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AUTOOSCILLATIONS GENERATED DURING A DIAPHRAGM DISCHARGE IN AN ELECTROLYTE

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The electrohydrodynamic autooscillations of a vapor–gas bubble and electric current accompanying a diaphragm electric discharge in an electrolyte were studied for a capacitor voltage from 200 to 900 V and a diaphragm hole diameter of 0.3–0.9 mm. The upper region of stable relaxation current oscillations was determined.

To the present, only a few papers reported on the properties of a diaphragm electric discharge. For example, the investigations described in [1, 2] aimed at the obtaining a dense plasma in a condensed medium at a storage bank energy of up to 7.5 kJ and a capacitor voltage up to 10 kV. Our study has pursued different purposes: exciting stable autooscillations of a vapor– gas bubble in an electric circuit by means of a diaphragm electric discharge in an electrolyte, finding the region of stable relaxation current oscillations, and determining the frequency characteristics of the autooscillating system. Below we present the results on the generation of autooscillations of the relaxation current and the vapor-gas bubble size in diaphragms with a hole diameter of d = 0.3–0.9 mm. The diaphragms, made of a Lavsan film with a thickness of h = 50 μm, were mounted vertically. The electrolyte was an aqueous sodium chloride solution with a concentration of k = 1–5 wt %. Two flat stainless steel electrodes were placed in different compartments of a cell filled with the electrolyte and separated by the polymeric diaphragm with a hole. A distance from electrodes to the hole in the diaphragm was $H > 10d$. The electrode area exceeded the hole area by more than one order of magnitude. The experiments were performed with a capacitive energy storage unit composed of replaceable capacitors (C = 2–100 μF) and a contact current commutator with an electromagnetic drive system. The current in a sample circuit was measured with the aid of a low-inductance Parker shunt (R = 0.148 .). The hydrodynamic processes were monitored by shadowing techniques using high-speed photoregistration systems of the SFR and ZhFR types.

Experimental results. The current oscillograms presented in Fig. 1 illustrate the dynamics of the transient process development into the relaxation current oscillations for various initial capacitor voltages in the range U = 100–400 V and the diaphragm with a hole diameter of d = 0.5 mm. As can be seen from these patterns, the development of the regime of stable autooscillations has a threshold character with respect to voltage. Figure 2 shows, on a common time scale, an oscillogram of the current variation I(t) and a pattern of the bubble boundary pulsations D(t) (a photoregistrogram processed and plotted in a dimensionless form of D/d (for d = 0.5 mm) observed for U = 500 V and an electrolyte concentration of k = 1 wt %. Both visual observations and the photo and video records showed that the initial stage of the electrohydrodynamic process corresponds to the corona discharge development on the perimeter of the diaphragm hole. The initial bubble has a toroidal shape. During the first pulsation, the toroidal bubble transforms into a spherical one. Subsequent radial pulsations of the spherical bubble proceed relative to the center of the diaphragm. The bubble pulsation kinetics is close to the Rayleigh law. As the bubble size grows to approach D/d = 2.4, the current halts, so that the bubble performs the function of a current interrupter. When the bubble collapses to D/d = 1.2–1.4, the current circuit is closed again. This cyclic process repeats as long as the stored energy is consumed. Figure 1d clearly displays the dynamics of current commutation and shows variation of the current pulse duration and repetition period accompanying a decrease in the stored energy. As can be seen from Fig. 2, a minimum (maximum) bubble size corresponds to the maximum (minimum) current. The minimum bubble size is always greater than the hole diameter. The energy lost during the bubble pulsation is compensated by the electric discharge initiated in the bubble along the hole perimeter at D/d = 1.2–1.4. The results of these experiments showed that the period of relaxation current oscillations in the stable regime depends but weakly on the electrolyte concentration and capacitor voltage. The most pronounced and important dependence of the autooscillation process on the system parameters is the relation-ship between the period T of the relaxation current oscillations and the diaphragm hole diameter d, which can be approximately described as T $390d$ μs (with T in microseconds and d in millimeters). In the range of parameters (d and U) studied, the current pulses are unipolar, exhibit a steep leading front, and decay within a time of $t \sim (0.2–0.5)$T. The current pulse decay dynamics depends on the capacitor voltage (Fig. 1).The experiments showed that a stable regime of autoscillations is attained in a limited region of the capacitor voltages U and diaphragm hole diameters d. We determined the upper limiting values of the hole diameter and the capacitor voltage for which the autooscillations may take place. A minimum voltage at which the autooscillations begin to develop are referred to as the lower "threshold", while a voltage at which the instabilities are developed is called the upper "boundary". Figure 3 shows a diagram of the upper domain of existence of the electrohydrodynamic autooscillations. No stable autooscillations take place in the right-hand region outside the domain. Increasing the voltage leads to instability of the autooscillation processes, a sharp increase in the current, a corona discharge development over the whole

