Observation of vacuum arc cathode spot with high speed framing camera

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ABSTRACT

A copper vacuum arc cathode spot at current 10-100 A was imaged by three-frame camera K 001[1] (BIFO Company, Russia) with frame exposures 30 ns and 6 ns and spatial resolution up to 7 μm. It was found that spot splitting into separate fragments occurs at currents higher than 50 A. The average fragment size was found to be 20 μm at current about 10 A (cathode spot consists of a single fragment). With the rise of the arc current the average fragment size rises too and reaches 50 μm at current 100 A (cathode spot consists of two or three fragments). The overall dimension of region occupied by cathode spot fragments rises from 20 μm at current 12 A to 120 μm at current 100 A. Observations with high temporal resolution (exposure time 6 ns) reveal the significant changes of cathode spot brightness occurring within about 10 ns time interval.

Keywords: cathode spot, ecton, vacuum arc, framing camera

1. INTRODUCTION

Vacuum arc current at the cathode passes through tiny luminous objects less than 100 μm in diameter called cathode spots. The cathode spots chaotically move over the surface and provide both the electrons for current flow and the medium (ions, plasma) to account for negative space charge of electrons, thus resulting in high current and low voltage (about 20 V for copper) vacuum discharge. The cathode processes of plasma injection are highly non-stationary and the instabilities of the current, voltage, radiation, plasma and ion flows are the main features of vacuum arc discharge [2,3]. The vacuum arc cathode spot structure and dynamics has been thoroughly investigated last years with high speed imaging techniques [4,5,6,7,8]. It was found that high speed images reveal the cathode spot internal structure, it consists of fragments of size from few microns to tens microns and carrying a current of few Amps and up to tens Amps. These fragments are highly non-stationary and appear and disappear within few nanoseconds or tens of nanoseconds. Such a behavior has its natural explanation within the ecton model of cathode spot operation [9,10]. The model presumes that the basic process of the cathode spot fragment is an ecton – the explosion of cathode metal micro-volume that produce plasma for current flow through the discharge. Meanwhile no investigations were made on the dependence of cathode spot structure on arc current. The aim of present work is to perform measurements of the number of fragments within the cathode spot as a function of arc current.

2. EXPERIMENTAL SET UP AND PROSEDURE

Experiments were made in stainless steel vacuum chamber evacuated to 10^{-8} torr by oil-free pumping system. The bandwidth of the chamber is about 1 GHz. The view of the electrode system is shown in Fig.1. The cathode spot was ignited on the lateral side of the cathode by auxiliary trigger pin electrode made of tungsten with the tip of 20 μm. Cathode was a 3 mm long piece of OFHC copper wire of diameter 300 μm at the tip, the anode was a tungsten wire 200 μm of diameter. Anode to cathode distance was 150-200 μm. Before the measurements the cathode surface was cleaned by multiple arcing with current 20 A rms and pulse duration 100 μs, for it is known [11] that the arc itself is reliable technique to remove surface contaminations. The electrical circuit diagram of arc power supply and measurements is

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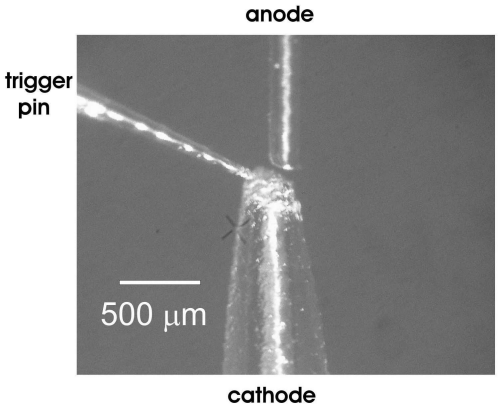


Fig.1. View of electrode system.

