Formation of Molten Metal Jets and Droplets in the Cathode Spot of Vacuum Arc Discharge

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The dynamics of molten metal during crater formation in the cathode spot of vacuum arc discharge was theoretically investigated. At the initial stage, a liquid-metal rim is formed around the crater. This process has been numerically simulated in the framework of the two-dimensional axisymmetric heat and mass transfer problem in the approximation of viscous incompressible liquid. At a more developed stage, the motion of liquid metal loses axial symmetry, which corresponds to a tendency toward jet formation. The development of azimuthal instabilities of the rim is analysed in terms of dispersion relations for surface waves. It is shown that maximum increments correspond to instability of the Rayleigh–Plateau type. Estimations of the time of formation of liquid metal jets and their probable number are obtained.

As is known, the cathode spot is a source of liquid metal jets and droplets that play an important role in the self-sustained operation of vacuum arc discharge [1]. They are formed whereas the molten metal is extruded by the pressure of explosive plasma out from craters formed on the cathode. A jet formation mechanism based on the development of azimuthal instability of the Rayleigh–Plateau (RP) type of the boundary of liquid expelled from craters has been proposed in Ref. [2]. However, a qualitative character of models used in [2] does not exclude that the Rayleigh–Taylor (RT) instability also develops, since the characteristic times of RP and RT instabilities are comparable.

The main idea of the present work is to combine numerical and analytical approaches in considering hydrodynamic processes in the cathode spot cell of vacuum arc. In the 2D axisymmetric problem formulation, we have numerically simulated the formation of a liquid metal rim around the crater. At the same time, we analytically studied linear stages of the development of 3D instabilities in the rim with allowance for a change in its geometry.

As can be seen from Fig. 1, the most pronounced growth of perturbations is observed for the azimuthal harmonic with n = 11 and results from development of the RP instability. The harmonic amplitude exhibits for 25 ns an almost fivefold increase, which can provide the formation of jets simultaneously with crater formation. At the same time, the RT instability ensures most rapid growth of the harmonic with n = 5, but it’s amplitude exhibits only threefold increase.

The characteristic time of development of the RP instability (i.e., the time for which the surface perturbation amplitude increases by a factor of e ≈ 2.72) amounts to 14 ns, while that for the RT instability is significantly greater and reaches 21 ns.

Thus, the results of our theoretical analysis with allowance for the substantially 3D character of deformations of the liquid rim lead to the conclusion that the RP instability is responsible for the formation of liquid metal jets (see also Ref. [3]).

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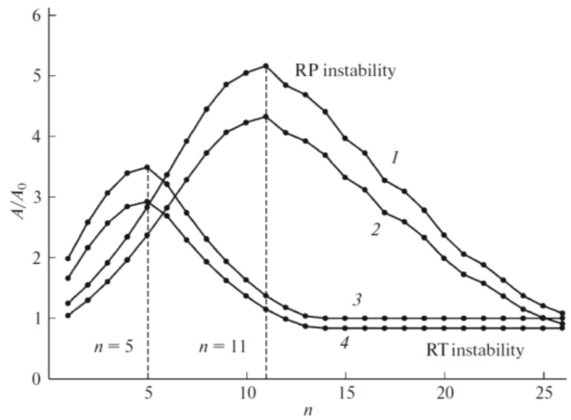

Figure 1. The results of calculations of the growth of amplitudes of azimuthal perturbations on the surface of liquid metal rim for modes with various numbers n during the time interval from t = 10 to 35 ns (A_0 and A being the initial and final values, respectively): (*1*, *2*) upper and lower estimates of the relative amplitude growth due to development of the RP instability; (*3*, *4*) same for development of the RT instability.

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