Proceedings of 14th International Conference on Dielectric Liquids (ICDL 2002), Graz (Austria), July 7-12, 2002

SELF-SYNCHRONIZATION AND AUTO-OSCILLATIONS IN DISCHARGE PHENOMENA

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Abstract: The discharges in conductive and distilled water occurring near two electrode tips and in the vicinity of two holes of thin dielectric film are investigated. The simultaneous plasma generation is observed in the sites with maximum strength without gap breakdown. Moreover, the periodical auto-oscillations of vapor-gas bubble and relaxation electrical current oscillations during discharge in a hole are revealed. The auto-oscillations are existed in a range of voltage between 100V and 10 kV. The experiments have been performed in a range of liquid conductivity between 0.0014 and 22 $\Omega^{-1}m^{-1}$.

INTRODUCTION

It is known that discharge in dielectric liquids begin to develop on the spot of electrode having maximum field strength. If the arrangement has two point electrodes the liquid breakdown takes place between one of these and opposite flat electrode. But if the conductivity is about 1 $\Omega^{-1}m^{-1}$ the discharges take place simultaneously. These can occur on any quantity of point electrodes. This effect is described, for instance, in [1] and studied in sea water mainly. In [2] the arrangement having two thousand point electrodes has been investigated. It has been shown that discharges occurring in aqueous salt solution begin to develop simultaneously if the conductivity of liquid is in a range 1-22 $\Omega^{-1}m^{-1}$. The shock waves accompany the plasma generation and the more liquid conductivity the less wave energy. But there are no studies of the phenomenon occurring in dielectric liquids. We have performed the more detailed experiments of the effect in water, changing the conductivity of water down to the conductivity of distilled one.

EXPERIMENTAL SETUP

The series circuit includes a storage capacitor, discharge switch with an electromagnetic drive system, two low-inductive shunts and discharge gap. The capacitor is charged by means of high-voltage power supply up to 10 kV. Its capacity is 2 μF. The shunt resistances are 0.2 and 0.15 Ω. The two arrangements are used as discharge gap. The first consist of two tungsten rods and one flat stainless steel electrode. The flush-mounted tungsten rods are in a rubber. The only flat rod tips make contact with a liquid. The rod diameters are 0.2 and 2 mm. The length of gap is 20 mm.

The second includes a dielectric film having one or two round holes. The films are made of teflon and textolit. The hole diameters are 0.3, 0.4, 0.5, 0.6, 0.7 and 0.9 mm. The thickness of films is 50 μm. Two flat stainless steel electrodes are placed in different compartments of a vessel separated by one film. The current flows only through the holes. The distance between electrodes and film is 20 mm. The electrode area exceeds the area of holes by more than one order of magnitude. In experiments the aqueous sodium chloride solution and distilled water are used. The liquid conductivity is in a range 0.0014-22 $\Omega^{-1}m^{-1}$.

The hydrodynamic processes are monitored by means of shadowing techniques using high-speed photo-registration systems of the SFR and ZhFR types.

EXPERIMENTAL RESULTS

Figure 1 shows the time dependence of current for rod diameter d_1 = 0.2 mm when the first arrangement is used. The liquid conductivity equals 22 $\Omega^{-1}m^{-1}$. The time dependence of current for rod diameter d_2 = 2 mm has the same form but differ from presented one by greater time delay. The discharge time delay t_d depends on capacitor voltage and water conductivity (see fig. 2). The more capacitor voltage and water conductivity the less time delay.

Other results are obtained when the second arrangement is used. The voltage of simultaneous discharge generation inception as a function of water conductivity and hole diameter is shown in figure 3. In that case the textolit film is used. There are two holes in the film. The pair holes have identical diameters of 0.15, 0.3 and 0.5 mm. The inception voltage U_i depends on conductivity like hyperbola function. If water conductivity is decreased U_i is increased. The liquid conductivities are in a range 0.005-0.3 $\Omega^{-1}m^{-1}$.

Figure 4 and 6 show the time dependence of current and bubble radius during bubble oscillations in a hole when the teflon film is used. The liquid conductivities are in a range 0.0014-22 $\Omega^{-1}m^{-1}$. If water conductivities are in a range 8-22

$\Omega^{-1}m^{-1}$ the auto-oscillations are existed in a limited region of voltages (see fig. 5).

