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STRUCTURE OF THE CARBON ARC AT LOWERED PRESSURE

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Abstract. The arc discharge between graphite electrodes (I = 60÷120 A, U = 20÷40 V, L = 1÷6 mm, P = 1÷500 torr) was found to exist in two modes, distinguished by time-spatial structure: in stationary mode with axisymmetric current-conducting channel and in non-stationary mode with two spiral channels originating from an anode spot and revolving on lateral surface of cylindrical electrodes with frequency of 10-20 kHz.

1. INTRODUCTION

When studying the processes of fullerene synthesis in carbon arcs Shimanovich et al. (1998) disclosed that the arc at lowered pressures of buffer gas operates in two modes. In the first mode the arc is stationary and axisymmetric. In the second mode the arc is non-stationary plasmoid with quasi-periodic pulsation of brightness. The arc transition into the non-stationary mode is accompanied by arc voltage drop of 4÷6 V as well as by considerable rising of plasmoid brightness. The brightness pulsation correspond to voltage pulsation with amplitude of 0.5÷2 V. The mode transition occurs spontaneously every 0.5÷5 ms and does not depend on external discharge parameters. Ratio between duration of these modes as well as structure and pulsation frequency of non-stationary stage of the discharge depends on pressure, kind of gas and arc current. At helium pressure near 100 torr the arc operates in stationary and non-stationary modes approximately equal time. When pressure is lower than a few torr only non-stationary mode of the arc exists. Shimanovich et al. (1998) advanced the hypothesis that formation of the non-stationary arc mode takes place due to development of overheating instability in the arc plasma.

The present work is aimed to study the structure of arc in non-stationary mode under wide range of the discharge parameters by means of methods of high-speed imaging.

2. EXPERIMENT

An arc is struck in helium, argon, krypton or nitrogen at lowered pressures (1÷500 torr) between graphite electrodes 6 mm in diameter. The electrodes are enclosed in a stainless steel vacuum chamber fitted with quartz windows and the cathode, anode and walls of the chamber are water-cooled. The arc is powered by a constant current supply with ripple factor less than 0.05.

Study of the arc was carried out with the help of high-speed camera operating in modes of frame-by-frame photography and continuous scanning of different arc sections with time resolution down to 10^{-6} s.

3. RESULTS AND DISCUSSION

The sequence of frames of the arc obtained at filming frequency of 50 f/s is given in Fig. 1. The filming exposure time of 10^{-6} s eliminates a possibility of contortion of the arc images due to the instability disclosed by Shimanovich et al. (1998). It is clear from the figure that arc channel is curved and the channel position permanently displaces. Besides, there are no any longitudinal displacements of luminous volumes in the discharge gap.

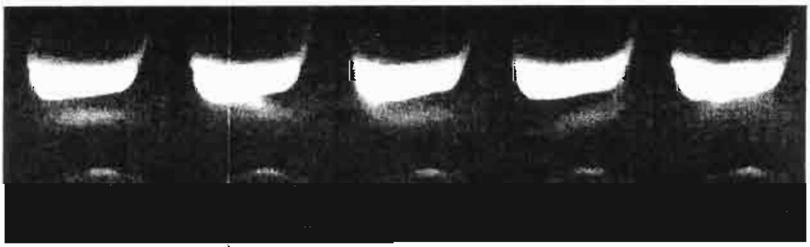

Fig. 1. A fragment of filming the arc (I = 80 A, P = 10 torr).

The analysis of the arc snaps (Fig. 1) as well as longitudinal and transversal continuous scans (see Fig. 2) has shown, that the arc under considered requirements has two spiral channels revolving on lateral surface of cylindrical electrodes. Unequal brightness of the channels on longitudinal scan apparently results from brightness extinction of the channel, remote from an observer, due to absorption and scattering of its radiation by a central zone of arc.

Model of such revolving arc is shown in Fig. 2. The continuous scans (Fig. 2, *c* and *d*) corresponding to the model and obtained by a computer simulation are in good agreement with the experimental continuous scans

(Fig. 2, *a* and *b*) obtained for the arc at I = 80 A, L = 5 mm and P_{He} = 2 torr. Therefore the suggested model may be used for description of behavior of revolving carbon arcs under considered requirements.

