

# High current electric arcs above the In–Ga–Sn eutectic alloy

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**Abstract.** The results of investigations of high-current dc and ac arc discharges of atmospheric pressure emerging above the free surface of liquid metal (In–Ga–Sn eutectic alloy) are presented in the paper. The mechanism of the arc formation due to pinch-effect is discussed here.

## 1. Introduction

Plasma technologies are widely used in processing industries. All the variety of constructive devices can be divided into that with plasma torches and with free burning high-current arcs [1]. The most promising method of waste recycling is the technologies using electro-arc reactors. In comparison with the plasma torches, they have grater capacity, but at the same time have a number of problems with the stability of the electric arcs.

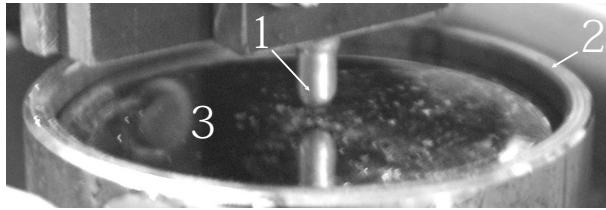
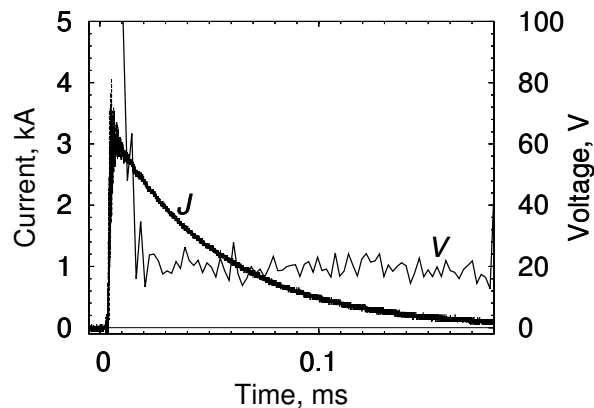
The paper is devoted to the investigation of the high current arc discharges of atmospheric pressure burning above the free surface of electro-conducting material that is initially in liquid aggregate state. The main tasks of the work are: to investigate the processes of the ignition, formation and evolution of the high-capacity pulsed arcs, dc arcs and ac arcs of industrial frequency and to determine their parameters under the conditions of consideration.

## 2. Experimental setup

The test section (figure 1) is a steel rod electrode 1 of 0.76 cm diameter with a hemispherical tip and cylindrical container 2 of 10 cm diameter and 4 cm depth filled with the eutectic alloy of gallium–indium–tin 3 playing the role of another electrode.

Electric current in the circuit is organized by a generator of current pulses of 25 kV, 30 kA and 300  $\mu$ s duration for the regimes with the high-capacity pulsed arcs, by an oscillating circuit of 10 kV, 10 kA, 10 ms duration and 50 Hz frequency for the regimes with the ac arcs, by accumulator batteries of 25 V and 1.5 kA for the regimes with the dc arcs. A current pulse of the current generator is organized at the discharge of a capacitor battery with charging voltage up to 25 kV through a ballast resistor and electrode unit. Current amplitude is specified by ballast resistance and charging voltage, pulse duration is defined by time constant of a capacity storage and ballast resistance. For ac current generation the capacitive storage with a connected inductive coil is discharged through the electrode unit. The oscillating circuit gives 25 complete



**Figure 1.** Test section.**Figure 2.** Current and voltage at high-capacity pulsed arc formation (interelectrode distance is 5 mm, current amplitude of the current generator is 3 kA).

periods of current. The accumulator batteries provide required long-term electric current through a low-resistance load.

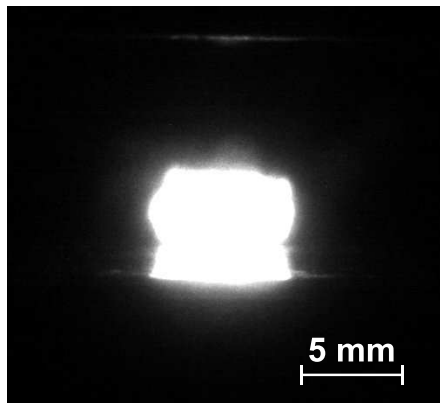
The data reflecting processes in the system with the rod electrode initially dipped into the melt—the deformation of the contact surface, ignition and evolution of the electric arcs,—and parameters of the processes were obtained in the experiments.