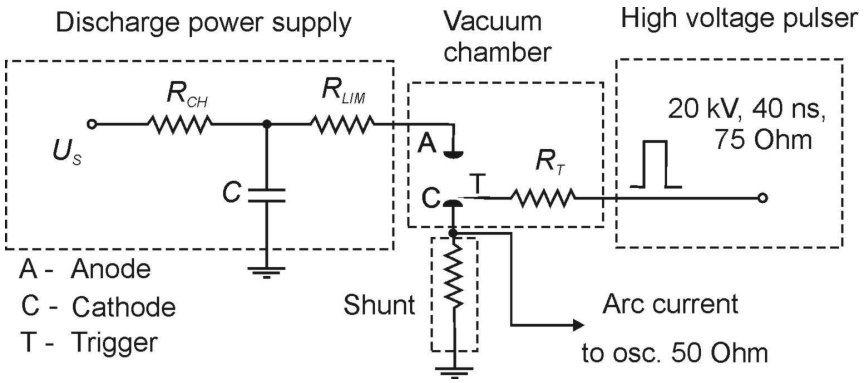
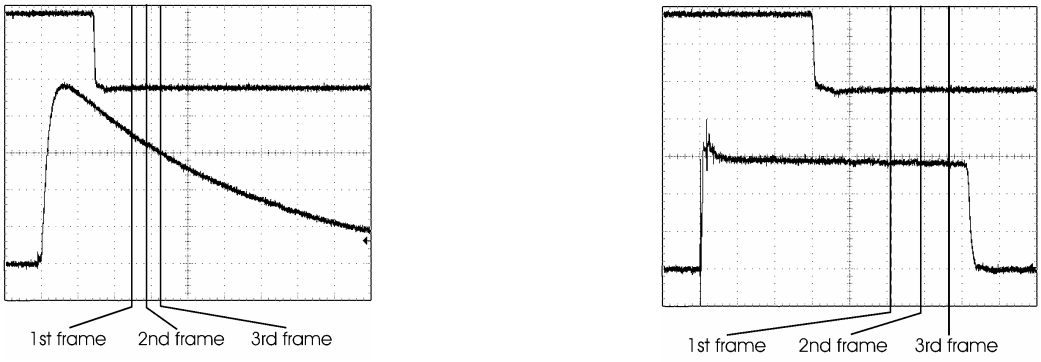


Fig.2. Electrical scheme of measurements and discharge power supply.



a b

Fig.3. Lower trace- arc current. Upper trace – camera trigger pulse; a -time 200 ns/div, current - 30 A/div. b – time 100 ns/div, current – 6 A/div.

given in Fig.2. High voltage pulse generator (HVPG) is based on co-axial cables of 75 Ω impedance, pulse amplitude is 15 – 20 kV. HVPG produces two pulses simultaneously, one for arc ignition (duration 40 ns, current 4 A) and another for framing camera triggering. For currents 30 – 100 A the main discharge was fed by low inductance *RC*- circuit (R – 10 Ω, C – 0,1 μF) connected to the anode, initially the capacitor was charged to a dc voltage, thus the discharge current was decreasing. The discharge duration was 1 – 2 μs depending on dc charging level. For currents 10-30 A we used a piece

