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ARC CURRENT FLUCTUATION POWER SPECTRA IN THE SYSTEM OF A SOLID METAL ELECTRODE AND CARBONATE MELT

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Arc current fluctuations between a solid metal electrode and a liquid melt of alkaline carbonates at atmospheric pressure are measured. Arc current fluctuation power spectra are determined from the measurement data. It is shown that the fluctuation power is inversely proportional to the frequency (1/f-fluctuations). The fluctuations have a normal Gaussian distribution. The observed 1/f fluctuations exhibit scale invariance.

Key words: *electric arc discharge, power spectrum, 1/f noise, liquid electrode, nonequilibrium phase transitions.*

An electric discharge is accompanied by significant current and voltage fluctuations. The observed increase in power pulsations at low frequencies indicates that large-scale surges are possible in the system. Electric fluctuations whose power spectrum changes in inverse proportion to frequency (the so-called flicker-noise or $1/f$ noise) were detected in electronic devices more than 80 years ago [1]. Random processes with $1/f$ spectra have proved to occur in many cases. However, a well-established model for this effect is not available. Various factors responsible for the occurrence of $1/f$ spectra have been considered and various models have been constructed. A feature of $1/f$ fluctuations is their scale invariance. Attempts have been undertaken to explain the mechanism of generation of scale-invariant fluctuations invoking the self-organized criticality concept [2], which is used to describe complex systems with developed fluctuations.

Investigation of random processes in thermal-physics systems has shown that fluctuations with $1/f$ spectra can result from interaction of various nonequilibrium phase transitions under flat noise conditions [3]. In this case, the fluctuations are characterized by a time-independent self-similar frequency distribution. A characteristic example of nonequilibrium phase transitions (changes in the steady-state process conditions) are the processes due to an electric discharge. In this case, interaction of various phase transitions in the discharge plasma and near-electrode regions is possible. Results of experimental studies of the fluctuation phenomena occurring in an electric arc discharge in water are given in [4]. It is shown that arc current fluctuation power spectra can have the form of $1/f$. Anders [5] studied power spectra with a low-frequency spread for a vacuum arc and the dynamics of cathode spots. Hladky and Dawson [6] investigated $1/f$ spectra in electrochemical processes.

The present paper gives results of experiments in which arc current fluctuation power spectra were determined in the system of a metal electrode (06Kh19N9T stainless steel) and a molten ternary carbonate eutectic (40% Li_2CO_3–30% Na_2CO_3–30% K_2CO_3). The choice of this system is motivated by the prospects of using liquid electrolytes in plasma technologies, in particular, in anodic treatment, and in the mode of local electric discharges for protection against corrosion [7].

An experimental setup was designed which allowed the control of the temperature, pressure, and the distance between the metal electrode and molten electrolyte [8]. The experiments were carried out at atmospheric pressure.

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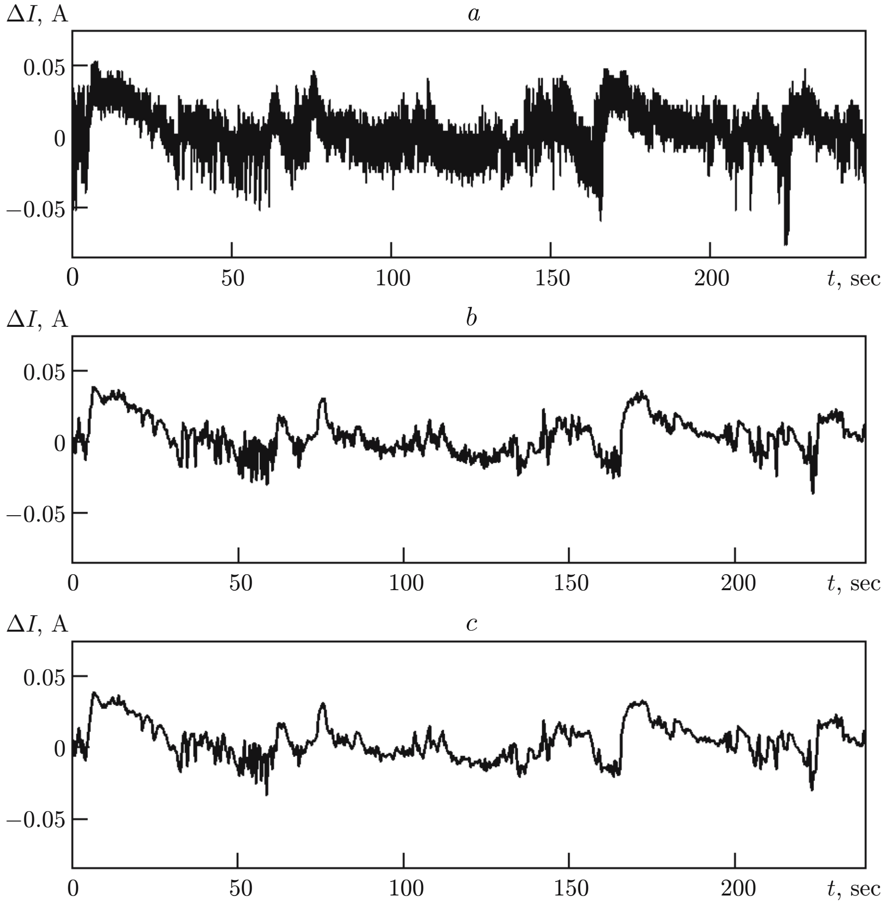

