Transient Spots on Cathodes of High-Pressure Arc Discharges

P. G. C. Almeida, M. S. Benilov, and M. D. Cunha

***Abstract*—Experimental and modeling results are reported on transient spots induced on thermionic cathodes by a rapid increase of the arc current and on their prevention.**

***Index Terms*—Arc attachment, arc cathode, cathode spots, high-pressure arc.**

APPEARANCE of spots on cathodes of high-pressure arc discharges is caused by a thermal instability resulting from the competition between two mechanisms: the growing dependence of the density of energy flux from the plasma to the cathode surface on the local temperature of the surface, which represents a positive feedback, and the thermal conduction in the cathode body, which tends to damp perturbations and, thus, represents a stabilizing mechanism. Typically, spots appear on electrodes of ac arc discharges, such as those in high-intensity discharge (HID) lamps, at the beginning of the cathodic phase. Once having appeared, a spot may survive during the whole cathodic phase, or alternatively, the whole cathode may get hot enough to cause the arc attachment to switch into the diffuse mode.

It seems natural to try to prevent transient spots on thermionic arc cathodes by means of an intelligent choice of the current waveform. Such choice can be guided by numerical modeling.

Results of such work are reported in this paper. Spots induced by a current step are studied. This way of inducing transient cathodic spots was proposed in [1] and [2]; while being convenient for methodical purposes, it represents an adequate way of reproducing the scenario of spot formation on cathodes of ac arcs after the change of polarity.

Experiments were performed on COST-529 standard lamps, which are HID lamps (with quartz walls and a quartz envelope) [3] operated in a vertical position. The lamps used were filled with mercury, and the operating pressure was about 4 bar. The results reported in this paper refer to lamps equipped with pure tungsten rod electrodes with a diameter of 700 μm and a length (from one tip to another) of 11 mm. The edge of the front surface of electrodes is rounded with a radius of about 25 μm, and the length of the electrodes inside the burner is about 3.7 mm.

The power supply was provided by a voltage-driven power amplifier FM 1295 DCU/I 750 made by MedTech Engineering, which functioned as a current source controlled by an arbitrary waveform generator Agilent 33220A. Transient spots were induced on the electrode at the bottom of the burner, which operated as the cathode, by a current jump.

The modeling of the plasma-cathode interaction was performed in the framework of the model of nonlinear surface heating (e.g., [4]). The thermal conduction problem in the cathode body was solved with the use of the commercial finite-element software COMSOL Multiphysics. Given the planar symmetry of the problem, only half of the cathode body was treated.

An example of formation and disappearance of a transient spot, as shown in the experiment and via modeling, is shown in Fig. 1. At the initial state, the temperature distribution in the cathode is axially symmetric, which is characteristic of the diffuse mode. After the current jump, axial symmetry breaks down, and a current distribution with a narrow maximum at the edge of the front surface of the cathode occurs; then, a hot cathode spot appears. Once having been formed, the spot exists during a certain time and then disappears; axial symmetry is then restored.

The computed near-cathode voltage drop and maximum temperature of the cathode surface are in a good qualitative agreement with the measured lamp voltage and intensity of light emitted by the near-cathode plasma and by the top of the cathode. There is also a good agreement between the threshold current and the time of formation of transient spots, although not on their lifetime.

Both the modeling and the experiment demonstrated a possibility of prevention of appearance of transient spots by means of a brief reduction of the arc current shortly after the jump. An example as described by the modeling is shown in Fig. 2: the appearance of a spot identical to the one shown in Fig. 1 is prevented by a reduction of current to 0.4 A, which starts 0.3 ms after the current jump and lasts for 0.5 ms.

Other aspects of this work and further details are reported in [5]. In particular, the formation of stationary and transient spots is analyzed in the context of the general pattern of steady-state modes of current transfer to thermionic cathodes and their stability.