### 3. Results and discussion

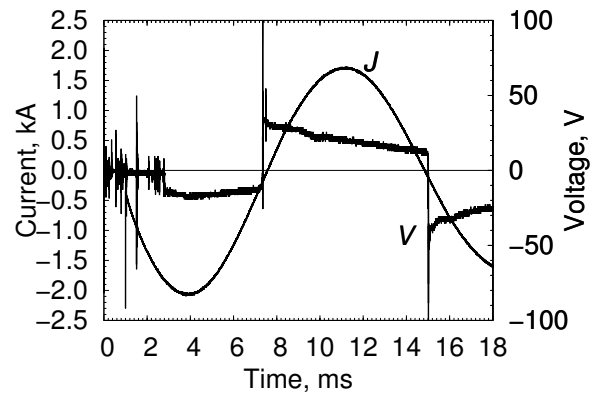
The rod electrode is mounted above the surface of the liquid metal in the experiments with the high-capacity pulsed arcs. The discharge is formed at electrical breakdown of an interelectrode gap in this case. A typical plot of the current in the circuit, voltage between the rod electrode and the liquid metal, a high-speed photograph of the arc at the maximum current value are shown in figures 2 and 3 correspondingly.

Figures 4 and 5 represent the circuit current, interelectrode voltage drop and high-speed photos of the processes at ac arc formation. In these experiments the rod electrode is initially dipped into the melt on the depth of the radius of the hemispherical tip. At switching on of electric current the surface of the liquid metal deforms with the following contraction of the melt in the region of its contact with the rod electrode and the electric arc ignites. The time moment of the first discharge appearance can be clearly seen in the oscillogram where the voltage peak takes place at 2.5 ms after the switching on of electric current under the conditions of the considered experimental run. The arc voltage is 15 V for the case. The voltage peaks on the waveform indicate the mode of the arc with cathode spot. Figure 6 depicts the dynamical characteristic that demonstrates the dependence of the arc voltage on the current in the interval of one complete period. The plot shows a hysteresis phenomenon in the system. It reflects the difference in the arc voltage for the same current value at its increase after the ignition of the discharge and at its decrease before the changing of polarity. That is connected with the thermal inertia of the arc [2, 3].

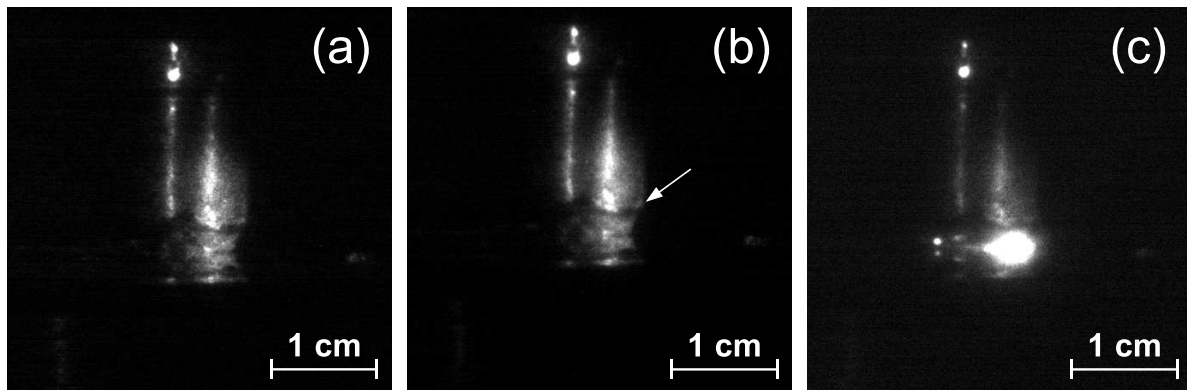
It is necessary to notice that thermal load on the rod electrode at currents higher than 1 kA leads to the destruction of the hemispherical tip within the second or third half-period of current.



