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Mode changes on thermionic cathodes: II. Preventing transient spots

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The paper is concerned with transitions between diffuse and spot modes of attachment of high-pressure arcs to thermionic cathodes, provoked by a current jump. These transitions are studied both numerically and experimentally. The experiment is performed with the use of COST-529 standard arc lamps, which were filled with pure mercury under the pressure of 4 bar HID and had different electrode radii. A good agreement between the experimental and modelling results is found and a possibility of prevention of appearance of spots by means of an intelligent power supply demonstrated.

1. Introduction

Ensuring an appropriate mode of attachment of the arc to the cathode is of paramount importance for a stable and lasting operation of arc devices. The diffuse attachment is usually preferred, however it may be unstable and spots appear on the cathode surface.

It is quite difficult to obtain in the experiment a reproducible transition between diffuse and spot modes of arc-cathode attachment. This suggests that this transition is highly sensitive to discharge and electrode parameters and it is this sensitivity that complicates the experiments. On the other hand, such sensitivity, if properly understood, promises a possibility of control of transitions between different modes and ensuring a desired mode.

In the first part of this work, the effect of three kinds of control parameters was studied numerically: of cathode geometry, of thermal conductivity of the cathode material, and of target current in a current jump. In the present contribution, transitions between diffuse and spot modes of attachment of high-pressure arcs to thermionic cathodes, provoked by a current jump, are studied by means of a numerical and physical experiment, with the aim to demonstrate the possibility of prevention of appearance of spots.

2. The approach

The numerical model has been described in the first part of this work [1]. Experiments were performed on COST-529 standard lamps, which are HID lamps with quartz walls and a quartz envelope [2]. The lamps had pure tungsten cylindrical electrodes with diameter of 500μm and height of 9mm (type 1) and with 700μm diameter and 11mm height. (type 2). Lamps filled with 5mg of mercury (apart from about 300mbar argon filling as the starter gas) were used, which resulted in an operating pressure of about 4bar.

The boundary condition (3) of [1], which is established at the current-collecting part of the cathode surface, applies only to the part of the cathode which is inside the burner. The rest of the cathode is considered thermal and electrically insulated. X-ray photographs showed that the part of the electrode which is inside the burner varies from one lamp of the type 2 to another, with the average length of the electrodes inside the burner being 3.7mm with a dispersion of 0.29mm. The X-ray photographs show also a rounding of the edge at the electrode front surface of 25μm radius in average. This rounding was taken into account in the modelling as well.

The power supply to the lamps 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, and an analogue function generator Leader LFG–1300S.

The image of the cathode and of near-cathode region was magnified 10 times and focused on a screen. The mode of arc-attachment to the cathode was diagnosed by photodiodes placed on the screen in front of the image of the cathode. The measurements were performed by a Yokogawa DL 1640 200MSs^{-1} digital oscilloscope. The lamps were operated in a vertical position.

3. The formation of transient spots

It has been found in the modelling that a convenient value for the initial current of the current jump was 0.2A for type 1 lamps, and of 0.3A for type 2 lamps. This choice is of great importance, since the useful lifetime of the lamp strongly depends on this parameter: the value of the initial current of the jump must be chosen in a way to minimise the sputtering that occurs at low currents, when the cathodic voltage drop is high, while at the same time it must ensure that the lamp would not operate at much more than 100 W at the final of a current jump which induces a transient spot. In figure 1 the near-cathode CVC obtained in the modelling is shown for type 1 and type 2 cathodes. The difference in the near-cathode voltage drop between type 1 and type 2 cathodes for 0.2A is of about 17V. This shows that sputtering for a type 2 lamp at 0.2A should be significantly increased as compared with a type 1 lamp operating at the same current. Indeed, an operation of a type 2 lamp with an initial jump current of 0.2 A resulted in a very fast blackening of the burner.

The modelling predicts that diffuse-spot-diffuse transitions could be induced in a typical type 1 lamp with a current jump to values greater than about 0.9A. For a typical type 2 lamp, the prediction from the modelling is that diffuse-spot-diffuse transitions can be induced with a current jump to values greater than about 1.3A.

In figure 2 modelling results for the cathodic voltage drop and the maximum cathode temperature are shown for an average type 1 cathode for 0.2A – 0.8A and 0.2A – 1.0A current jumps.

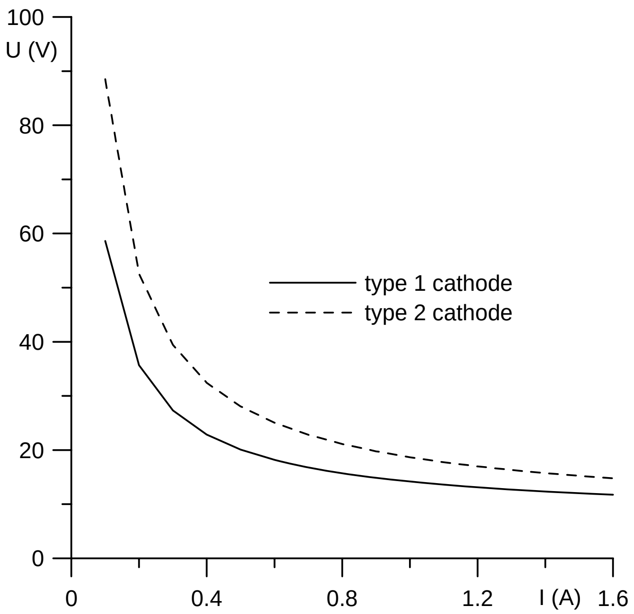

Figure 1: CVC of the near-cathode plasma layer for type 1 and average type 2 cathodes (modelling).