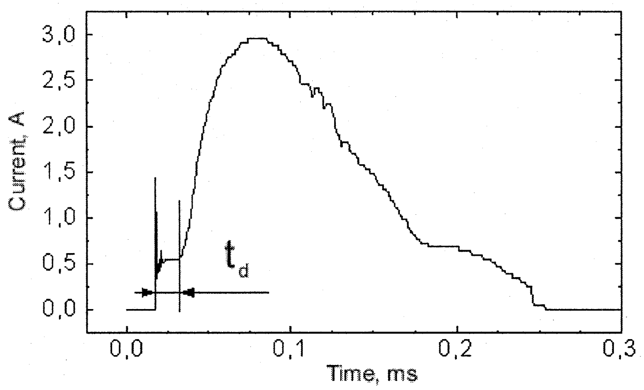

Fig. 1. Time dependence of discharge current for rod diameter d_1 = 0.2 mm. The water conductivity is 22 $\Omega^{-1}m^{-1}$.

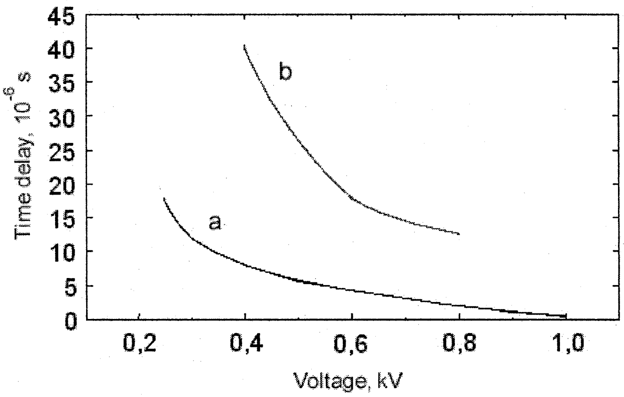

Fig. 2. Time delay t_d as a function of capacitor voltage for rod diameter d_1 = 0.2 mm. The water conductivities are 22 $\Omega^{-1}m^{-1}$ (a) and 8 $\Omega^{-1}m^{-1}$ (b).

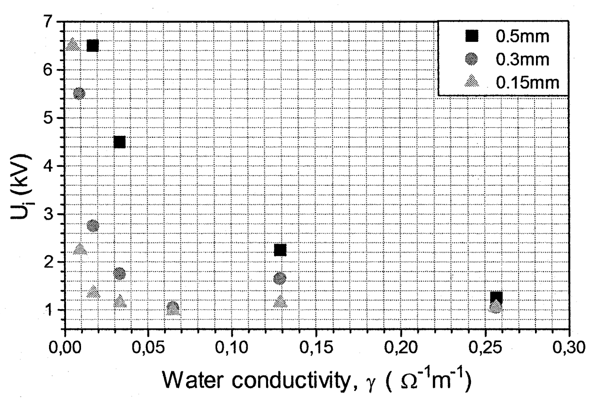

Fig.3. The inception voltage U_i vs. water conductivity γ. The discharges begin to develop simultaneously in two holes under such conditions. The identical hole diameters are 0.15 mm, 0.3 mm and 0.5 mm.

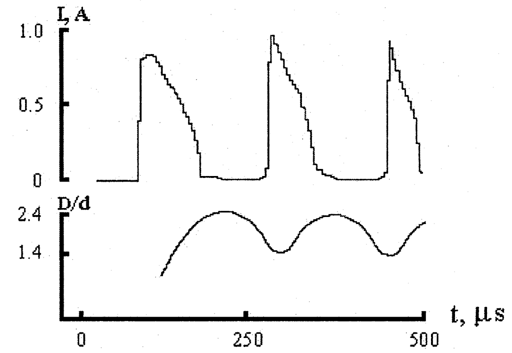

Fig. 4. Synchronous registration of the current I and the bubble size (presented in the dimensionless form of D/d) pulsations in a common time scale for a system with hole diameter d = 0.5 mm, capacitor voltage U = 500 V and water conductivity γ = 22 $\Omega^{-1}m^{-1}$.

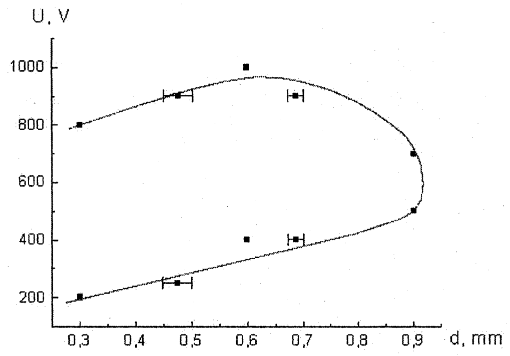

Fig. 5. The domain of electro-hydrodynamic auto-oscillations existence. The liquid conductivity is 22 $\Omega^{-1}m^{-1}$. No stable auto-oscillation regime is possible in the right-hand region out-side the domain depicted by the solid curve.

