regions have to be distinguished: 1) the central part, the "core" of the spot, with a high energy input that causes melting, evaporation, cratering, TF-electron emission and explosive processes, and 2) the surrounding "halo" region of interaction between the cathodic plasma and the surface with a lower energy input and without essential surface processes (compare Daalder /2/). According whether the halo is included or not, the calculated mean current densities of the arc spot i_s differ by orders of magnitude.

The main cause of this bipartition is the decreasing density of the expanding plasma outside of the central crater region, and the corresponding decrease of the ion current density i_i impinging on the surface.

The ion current is the main surface heat source of the quasi-stationary arc spot. The total ion impact power within the crater area becomes

$$P_i = I_s U_c^{\prime}/(1+\gamma),$$

I_s: spot current, $\gamma = i_e/i_i$, $U_c^{\prime} = U_c + \varepsilon_i - \varphi + 2kT_p/e$ (U_c: cathode fall of potential, ε_i: ionization potential, φ: work function, T_p: plasma ion temperature). This surface power input is diminished by electron emission cooling because of thermo-field emission and ion induced secondary emission (coefficient γ_s), that results in the power

$$P_e = -I_s[(\gamma-\gamma_s)\bar{U}_e + \gamma_s\varphi]/(1+\gamma).$$

The mean effective work function $\bar{U}_e$ and the electron current density i_e are functions of the surface temperature T_c and the surface field strength F_c, both of which again depend mainly on i_i.

Besides of this surface source there exists a volume heat source because of the Ohmic (Joule) heating below the spot area. From the power density $q_i = i^2T/\sigma_0$ (i: current density, $\sigma = \sigma_0/T$ electric conductivity) we get by integration (applying the known current distribution and temperature distribution /3/) the total Joule power within the cathode

$$P_j = I_s T_0 \sqrt{\varkappa/\sigma_0}\,\mathrm{tg}X + (P_i+P_e)(1/\cos X - 1).$$

where T_0 is the cathode temperature far away from the spot, $\varkappa$ the heat conductivity of the cathode, $X = I_s/4a\sqrt{\varkappa\sigma_0}$, a the spot radius. The ratio $P_j/(P_i+P_e)$ depends mainly on I_s/a and weakly on I_s (or i_s). The percentages of both heat sources in the case of Cu cathodes are shown in the figure. Stationary solutions exist if $I_s/a < (I_s/a)_{crit} = 2\pi\sqrt{\varkappa\sigma_0} = 13.9$ A/μm (Cu).

Article published online by EDP Sciences and available at http://dx.doi.org/10.1051/jphyscol:19797213

Models of stationary arc spots (including the evaporation flux density that limits i_i) result in $0.1 \lesssim I_s/a \lesssim 0.5$ A/μm (Cu cathodes, /4/). However, measurements of I_s and a (assuming crater radius = spot radius) give $2 \lesssim I_s/a \lesssim 20$ A/μm /5/. This discrepancy may be explained by the assumptions that 1) the cathode spot is an essential non-stationary phenomenon, 2) a large part of the current passes through the surface outside of the crater area. A discussion of non-stationary effects shows: a) the spot motion results in a reduction of Joule heating (if I_s/a = const); b) each kind of surface roughness increases Joule heating; c) in essentially non-stationary processes (such as explosions of protrusions, compare /6/), the critical limit $(I_s/a)_{crit}$ may be considerably exceeded, the temperature rises exponentially with time, and even in the temporal average the Joule heating dominates.

The current density and the temperature in the halo region of the spot is so low, that resistive heat production is negligible. The over-all percentages of Joule heating and impact heating depend on the role of explosive processes in the spot mechanism and on the role of the halo current relative to the core (crater) current in the arc spot. Both are still unsolved problems.

References:

/1/ V.I. Rakhovsky, IEEE Trans. Plasma Sci. PS 4 (1976), 81

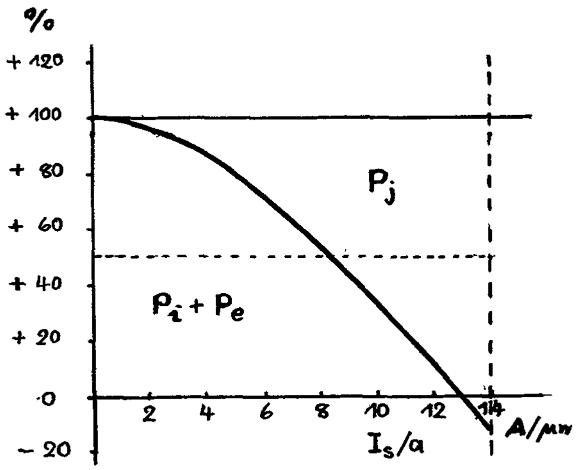
/2/ J.E. Daalder, J. Phys. D 11 (1978), 1667

/3/ E. Hantzsche, Beitr. Plasmaphys. 12 (1972), 245

/4/ E. Hantzsche, Beitr. Plasmaphys. 14 (1974), 135

/5/ J.E. Daalder, IEEE Trans. Pow. App. Syst. PAS 93 (1974), 1747

/6/ J. Mitterauer, P. Till, E. Fraunschiel, M. Haider, Proc. 4. Conf. Gas Disch. (London) 1976, 421



Percentages of surface heating (P_i+P_e) and of resistive heating (P_j) in a stationary cathode arc spot, current I_s = 50 A, as a function of I_s/a, plane Cu cathode.