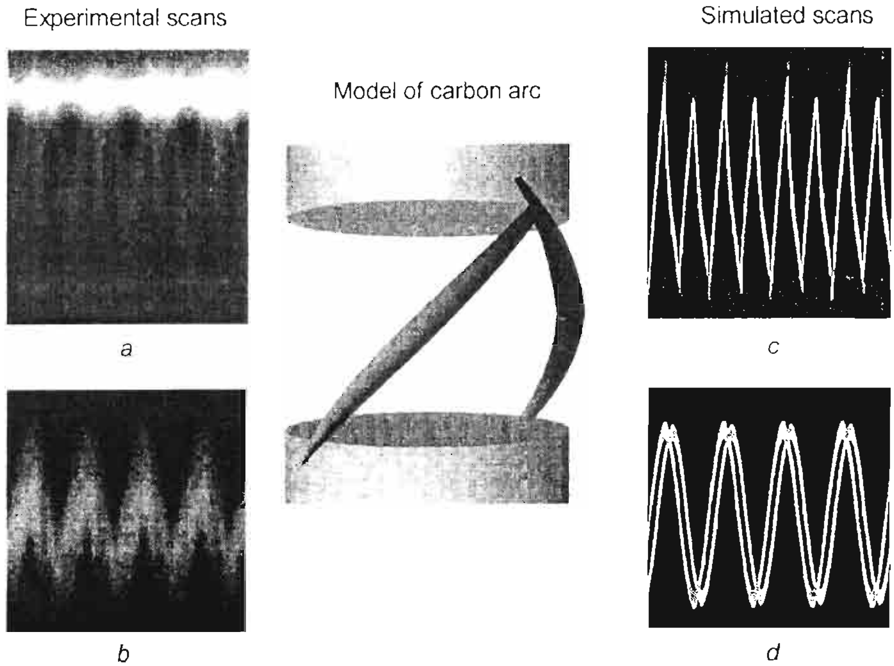

Fig. 2. Model of arc between graphite electrodes at lowered pressure and continuous scans of longitudinal (*a* and *c*) and transversal (*b* and *d*) sections of the arc.

Instability of the arc in question is caused by a competition of physical processes under entering of carbon vapour and particles from the anode into the arc and removing them from the discharge zone. At small content of carbon atoms and crystallites in plasma of arc with distributed anode attachment, the overheating instability develops due to inefficient heat transfer from the arc plasma. At certain parameters the stationary arc discharge transforms into non-stationary one with formation of electrode spots and contracted current-conducting channels. Under the influence of magnetic field the contracted channels are blown on lateral surface of cylindrical electrodes and revolve around the axis of electrodes.

To improve stability the spinning spiral channel splits in two symmetric ones originating from an anode spot. The formation of two current-conducting channels for a plasmoid stability improvement was observed earlier by Azharonok et al. (1986).

Increase of anode erosion as a result of the spot formation leads to rising of carbon partial pressure and carbon particle density in the discharge gap thus promoting the rise of heat transfer from the arc plasma due to radiant and convective thermoconductivity. As a result the overheating instability is dumped and non-stationary arc transforms into the stationary mode. The increase of electron emission due to heated carbon particles reduces the current density near anode and also promotes the suppression of overheating instability. The arc mode transition repeats periodically during all time of the arc discharge existence.

The observed dependence of carbon arc structure on buffer gas pressure is a circumstantial confirmation of this explanation. At pressure lower a few torr the only revolving double channel spiral arc exists that specifies the heat transfer from plasma to be inefficient for inhibition of overheating instability. Decrease of radiant and convective thermoconductivity with lowering of gas pressure conforms to general conceptions about transport processes in gases and plasmas.

The conditions of alternate existence of arc in stationary symmetric or revolving spiral modes are most favorable for fullerene synthesis. Study of this accordance may be a rather successful direction of investigation of fullerene formation mechanisms in carbon arcs.

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References

Azharonok V.V., Gubkevich V.A., Zolotovsky A.I., Chubrik N.I. and Shimanovich V.D.: 1986. *J. Phys. Engineering* **50**, 362 (*in Russian*).

Shimanovich V.D., Smyaglikov I.P. and Zolotovsky A.I.: 1998, *J. Phys. Engineering* **71**, 669 (*in Russian*).