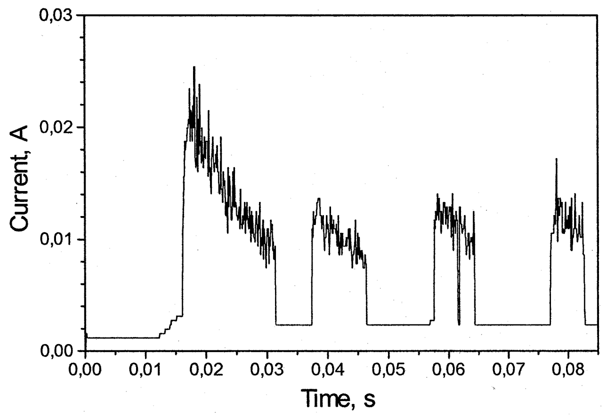

Fig. 6. Current auto-oscillation in one hole in distilled water at 10 kV. The water conductivity is 0.0014 $\Omega^{-1}m^{-1}$.

DISCUSSION

The behavior pattern of currents, shown in figure 1, can be explained in the following way. The maximum current density is on the edge of rod. The liquid heating leads to inception of bubble in the form of tore. The bubble isolate the flat tip surface from water and decrease the value of current. After the lapse of t_d the discharge occur inside bubble. This leads to second current growth and rapid capacitor discharge. The increasing capacitor voltage and liquid conductivity leads to increasing the heating power and, as consequence, decreasing time delay (see fig. 2). When the t_d equals zero for each rod the discharges begin to develop simultaneously. Thus to know the inception voltage of simultaneous discharge generation U_i for any number of rods it is sufficiently to know the time delay dependence from voltage and conductivity for electrode having maximum value of diameter.

The experiments using the second arrangement show that the initial stage of the electro-hydrodynamic process corresponds to the corona discharge development along the edge of the film 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 hole. 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 (see fig. 4). 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. As can be seen from figure 4, 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 edge at D/d = 1.2–1.4. The results of these experiments show that the period of relaxation current oscillations in the stable regime depends but weakly on the water conductivity in a range 5-22 $\Omega^{-1}m^{-1}$ and capacitor voltage.

The most pronounced and important dependence of the auto-oscillation process on the system parameters is the relationship between the period T of the relaxation current oscillations and the film hole diameter d, which can be approximately described as T 390•d μs (with T in microseconds and d in millimeters) [3]. 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 ~ (0.2–0.5)•T.

It can be assumed that the character of bubble pulsations depends on the type of discharge occurring inside vapor-gas phase. If the sea water conductivity is used the discharge can be similar to arc in air as current amplitude is about 1 ampere and voltages are hundreds volts. If the distilled water is used the discharge can be similar to air crown because currents do not exceed several tens milliamperes and voltages are about thousands volts. It can be proved partly by high frequency signal shown in figure 6.

CONCLUSIONS

An analysis of the results of our experiments leads to the following conclusions:

(i) It is possible to create simultaneous discharges inside a lot of bubbles, which are formed in distilled water both in the dielectric film holes and on the point electrodes;

(ii) Using the discharge in a hole of dielectric film in water, it is possible to generate auto-oscillations of the current and the vapor-gas bubble. A nonlinear element is a cell with the film, which plays the role of a nonlinear resistor in the circuit. The nonlinear resistance depends on the current density in the film hole and the minimum and maximum bubble size;

(iii) The experiments show 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 film hole. This is accompanied by the supply of an additional electric energy providing for the continued pulsation of the bubble. Thus, the electro-hydrodynamic current commutation with the cyclic energy supply and loss in the hole is repeated in the form of auto-oscillation process;

(iv) The important parameters of the auto-oscillation 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 films with the hole diameter ranging from 0.3 to 0.9 mm showed that the period of pulsations obeys the relationship T ~ K•d with K = 380 μs/mm. The current pulses are unipolar, exhibit a steep leading front, and decay within a time of t ~ (0.2–0.5)•T;

(v) The process of auto-oscillations in the system studied can be implemented in acoustics, hydro-dynamics, electrodynamics, and biophysics, and in a number of other applications related to modeling and development of the auto-oscillating systems employing phase transitions in liquid media.

ACKNOWLEDGMENTS

The authors are grateful to V. V. Mitrofanov and A. P. Ershov for fruitful discussions. This study was supported by the Russian Foundation for Basic Research, projects no. 00-02-17992 and no. 01-02-06443.

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