Simulating Ignition and Development of Cathode Spots in Vacuum Arcs

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A detailed numerical model of individual cathode spots in high-current vacuum arcs is developed with account of all the relevant mechanisms. The spot is ignited and a crater is formed on the cathode surface. A jet of liquid metal in the direction of the plasma is formed and in certain cases the jet may detach from the cathode surface. No microexplosions (thermal runaway) are observed.

1. The model

A detailed numerical model of individual cathode spots in high-current vacuum arcs is developed. The model takes into account an "external" plasma (e.g., a plasma generated for arc triggering, a bulk background plasma, or a plasma cloud left over from a previous spot in the immediate vicinity) and the plasma produced due to ionization of the metal vapor emitted in the spot. Both kinds of plasma provide energy and momentum fluxes over the cathode surface. Ions from the external plasma enter the cathode space-charge sheath with Bohm's velocity and are accelerated in the direction of the cathode. The plasma produced in the spot is described by means of the model [1]. Melting of the cathode metal and motion of the melt are described by means of the heat conduction and Navier-Stokes equations.

2. Results

All phases of life of an individual spot on copper cathodes with microprotrusions and planar cathodes, are investigated. The spot is ignited by the action of the external plasma, provided that this action is sufficiently strong and not too short-lived. The metal in the spot is melted and the melt is accelerated toward the periphery of the spot, the main driving force being the pressure exerted by incident ions. In this way, a crater is formed on the cathode surface (Fig. 1). A jet of liquid metal in the direction of the plasma may be formed as well and in certain cases the jet may detach from the cathode surface (Fig. 1b). Vaporization and/or electron emission, as well as the convective heat transfer, are dominant mechanisms of cooling of the spot and solidification of the metal. No microexplosions (thermal runaway) are observed. The results seem to be in stark contrast with the popular concept of explosive emission.

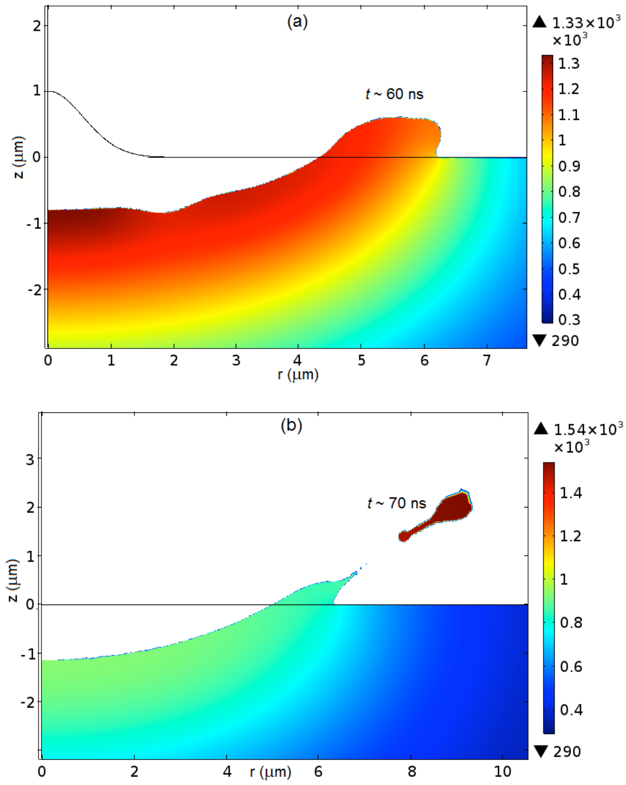

Fig. 1. Results of simulation for (a) cathode with a microprotrusion: solidification of the melt after extinction of the external plasma; and (b) planar cathode: formation of a jet and ejection of material occur after extinction of the external plasma. The colors denote the temperature distribution; the bar in K.

3. Acknowledgements

The work at Universidade da Madeira was supported in part by FCT of Portugal through the project Pest-OE/UID/FIS/50010/2013 and in part by Siemens AG.

4. References

[1] N.A. Almeida, M.S. Benilov, L.G. Benilova, W. Hartmann, N. Wenzel, IEEE Trans. Plasma Sci. 41, 1938 (2013).