Sheath vs. arc-column voltages in high-pressure arc discharges

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Abstract

Two very different approaches to theoretical description of interaction of high-pressure arc plasmas with refractory cathodes emerged in the literature in the last 20 years. One group of researchers believes that space-charge effects on refractory cathodes are small and contribute to the arc voltage no more than one or two volts. Accordingly, these researchers use simulation models which are based on the assumption of quasi-neutrality, or even stronger assumption of local thermodynamic equilibrium (LTE), in the whole arc volume, which means neglect of all space-charge sheaths (e.g., review [1]; [2,3] may be cited as the latest examples). Other researchers believe that the voltage drop in the near-cathode space-charge sheath is no less than 10 V and rely on models where the near-cathode sheath plays a central role; e.g., [4,5].

Extensive experimental data on near-cathode voltage obtained during the last decade for low-current arcs ($I \leq 10$ A), in particular by Mentel and co-workers, are in the range 10-50 V and indicate that the first above-described (no-sheath) approach is not justified and the second (sheath-accounted) approach should be used for such arcs, and this is common knowledge now. Unfortunately, experimental data for high-current arcs are very scarce. The status quo is as follows: the sheath-accounted approach is used in virtually all works on modelling of low-current arcs; the no-sheath approach is used in most works on high-current arcs. Amazingly, there has been little interaction between research in these two fields, in spite of the physics of near-cathode plasma layers in high- and low-current arcs being similar, and the question as to what physical reasons could justify the use of so strongly different approaches has not even been asked.

In this work, both a 2T sheath-accounted model similar to the one used in [6] and an LTE model are used for modelling of electrical characteristics of a short atmospheric-pressure argon arc. It is shown that the values of the arc voltage given by the 2T sheath-accounted model are in a reasonable agreement with the experiment [7]. Values given by the LTE model are not very different from the experimental values for $I \geq 120$ A, however the difference becomes significant at lower currents.

It is found that the LTE model substantially overestimates the resistance of the arc column. One of the reasons is that the arc core as described by the LTE model is hotter and narrower than that described by the 2T-sheath model, hence the energy losses from it are higher and the arc column consumes a higher electrical power. The other reason is that the LTE model neglects transport into the arc column of a part of the electric power deposited into the sheath (an effect described in [6] and confirmed in [8]) and therefore overestimates the resistance of the part of the arc column adjacent to the cathode sheath.

Furthermore, it is shown that if the latter resistance is evaluated in the framework of the LTE model in an accurate way, than the overestimation will be still stronger and the obtained voltages will significantly exceed those observed in the experiment. However, conventional numerical algorithms like SIMPLE perform this evaluation in an inaccurate way and the use of these algorithms amounts to a cut-off, which is why it is possible to obtain in LTE modelling arc voltages comparable to the experimental values.

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