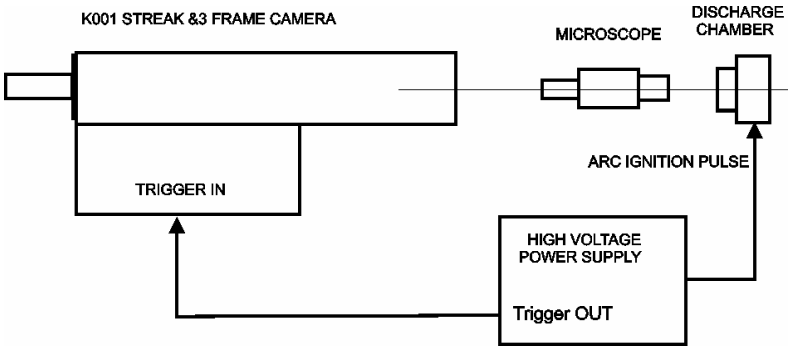


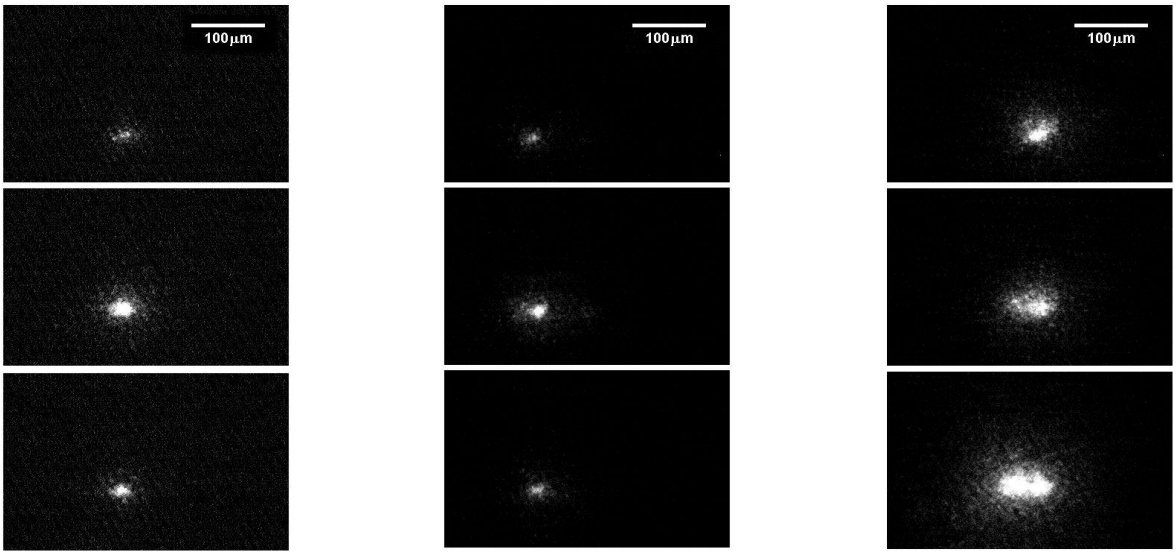
Fig.4. Scheme of optical measurements

Fig.5. Experimental arrangement.

of coaxial cable of 75 Ω impedance and electrical length 350 ns instead of *RC*-circuit. The arc current was measured by 0.34 Ω resistor in the cathode circuit by using the Tektronix 684B digital oscilloscope that has 1 GHz bandwidth and up to 5 Ghz sampling rate. An example of the arc current waveforms is given in Fig.3, the pulse that triggers the K001 camera is also shown. All experiments were performed at fixed delay of camera trigger to arc ignition, and it was set to 300 ns. The scheme of optical measurements is shown in Fig.4. Cathode spot was observed end on through the glass window and photo-port of Stemi 2000C Carl Zeiss stereomicroscope (glass optics) by using K001[1] universal image converter camera. This camera operates in spectral range of 380 – 800 nm and has a several picosecond limiting temporal resolution in streak mode and near 4GHz maximum frame repetition rate with 160 ps frame duration in three-framing mode. Figure 5 represents the view of the experimental arrangement. Microscope has a numerical aperture N.A.= 0,085 and theoretical spatial resolution of magnifying optics at 400 nm wavelength is 2,9 μm. The spatial resolution at the photocathode of K001 camera in framing mode is 3 pl/mm that means approx. 7 μm spatial resolution in the object plane at our magnification, magnification was 23 times and 1 μm in object plane corresponds to 1 pixel of the final image. We used two regimes of camera in framing mode (Table 1).

