Stability of near-anode layers of high-pressure arc discharges

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Abstract
High-pressure xenon arcs develop under certain conditions voltage oscillations accompanied by electromagnetic interference (EMI) [1-4]. The question arises in which region of the discharge the instability responsible for these oscillation develops and what its mechanism is.

This question was considered in [1] and the conclusion was that the instability develops in the plasma column. This conclusion was supported by a local dispersion analysis, which revealed the potential presence of an instability of the energy balance of the electron gas in the plasma column. This instability has been described previously and originates in the variations of heating of the electron gas by the electric field occurring faster than the variations of cooling by collisions with heavy particles.

However, subsequent experimental investigations have pinned down the instability to the near-anode region rather than to the plasma column [2-4]. In particular, it was found that EMI is correlated with the temperature of the surface of the anode and the type of arc attachment to the anode. Therefore, the theoretical mechanism of instability leading to voltage oscillations must be revisited. A related topic of considerable interest is a potential relation between this mechanism and that of multiple attachments of high-pressure arcs to the anodes (e.g., [5,6] and references therein).

These tasks are dealt with in the present work. A local dispersion analysis of high-pressure Xe arc plasmas has confirmed the conclusion of [1] on a potential instability against perturbations of the electron temperature parallel to the arc current. The instability has been traced back to a growing dependence of the electron-neutral collision frequency on the electron temperature T_e. This dependence ensures that the Joule heating of the electron gas (which in the case of a constant current density is inversely proportional to the electron mobility) is a growing function of T_e, thus providing a positive feedback. As a manifestation of this mechanism, the value of T_e that limits the instability window in Xe from below approximately corresponds to the Ramsauer minimum of the electron-atom cross section. In principle, the instability may occur not only in Xe but also in other gases, for example, in Hg: there is no Ramsauer minimum in Hg and the electron-neutral collision frequency monotonically grows for all T_e of interest, including low values.

The conclusion of [1] that this instability develops in the arc column has not been confirmed: T_e in a high-pressure radiation-dominated Xe plasma is above the window of existence of the instability. Similarly, the instability is not possible in the near-cathode layer, where T_e is still higher. But according to the modelling [7], T_e goes down to quite low values (of the order of 5000K) in the near-anode layer; then this is the only region where the instability is possible. This conclusion agrees with the experimental observations [2-4] and the increment of the instability conforms to the experimental rise time of a single pulse. The above agreement represents an important, although inevitably indirect, confirmation of the theoretical conclusion [7] that T_e in the near-anode layer of the high-pressure arcs is quite low.

There is a similarity between the formalisms of the theory of instability behind multiple anode attachments in high-pressure arcs, and of the present theory of instability leading to EMI. However, the mechanisms of the instabilities are different: the Joule heating effect that is stabilizing in one case is destabilizing in the other.

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