In figure 3 experimental results for the lamp voltage drop and for light intensity of the near-cathode region are shown under the same conditions of the modelling results shown in figure 2. For the 0.2A – 0.8A current jump the light intensity in the near-cathode region increases before it stabilizes about 0.1s after the jump. This is the expected behaviour: the cathode and arc temperatures are higher at higher currents. For this jump there is a sharp peak in the lamp voltage just after the jump, which afterwards undergoes a smooth decrease down to a constant voltage of about 80V. For the 0.2A – 1.0A jump, there is a steep increase of the light intensity in the near-cathode region at about 0.7ms which is accompanied by a steep decrease of the lamp voltage at the same instant. After about 50ms, the light intensity steeply decreases to a constant value, this decrease being accompanied by a small peak in the lamp voltage. These results indicate the formation of a spot about 0.7ms after the 0.2A – 1.0A current jump. The spot decays after 50ms.

The experimental results for the lamp voltage conform to trends observed in [3]. However, the measured light intensity does not conform to the results in [3]. In that work, triangle-shaped peaks in the light intensity of the near-cathode region are associated with the formation of the spot. In the present work what indicates spot formation is a change of slope in the light intensity of the near-cathode region, which is accompanied by a steep decrease of the lamp voltage drop at the same instant. Furthermore, the light intensity signal reported in the present work is rectangle-shaped and not triangular. It should be emphasized that rectangular peaks in the light intensity are in good qualitative agreement with the numerical results for the maximum cathode temperature.

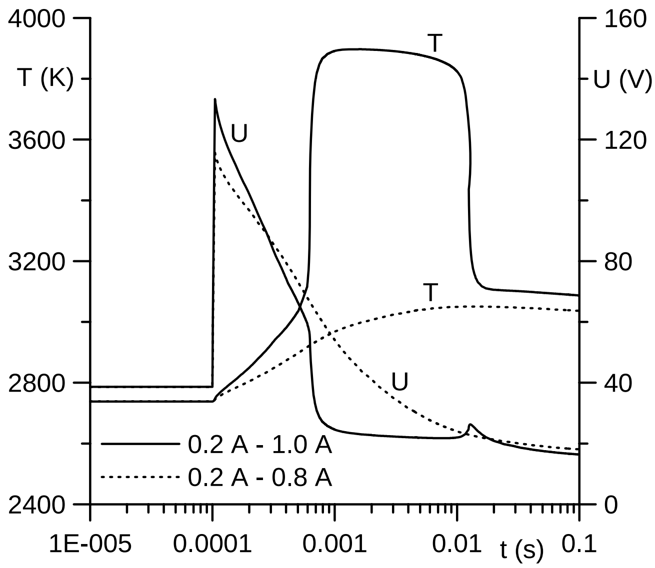

Figure 2: Modelling results for the maximum cathode temperature (T) and near-cathode voltage drop (U) for different current jumps imposed to a cathode operating in the mercury plasma.

Comparing figures 2 and 3, one can see that the qualitative agreement between the simulations and the experiments is quite good, although the model predicts a decay of the spot about 20ms after the current jump, i.e., much earlier than this happened in the experiment. This issue is very significant and will be discussed in detail at the conference.

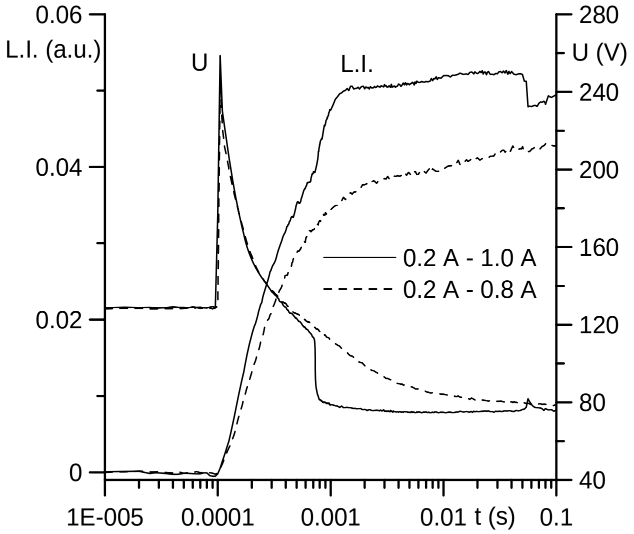

Figure 3: Experimental results for the lamp voltage, U, light intensity in the near-cathode region, L.I., for different current jumps imposed to a type 1 typical lamp.

