Studies of initiation and quenching of extensive high-current discharges

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Abstract. The system has been developed for initiating and quenching the arc discharges by means of moving apart the initially closed electrodes at a variable speed. The experimental studies of the extensive high-current electric arc discharges were performed in the atmospheric air. By means of optimizing the process of moving apart the electrodes and matching their sizes and shapes, it is possible to increase up to ten times the length of the stably burning high-current arc without using the external magnetic field for its stabilization.

1. Introduction
The initiation, stabilization and quenching of the extensive (tens of cm) high-current (hundreds of amperes) arcs are studied in this work. The experiments were performed in the atmospheric air at the electric discharge test bench of the P-2000 facility [1] (see Figure 1).

Figure 1. The P-2000 facility: (a) GP2000 DC generator (750V, 3kA); (b) unit of GP9-10 generators (230V, 600A); (c) water-cooled ballast load; magnetic systems (MS) with inductions of: (d) up to 1.8 T; (e) tens of mT (the rod MC); and (f) tens of mT (two-turn Helmholtz coil).
For these experiments, the devices were specially developed for initiating and quenching the extensive arcs, which make it possible to implement different regimes of displacing the discharge electrodes (the interelectrode gap \( l(t) \) increases till it reaches the given value \( l_o \)), and provide the possibility of imposing time-dependent disturbances \( d/l \). In one of such devices, the special program controls the electrode displacements. This makes it possible to conduct experiments on the optimization of the regimes of arc initiation and quenching. It is also possible to study the stability of their burning.

2. Formulation of the problem

When performing the experimental studies of the extensive (several cm or more) arcs, it is important to ensure the stable discharge initiation and minimum noise affecting the measuring loops [2, 3]. Therefore, in recent years, when the extensive electric arcs were studied at the electric discharge test bench of the Institute of Mechanics of the Moscow State University, the discharge initiation by means of closing the electrodes and then moving them apart to the selected interelectrode gap \( l_o \) has been used (see Figure 2a).

In this case, the following devices for moving apart the electrodes are used:

1) the device based on the rectilinear mechanism of printers (or plotters), providing the approximately constant speed of the interelectrode gap expansion;

2) the device consisting of a set of rectilinear mechanisms, which provide the regimes of the interelectrode gap expansion at the speeds that are piecewise constant in time;

3) the device based on the high-precision linear drive unit of the milling machine with the programmable law of the electrode displacements.

![Figure 2](image-url)

**Figure 2.** Time dependence of the interelectrode gap for different methods for displacing electrodes based on: (a) devices (1) or (2) and (b) programmable drive (3); \( dt_1 \), \( dt_2 \) and \( dt_3 \) are the specified time intervals; \( t_o \), \( t_d \), and \( t^* \) are the times corresponding to the termination of interelectrode gap expansion, application of local disturbance, and the beginning of arc quenching.

In the experiments, the characteristic time \( t_o \) of displacing the electrodes is 0.1–0.2 s. Waveforms of the current \( I(t) \) and voltage \( U(t) \) in the discharge gap were also recorded synchronously with the arc images. Two series of different measurements were performed. In the first series, the dimensions of the anode and the cathode were comparable, \( \Omega = 16 \) mm; in the second series, the anodes were massive and many times exceed the cathode in size. The electrodes were made of graphite. Generally speaking, we studied the extensive electric arc discharge between the graphite electrodes with the quasi-stationary currents, which proceeded in the atmospheric air in the presence of the external magnetic field provided by one of the magnetic system (MS). The experiments provide information on the structure of the plasma armatures that are important elements of different electrophysical facilities. The efficiency and resource of their operation considerably depend on the compactness and degree of spatial homogeneity of such armatures. The processes associated with the current flow were visualized using the high-speed shooting (1200 frames/s) in the visible wavelength range (0.4÷0.8 μm). In addition, the pyrometric temperature measurements can be simultaneously performed on the electrode surfaces. The possibility of superimposing different (in amplitude and shape) disturbances \( d/l \).
at different times (see Figure 2b) makes it possible to trace their effect on the stability of arcs. Schematic and view of the technical device for moving the electrodes apart are as follows (see Figure 3):

![Figure 3](image-url)

**Figure 3.** (a) Block diagram of the automated control system for the displacement of electrodes, and images of its units: (b) linear drive and (c) box with equipment for its control; and (d) PC with PUMOTIX software within the Purelogic numerical control system.

### 3. Results

In the case of the electrodes comparable in size, the effect of the amplitude of pulsed disturbances $d/l$ of the interelectrode gap is shown in Figure 4.

![Figure 4](image-url)

**Figure 4.** Effect of the amplitude of the $d/l$ disturbances of interelectrode gap on the discharge stability: (a), (c), and (e) waveforms of current $I$ and voltage $U$ and (b), (d), and (f) the corresponding typical images: $l_o = 100$ mm; $d/l_o = 0$, 10 and 50% in Figures 4a and 4b, 4c and 4d, and 4e and 4f, respectively.
In the case of the massive anodes (\(\Phi = 150\) mm), it is possible to suppress the spiral instabilities [4] of extensive arcs (\(l > 35\) mm) by means of choosing the special shape of the electrodes and the law of their moving apart, even without using the external magnetic field for the arc stabilization [1, 5] (see Figure 5):

![Figure 5](image)

**Figure 5.** (a) Discharge instability developing at slow velocity (90 mm/s) of electrode displacement: (1) zone of the initial contact between the electrodes; interelectrode gap is 100 and 200 mm, and (b) optimized regime of electrode displacement (300mm/s): gap is 300 mm.

4. Conclusions
The automated system has been designed for initiating and quenching the arc discharges by means of moving apart the initially closed electrodes. The first results have been achieved in the implementation of the automatic quenching of arcs at a given time using the system for displacing the electrodes controlled by the special subroutine of the PURELOGIC software package. The arc quenching process proceeds without the direct participation of the operator of the experimental facility control panel and without using the commutation switches in the circuit. This makes it possible to increase the resource of the quenching system and simplify the synchronization of the facility operator activities. It is shown that the optimization of the regimes of electrode displacements and matching of the electrode units make it possible to obtain stable burning of the extensive electric arcs with lengths of up to 30 cm in open air. The results of this work can be useful when developing the systems for initiating and quenching the extensive electric arcs and performing simulating tests of the protective coatings for aircraft.

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