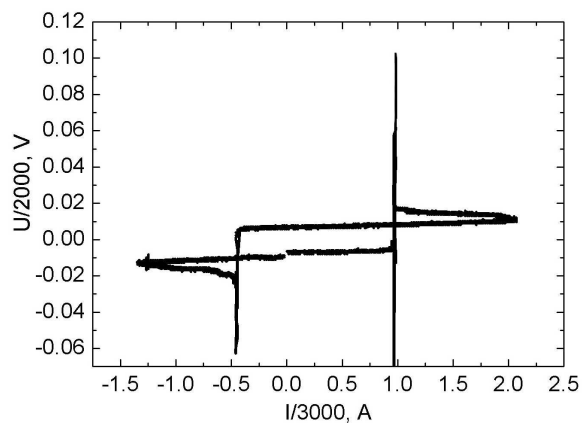
**Figure 3.** High-capacity pulsed arc 10  $\mu\text{s}$  after its ignition (exposure time is 1  $\mu\text{s}$ ).



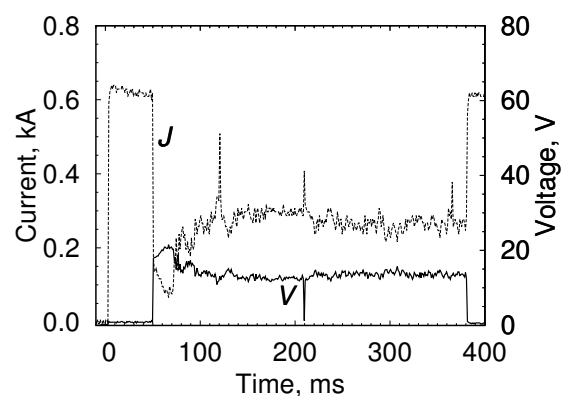
**Figure 4.** Current ( $J$ ) and voltage ( $V$ ) at ac arc formation (maximum current amplitude is 2 kA).



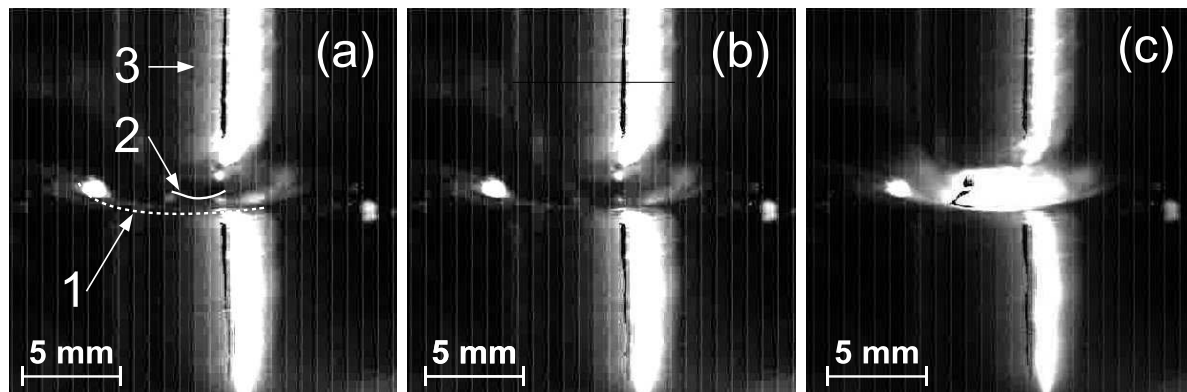
**Figure 5.** Images of ac arc formation (exposure time is 5  $\mu\text{s}$ ): (a) the contact between the rod electrode and the melt at the current beginning, (b) surface deformation in 1 ms after the current beginning, (c) the arc discharge in 2.5 ms after the current beginning.



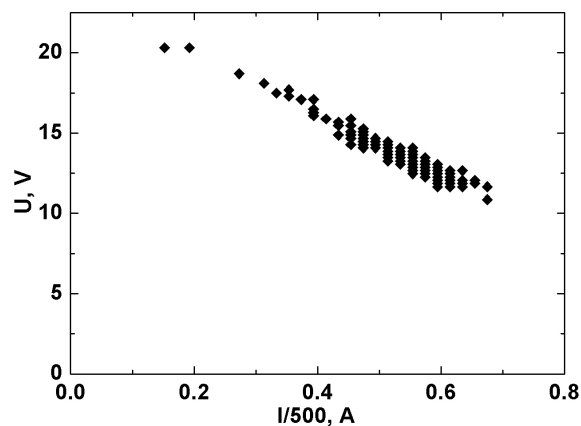
**Figure 6.** Dynamical characteristic of the ac arc.