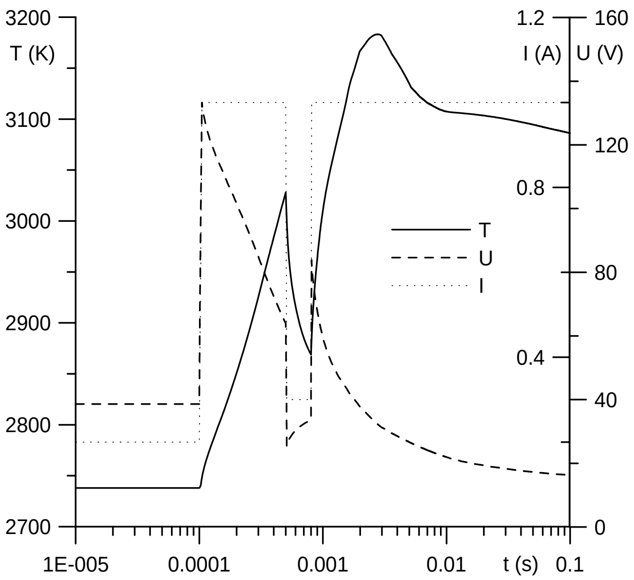

Figure 4: modelling: the prevention of a diffuse-spot-diffuse transition in a 0.2A – 1.0A current jump. T: maximum cathode temperature U: near-cathode voltage drop; I: current.

4. Prevention of spots

The formation of a spot induced by a current jump can be interpreted as a result of the failure of the cathode to undergo a uniform heating as a response to the increase of the current. Educated guesswork would lead one to expect that a brief decrease of the current shortly soon after the jump could aid the cathode to heat up uniformly, thus preventing the appearance of a transient spot.

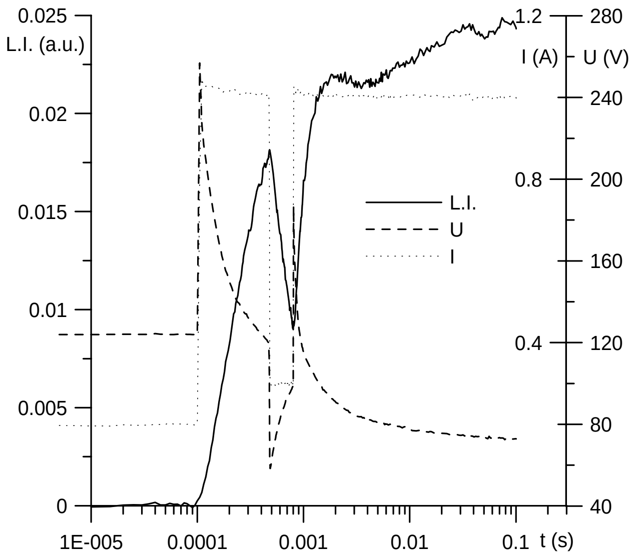

Figure 5: experiments: the prevention of a diffuse-spot-diffuse transition in a 0.2A – 1.0A current jump. U: lamp voltage; I: lamp current.

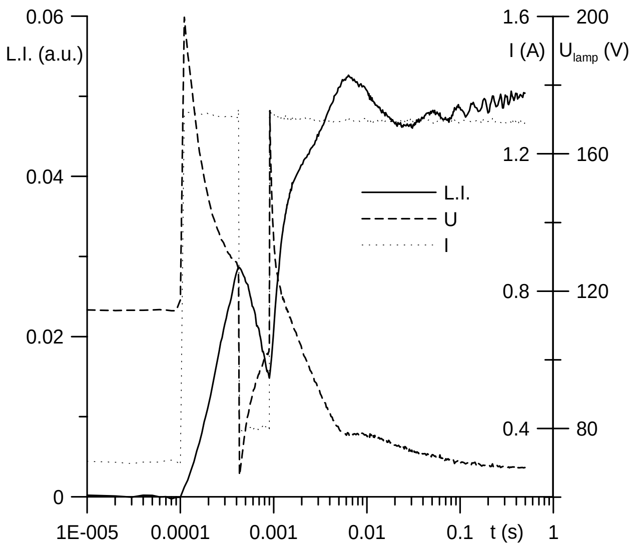

Figure 6: experiments: the prevention of a diffuse-spot-diffuse transition in a 0.2A – 1.0A current jump. U: lamp voltage; I: lamp current.

The modelling results shown in figure 4 confirm this prediction. A 0.2 A – 1.0 A current jump on a type 1 cathode is shown with a decrease of the current to 0.3 A during approximately 0.3 ms. The appearance of a spot is indeed prevented.

The experimental results shown in figure 5, which were obtained for a type 1 lamp, are in excellent agreement with the modelling results. In figure 6 are shown similar experimental results obtained for a type 2 lamp.

Experiments performed in different lamps and also for different current jumps in the same lamp confirm the reproducibility of the results obtained on the prevention of transient spots. There are experimental indications that the prevention of the spot under the conditions of this work results in a decrease of the blackening of the burner around the electrodes.

5. Acknowledgments

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6. References

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