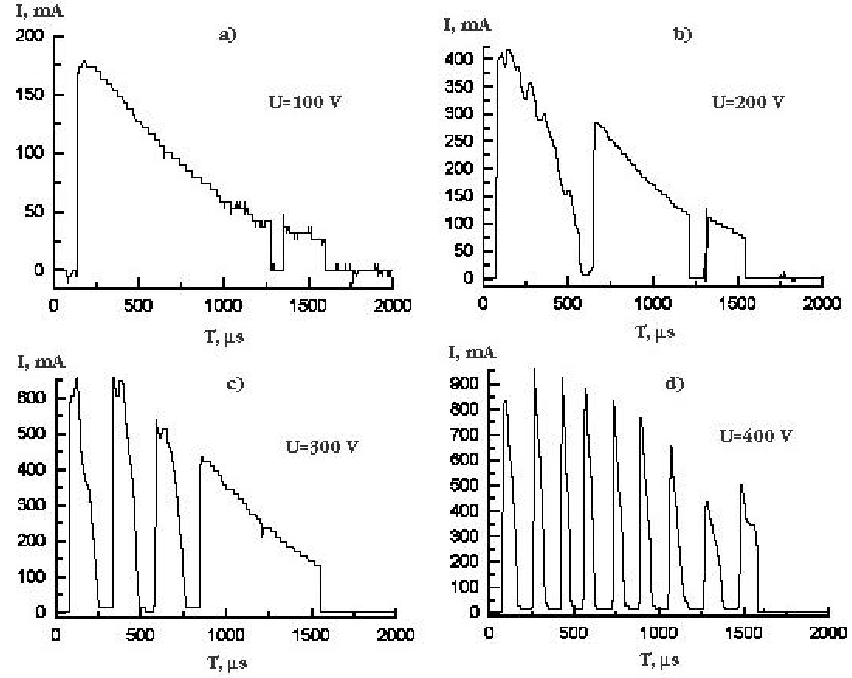

Fig. 1. The dynamics of a transient (threshold) process development into a stable regime of the relaxation current oscillations in a system with the diaphragm hole diameter $d = 0.5$ mm and a capacitor of $C = 2$ μF charged to various initial voltages

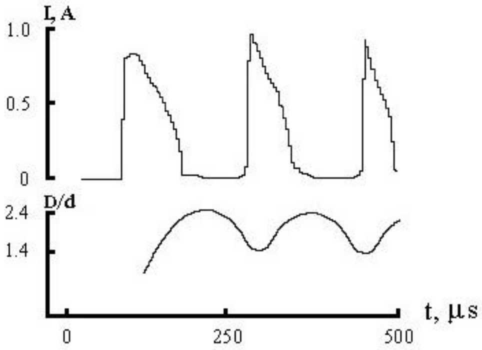

Fig. 2. Synchronous registration of the current I and the bubble size (presented in the dimensionless form of D/d) pulsations in a common time scale for a system with $d = 0.5$ mm, $U = 500$ V, and $k = 1$ wt %.

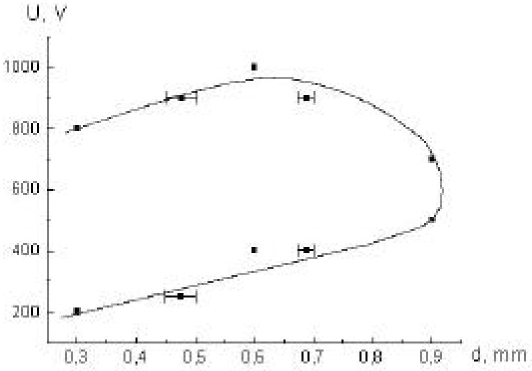

Fig. 3. A diagram of the domain of existence of the electrohydrodynamic autooscillations. No stable autooscillation regime is possible in the right-hand region out-side the domain depicted by the solid curve.

diaphragm cross section, and the bubble size growth up to $D > 3$d. The breakage of a stable autooscillation process may be related to several factors, such as the bubble center displacement off the diaphragm center, instability development on the bubble surface during collapse from $D > 3$ mm, etc. The dynamics of processes developed in a diaphragm discharge at still higher voltages (i.e., for $D > 5$d) is described elsewhere [1, 2].

Conclusion. An analysis of the results of our experiments leads to the following conclusions:
(i) Using the diaphragm discharge in an electrolyte, it is possible to generate autooscillations of the current and the vapor-gas bubble. A nonlinear element in the electric chain is a cell with the diaphragm, which plays the role of a nonlinear resistor in the circuit [3]. The nonlinear resistance depends on the current density in the diaphragm hole and the minimum and maximum bubble size.
(ii) The experiments showed that the current is switched by the oscillating bubble. The current is interrupted when the bubble grows to a maximum size of $D = 2.4$d. Upon the hydrodynamic collapse to $D = (1.2–1.4)$d, the current is switched on and the corona discharge initiated over the perimeter of the diaphragm hole. This is accompanied by the supply of an additional electric energy providing for the continued pulsation of the bubble. Thus, the electrohydrodynamic current commutation with the cyclic energy supply and loss in the diaphragm hole is repeated in the form of a autooscillation process.
(iii) Important parameters of the autooscillation process in the system under consideration are the period (T) of pulsations of the bubble and current involving the energy conversion from one to another type in the form of electromagnetic radiation, light, heat, hydrodynamic pulses, and acoustic waves. The experimental results obtained for diaphragms with the hole diameter ranging from 0.3 to 0.9 mm showed that the period of pulsations obeys the relationship $T \sim Kd$ with $K = 380$ μs/mm. The current pulses are unipolar, exhibit a steep leading front, and decay within a time of $t \sim (0.2–0.5)$T.
(iv) The process of autooscillations in the system studied can be implemented in acoustics, hydrodynamics, electrodynamics, and biophysics, and in a number of other applications related to modeling and development of the autooscillating systems employing phase transitions in liquid media.

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