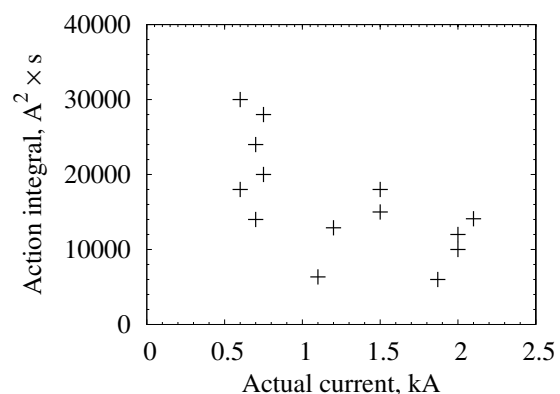
**Figure 7.** Current ( $J$ ) and voltage ( $V$ ) of dc arc formation.



**Figure 8.** Images of dc arc formation (exposure time is  $5 \mu\text{s}$ ): (a) the constriction in 47.5 ms after the current beginning (1—the boundary of the deformed surface, 2—the contact of the rod electrode with the melt, 3—the rod electrode), (b) the system in 48.5 ms after the current beginning, (c) the arc discharge in 50 ms after the current beginning.



**Figure 9.** Volt-ampere characteristic of the dc arc.



**Figure 10.** Action integral of current.

The electrode edge becomes flat and do not have connection with the liquid metal any more and hence further discharge ignitions occur without the initial contact of the rod electrode with the surface of the melt.

Oscillograms of the circuit current, voltage and high-speed photos of the dc arc formation are shown in figures 7 and 8 correspondingly. As in the described above experiments here the rod electrode is initially dipped into the melt on the depth of the hemispherical tip. At switching on of the power supply under the action of the electro-motive body force, that is the result of the interaction of passing through the liquid metal current with its own magnetic field, the free surface of the melt caves in near the rod electrode [4, 5]. While deforming the interface boundary takes the complex structure defined by the distribution of current density around the hemispherical tip. That is concave with a constriction forming due to the pinch-effect under the central part of the rod electrode. The liquid metal constriction contracts, overheats, explodes and as a result the electrical discharge ignites. In the experiments the power supply has sufficient capacity for the realization of the regime with the stationary burning of the arc in the system. But during the runs the hemispherical tip of the rod electrode is destroyed as well. Volt-ampere characteristic of the arc discharge is falling (figure 9). At the current values lower then 250 A

the surface deformation is not sufficient for the formation of the liquid metal constriction and for the following ignition of the discharge under the considered conditions.

The movement of the surface of electro-conducting liquid is defined mainly by magnetic pressure that is proportional to square of electric current value. To confirm that we can calculate the action integral of current over the period of time up to discharge ignition (figure 10).

#### 4. Conclusion

It were carried out the experimental investigations of the high-power pulsed arcs, dc arcs and ac arcs of industrial frequency at atmospheric pressure that burns under the free surface of the electro-conducting liquid. It was fined out that the reason of the ignition of the electrical discharges in the system is the deformation of the free surface due to the action of the electro-motive force, the formation of the constriction due to the pinch-effect under the central part of the rod electrode, the contraction, overheating and explosion of the constriction.

#### Acknowledgments

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#### References

- [1] Mikhailov B 2010 *Thermophys. Aeromech.* **17** 397–410
- [2] Rayzer Y 1992 *Gas Discharge Physics*
- [3] Finkelburg W and Maecker H 1956 *Electrische Bogen und Thermische Plasma* (Berlin: Springer)
- [4] Klementyeva I and Pinchuk M 2015 *J. Phys.: Conf. Ser.* **653** 012150
- [5] Klementyeva I, Pinchuk M and Teplyakov I 2016 *Tech. Phys.* **61** 146–148