Fig. 1. Realization of arc current fluctuations: (a) initial experimental realizations; (b) smoothed realizations for a scale transformation coefficient equal to 32; (c) smoothed realizations for a scale transformation coefficient equal to 64.

Alkaline carbonates were melted in an alundum crucible of volume 10 mliters by resistive heating to a temperature of 550°C. One of the electrodes, in the shape of a plate, was completely immersed in the melt. The rod which holded the electrode was insulated by an alundum tube. The second electrode (movable) 1.6 mm in diameter was placed above the melt and detected the melt level by short circuiting. A constant voltage 350 V was applied between the mobile electrode and the melt. Then, this electrode was slowly removed from the melt. Arcing occurred between the solid electrode and the melt surface. The working distance between the electrodes was 10–15 mm. The average discharge current strength was 0.8–0.9 A. Initially, the arc was substantially unsteady. After a time, the arc conditions became steady-state. In this case, the temperature of the melt was about 640°C, and the average arc voltage drop across the electrodes was about 50 V. In the experiments, the polarity of the electrodes was changed.

After the arc was ignited and reached a steady state, arc current fluctuations were recorded. The data presented in Fig. 1a correspond to the case where the solid electrode was the cathode, and the liquid melt was the anode. The length of the realization is 65,536 points. Figure 1b and c shows realizations obtained from the initial realization (Fig. 1a) by averaging over a certain time scale. Thus, the realization in Fig. 1b was obtained from the initial realization by averaging over windows containing 32 points, and that in Fig. 1c by averaging over windows containing 64 points. It is evident that the realizations in Fig. 1b and c differ insignificantly. This implies that during successive averaging of the realizations over different scales, the fluctuations demonstrate scale-invariant properties.

Scale invariance implies that the fluctuation distribution function does not change during averaging of the realizations. The current fluctuation distribution function is given in Fig. 2. It is evident that the fluctuation