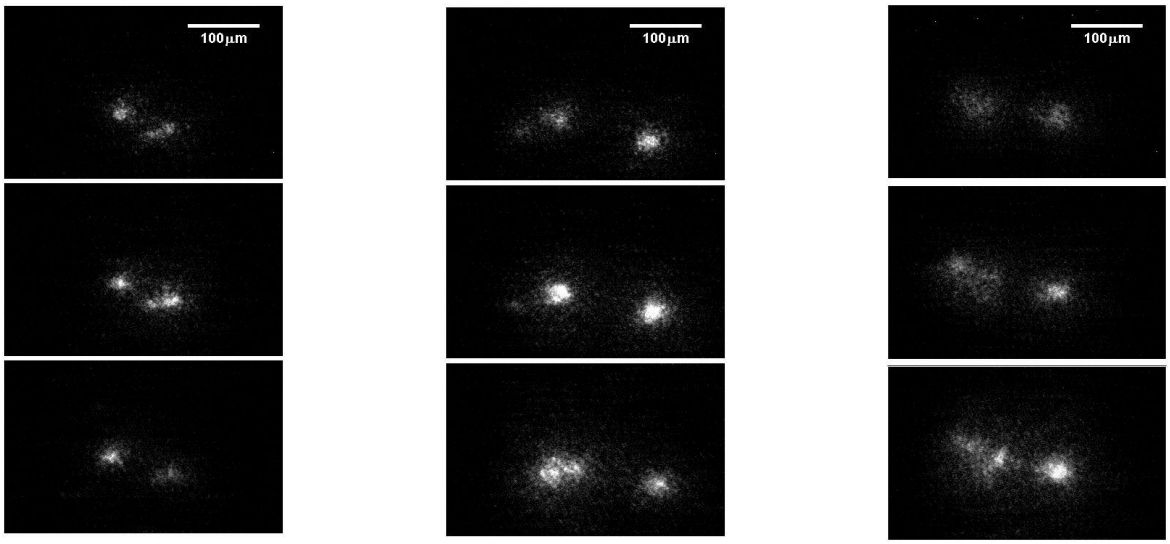
Table 1. Camera regimes used in the experiment

Exposure time	Interframe period	Dark time	Delay from the trigger pulse to the start of the first frame
30 ns	77 ns	47 ns	190 ns
6 ns	11,35 ns	5,35 ns	85 ns



a b c

Fig.6. Frame sequences from top to bottom; a –17 A, b- 34 A, c - 50 A. Exposure time 30 ns.

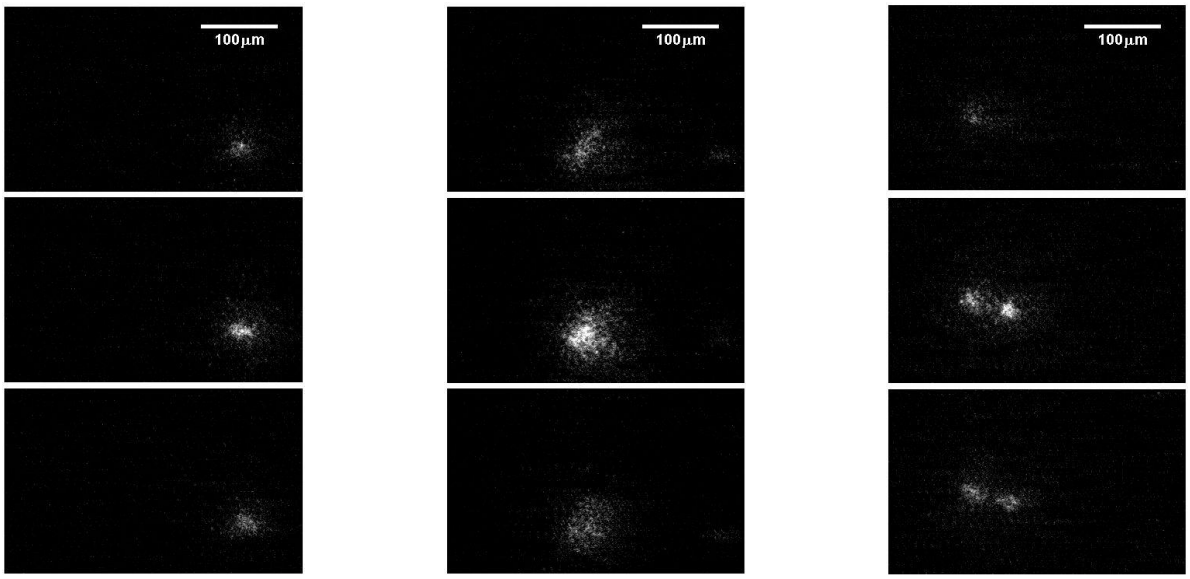


a b c

Fig.7. Frame sequences from top to bottom; a –50 A, b- 75 A, c - 100 A. Exposure time 30 ns.

