Transient spots on thermionic arc cathodes I. Modeling

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Abstract: *A study on dynamic mode change of cathodic arc attachment in high pressure arc discharges in HID lamps is performed. A general scenario of transient spot formation is established, which could be used as guidance for experimental purposes.*

INTRODUCTION

Dynamic transitions between the diffuse and spot mode of arc attachment to cathodes of high-intensity discharge (HID) lamps may occur when these lamps operate with ac current. Such transitions are of special interest for the performance and lifetime of the lamp. For example, the erosion of the electrodes, which causes wall blackening, occurs with different rates in each mode of cathode operation. Therefore, the understanding of transient spot formation is of great importance to improving a proper design of electrodes that operate in a desired attachment mode.

Transient spot formation in cathodes of high-pressure arc discharges have been studied both numerically and experimentally in [1,2]. However, a number of questions still remain open. For example, no stationary spot mode has been detected and the role of change of input parameters on spot formation was not investigated. These questions will be addressed in this work.

MODEL AND NUMERICS

A time dependent temperature distribution in the body of a cathode is calculated by numerically solving a transient thermal conduction equation, supplemented with a nonlinear boundary condition describing a dependence of the energy flux from the plasma to the cathode surface on the surface temperature. Input parameters for calculations are plasma-producing gas and its pressure, cathode geometry and material. The cathode has a base that is maintained at a fixed temperature by external cooling. The rest of the cathode surface is in contact with the plasma or cold gas, exchanging energy with it. The nonlinear boundary-value problem was solved by means of the approach described in [3,4].

RESULTS AND DISCUSSION

Numerical results given in this work have been obtained for a tungsten cathode in the form of a rod of radius 0.5mm and height 13.2mm, operating in the argon plasma under the pressure of 2bar; the temperature of the base of the cathode was set to 1000K. This geometry is convenient for purposes of illustrations. Data on thermal conductivity and on emissivity of tungsten was the same that was used in [5], and data on specific heat capacity of tungsten was taken from [6]; the value of 4.55eV was assumed for the work function of tungsten.

In order to establish the general scenario of dynamic mode change of cathodic arc attachment, knowledge of the stationary current-voltage characteristics (CVC) of different modes of cathodic arc attachment is required. It was established in [4] that the CVC of the stationary spot mode (mode with a spot at the edge of the front surface of the cathode) consists of two branches, a high-voltage branch which exists in the current range from zero up to a current corresponding to the turning point, and a low-voltage branch which exists in the current range between the bifurcation point (the point at which the spot branch off from the diffuse mode) and the turning point. For the presented case, the bifurcation point is positioned into the region of very high voltages (well in excess of 200V), while the current corresponding to the turning point is around 1.73A.

Figure 1 shows simulations results of the temporal variation of the maximum temperature of the cathode surface and near-cathode voltage drop for current jumps starting in the stationary diffuse mode at 0.4A, with a target current of 1.0A, 1.3A and 1.8A, respectively. At time 0.1ms the current jumps to the target current with a rise time of 0.1μs. Similarly to [1], transient spots occur only if the target current exceeds a distinct threshold. We have found that this threshold corresponds to the turning point of the CVC of stationary spot. Below this threshold, a stationary spot belonging to the high-voltage branch occurs. This behavior of the system should be taken into account when performing experiments on transitions between diffuse and spot modes of cathodic arc attachment. An interesting question which arises at this point is why the stationary spot was not found in the experiments reported in [1]. To give an answer to this question, we have performed simulations for the same cathode geometry used in [1], i.e., a cathode with the same dimensions used in this work but with a rounding edge at the front surface of 100μm radius. It was found that for this geometry the current corresponding to the turning point has changed to about 0.41A, which is slightly above the initial value of the current jump. This explains why the stationary spot has not been detected in [1].

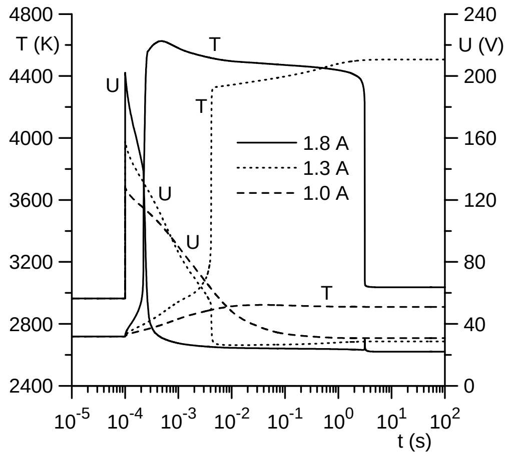

Figure 1. Maximum temperature on the cathode surface and near-cathode voltage drop.

Calculations reveal that the spot formation is also strongly affected by the cathode geometry and thermal conductivity of the cathode material. For a current jump from 0.4A to 1.8A, we have found that the spot has been formed at about 0.15ms and 1.34ms, after the current jump, for a cathode in the form of a rod and for the cathode with a rounding edge at the front surface of 100μm radius, respectively. This difference can be interpreted as a consequence of the fact that heat flow resistance between the edge and the bulk of the cathode decreases as the rounding of the edge of the front surface of the cathode increases. On the other hand, for the same current jump, we have found that the spot life time has changed from about 3s to 0.2s when we replace the thermal conductivity of tungsten used in our calculations by the one used in [1], being the time formation of the spot virtually unchanged. This effect can be attributed to the fact that the temperature dependence of the thermal conductivity used in [1] is nearly the same as the one used in our calculation at low temperatures and appreciably higher at high temperatures.

Simulation results have revealed that the temperature distribution along the cathode surface virtually does not change during the current jump. This effect can be attributed to the thermal inertia of the cathode material. For such a short time the heat propagated throughout the cathode structure is virtually null. The high value attained by the voltage at the end of the current jump can be seen as a consequence of this inertia. The demanded integral current can be assured only by an increase of the voltage. This fact allows us to calculate the CVC during the current jump without solving the above mentioned nonlinear problem. Using the temperature distribution along the cathode surface corresponding to the initial current and changing the voltage, the current delivered to the cathode is calculated. Simulation results have confirmed this hypothesis and showed an excellent agreement between the characteristics calculated by these different approaches.

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