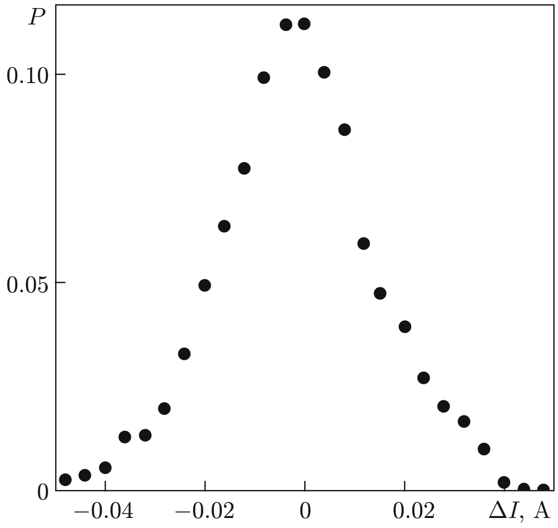

Fig. 2

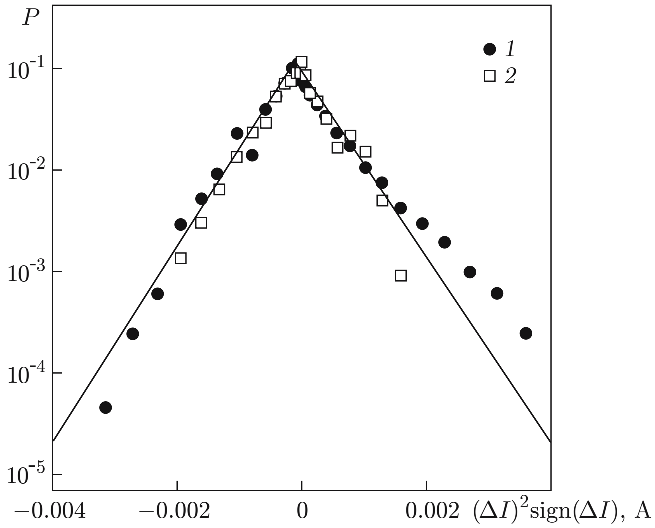

Fig. 3

Fig. 2. Current fluctuation distribution function.

Fig. 3. Fluctuation distribution function: points 1 refer to the initial experimental realization and points 2 refer to the smoothed realization; the solid curve is a Gaussian distribution.

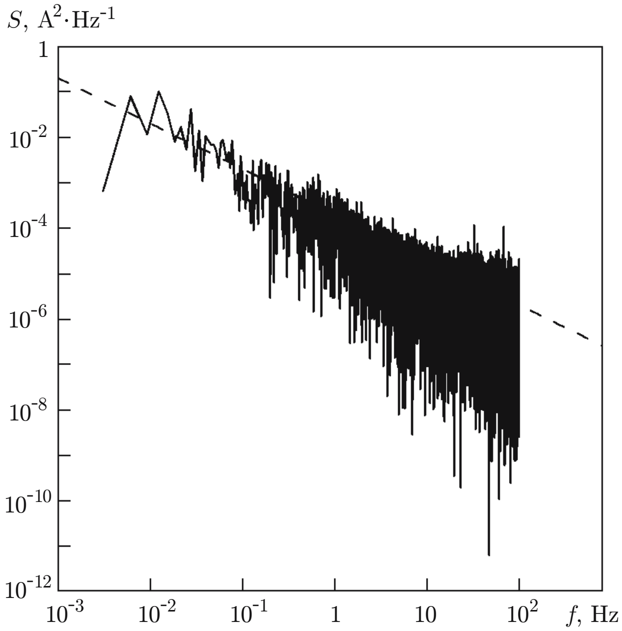

Fig. 4. Current fluctuation power spectrum.

distribution is close to a normal Gaussian distribution. Figure 3 gives the distribution function versus the squared argument in semilogarithmic coordinates. In this case, the normal Gaussian distribution is represented by straight lines. Points 1 in Fig. 3 correspond to the initial realization (see Fig. 1a), and points 2 to a smoothed realization (see Fig. 1b).

In the model of interacting nonequilibrium phase transitions, the distribution function of $1/f$ fluctuations for one source is also close to a Gaussian distribution but it has long tails of peak surges. In scale transformations, the density function of a stochastic process with $1/f$ spectra takes a bimodal shape and becomes scale-invariant [9].

For superposition of independent fluctuation sources, the distribution function takes a Gaussian shape, which agrees with the central limiting theorem. In this case, the scale-invariant properties of the fluctuations are retained. In experiments, ensembles of independent fluctuation sources are usually studied, and, hence, experimental realizations, as a rule, have a Gaussian distribution (see Figs. 2 and 3).

Fluctuation power spectra were determined from the measured realizations using a Fourier transform. The data in Fig. 4 correspond to the realization shown in Fig. 1a. The dashed curve in Fig. 4 corresponds to the inversely proportional frequency dependence of the power spectrum ($S \sim 1/f$). It is evident that the experimental power spectrum has the form of $1/f$ with a frequency change by more than three orders of magnitude. A change in the polarity of the electrodes did not lead to a significant change in the behavior of the power spectra.

Thus, an electric arc discharge in the system with the liquid Electrode is accompanied by large-scale low-frequency arc current fluctuations with a power spectrum inversely proportional to the frequency. The fluctuations have a normal distribution and possess scale-invariant properties.

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