3. RESULTS AND DISCUSSION

Due to the lack of light intensity we were able to start measurements from current level 10 A. From this current and up to 50 A the cathode spot consists of only single fragment. An example of frame sequence with exposure 30 ns at currents 17 A, 34 A and 50 A is shown in Fig. 6. At current 50 A the elongation of cathode spot could be seen, while no division into fragments occurs. Nevertheless, sometimes at current 50 A cathode spot division is observable. Figure 7 represents the cathode spot division into two or, as in the case of Fig.7c, presumably into three fragments. We have never seen three distinctly separated fragments in our experiments. This finding contradicts to available literature data when authors [4,5,6] agree that at currents 60 –80 A cathode spot has 4-6 separate fragments carrying a current approximately 10 A each. The possible explanation is that authors mentioned above carried measurements after tens microseconds after the arc ignition, in our case the time elapsed from arc ignition is approx. 500 ns and the cathode processes is not steadied yet.



a b c

Fig.8. Frame sequences from top to bottom; a –50 A, b- 100 A, c - 100 A. Exposure time 6 ns.

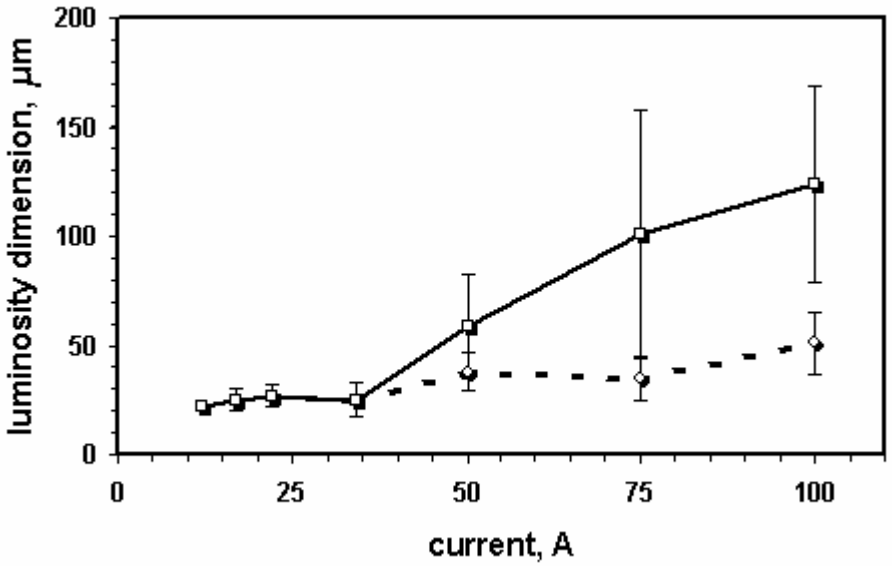


Fig.9. Overall spot dimensions (solid line) and the size of individual fragments of which the spot consists (dashed line) as a function of arc current. Data for exposure time 30 ns.

Observations with higher temporal resolution (exposure time 6 ns) reveal the spot brightness fluctuations occurring in 10 ns time scale (inter-frame period 11,35 ns) that illustrated in Fig.8. for currents 50 and 100 A. For lower currents the luminosity of spot is too weak to be observable at such short an exposure. In general our observations confirm the literature data concerning luminosity dynamics of cathode spot and fragments, namely the changes of luminosity occur on tens nanosecond time scale and the appearance and disappearance of cathode spot fragments can occur within 10 ns time interval. Finally, the Fig.9 represents the results of measurements with the exposure time 30 ns of overall spot

dimensions (solid line) and the size of individual fragments of which the spot consists as a function of arc current. The dimensions of the luminous objects were measured as full width at half maximum of luminosity profiles..

4. CONCLUSIONS

It was found that spot splitting into separate fragments occurs at currents higher than 50 A. The average fragment size was found to be 20 μm at current about 10 A (cathode spot consists of a single fragment). With the rise of the arc current the average fragment size rises too and reaches 50 μm at current 100 A (cathode spot consists of two or three fragments). The overall dimension of region occupied by cathode spot fragments rises from 20 μm at current 12 A to 120 μm at current 100A.

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