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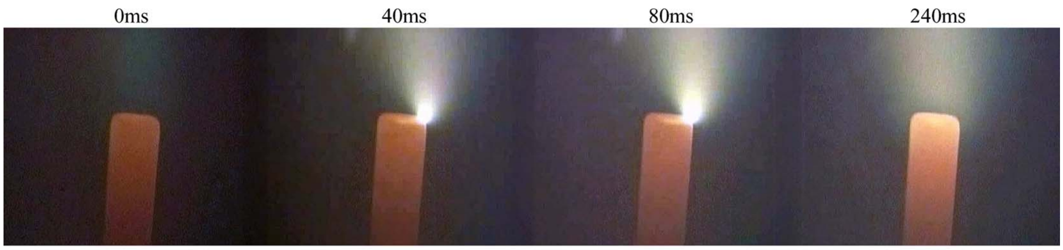
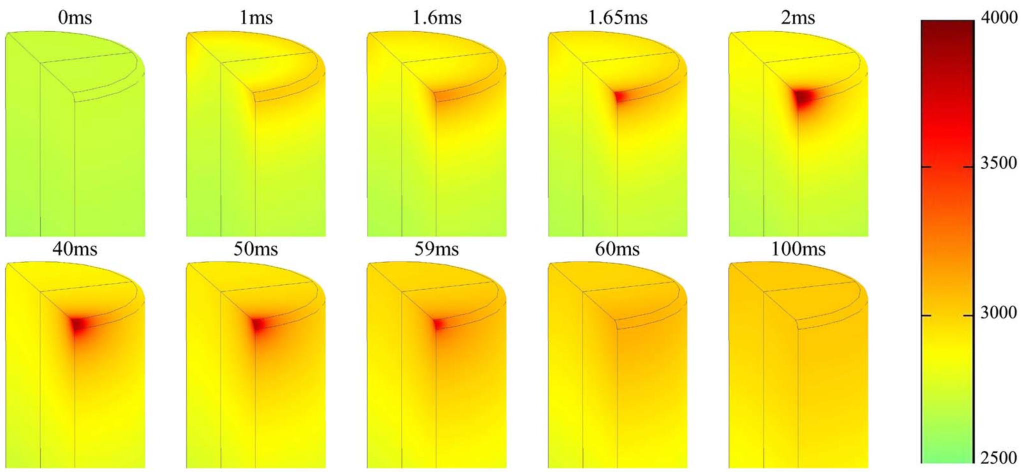


(a)



(b)

Fig. 1. Transient spot on the cathode of a COST-529 standard HID lamp. At $t = 0$, the current rises from 0.3 A within 5 μs to 1.3 A. (a) Photos taken in the experiment. (b) Computed distribution of temperature along the surface of the cathode (bar, in kelvins).

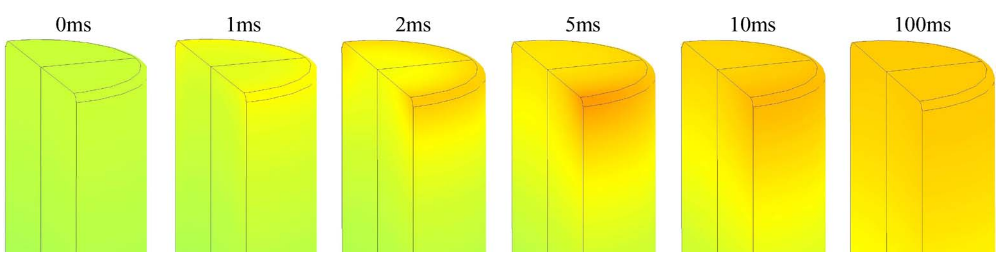


Fig. 2. Prevention of transient spots under conditions of Fig. 1. At $t = 0$, the current rises from 0.3 A within 5 μs to 1.3 A. At $t = 0.3$ ms, the current is reduced to 0.4 A. At $t = 0.8$ ms, the current again rises to 1.3 A. The bar is shown in Fig. 1.

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