Numerical modelling of high-pressure arc discharges: computing anode heating voltage

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Two simple approaches to simulation of plasma-electrode interaction in high-pressure arc discharges are available in the literature: the so-called model of nonlinear surface heating, which is applicable for cathodes, and an approximate model based on the concept of electrode heating voltage, applicable for anodes. In this work, the anode heating voltage is computed for three plasma-producing gases (Ar, Xe, and Hg) in a wide range of plasma pressures, anode surface temperatures, and current densities. The results can be used for modelling the plasma-anode interaction in a wide range of conditions of high-pressure arc discharges. As an example, modelling is reported of interaction of arc plasmas with rod electrodes in both dc and ac arcs.

1. Anode heating voltage

It is known from the experiment that the power input Q from the plasma to anodes of high-pressure arc discharges is proportional to the arc current I: $Q = U_h I$, where the proportionality coefficient U_h (the anode heating voltage) may depend on the plasma-producing gas, its pressure, and the electrode material. For example, results of experiments with tungsten rod electrodes of different dimensions in an arc in argon at pressure of 2.6 bar are well described by this relation with $U_h = 6.24$ V [1].

The anode heating voltage may be theoretically evaluated by means of a suitable 1D numerical model of near-anode layers in thermal plasmas; e.g., [2, 3]. A few results have been calculated for conditions typical of UHP lamps: xenon or mercury plasmas at very high pressures (of the order of 100 bar) [2]. In this work, the anode heating voltage is calculated for a wide range of conditions: the plasma-producing gas is Ar, or Xe, or Hg; the anode material is tungsten (the work function 4.55 eV); the plasma pressure is atmospheric, $p = 1$ bar, or very high, $p = 100$ bar; the temperature of the anode T_w = 300, 1000, 3000 K for the atmospheric pressure and T_w = 1500, 2500, 3500 K for $p = 100$ bar; the current density varies in the range $j = 10^5$-10^7 A m^{-2}.

Calculations have been performed by means of the code [2] and another code, in which the original equations are solved without preliminary transformations. An example of results is shown in Fig. 1. The density q of energy flux from the plasma to the anode is governed primarily by the local current density j and varies approximately proportionally to j: $q = U_h j$. The computed anode heating voltage U_h is virtually independent of the anode temperature and close to 6 V for all the three gases for $p = 1$ bar. For $p = 100$ bar, U_h is close to 7 V for Ar, 6 V for Xe, and 9 V for Hg.

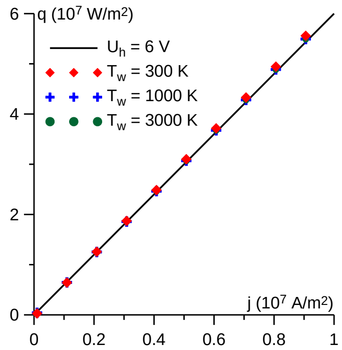

Fig. 1. Points: modelling, $p = 1$ bar, Ar. Line: $q = U_h j$ with $U_h = 6$ V.

2. Rod electrodes

As an example, computed values of the anode heating voltage are applied, jointly with the model of nonlinear surface heating for cathodes, to the modelling of interaction of arc plasmas with rod electrodes. A simple and free of empirical parameters model is developed, which is applicable to the anode and cathode dc regimes as well as ac regimes, provided no anode spots are present. The model is in good agreement in a wide range of conditions with the available experimental data.

3. Acknowledgements

The work was supported by FCT of Portugal through the project Pest-OE/UID/FIS/50010/2013.

4. References

[1] J. Mentel and J. Heberlein, J. Phys. D: Appl. Phys. 43, 023002 (2010).

[2] N. A. Almeida, M. S. Benilov, U. Hechtfischer, G. V. Naidis, J. Phys. D: Appl. Phys., vol. 42, no. 4, pp. 045210 (11pp), 2009.

[3] I. L. Semenov, I. V. Krivtsun, and U. Reisgen, J. Phys. D: Appl. Phys. 49, 105204 (2016).