Shock waves in water at low energy pulsed electric discharges

M.E. Pinchuk, V.A. Kolikov, Ph.G. Rutberg, A.G. Leks, R.V. Dolinovskaya, V.N. Snetov, A.Yu. Stogov

Institute for Electrophysics and Electric Power of Russian Academy of Sciences, Dvortsovaya nab. 18, St.-Petersburg, 191186, Russia

E-mail: rc@iperas.nw.ru, pinchme@mail.ru

Abstract. Experimental results of shock wave formation and propagation in water at low energy pulsed electric discharges are presented. To study the hydrodynamic structure of the shock waves, the direct shadow optical diagnostic device with time resolution of 5 ns and spatial resolution of 0.1 mm was designed and developed. Synchronization of the diagnostic and electrodischarge units by the fast optocouplers was carried out. The dependences of shock wave velocities after breakdown of interelectrode gap for various energy inputs (at range of ≤1 J) into discharge were obtained. Based on the experimental results the recommendations for the adjustment parameters of the power supply and load were suggested.

1. Introduction
Nowadays a low energy pulsed electric discharges have wide prospects in various applications such as materials processing, plasma-chemical technologies and so on. Widespread use is also found in medical or biological applications [1-4]. One of widely spread practice is using the discharge for water purification [5]. In each case advantages of pulsed discharge is caused by many physical, technical, and economical factors. That is concerned the last mentioned application areas, this great perspectives are connected with prolonged microbial resistance of water [6,7], high efficiency of conversion or purification from organic substance [8] and from microorganisms during the discharge[9]. Apparently, UV-radiation and shock waves play main role for disinfection of water by pulsed electric discharges among the factors acting directly on pathogenic bacteria during the discharge [7].
To kill the bacteria by the shock waves it is necessary to break the bacteria membrane. In this case the pressure front thickness must be comparable with size of microorganisms, and the amplitude of pressure in the front of shock waves must be >2 MPa.
The energy transfer from the discharge channel to the shock wave is not fully studied so far. The simple increasing of energy input in the discharge does not lead to significant increasing of the pressure steepness and amplitude pressure of shock wave [6,7]. Thus the electro acoustic coefficient of energy transfer from discharges to water is low, the energy released in the channel of leaders, is small due to high ballast resistance of water [10]. Main channel, formed in a subsequent step of discharges, also has low resistance and energy-release is redistributed in the power supply system. Discharge channel is practically no longer expands and not transmits the mechanical energy to the surrounding water. From an economic and technological points of view it is advantageously to use the low power installations.
Thus the purpose of this work was investigations of shock waves formation, research and development industrial installation with controllable level of energy transfer to shock wave at low energy in pulse.

2. Experimental setup
Electric discharge under investigation were initiated in discharge chamber with volume 8 cm³ made of an insulating material by electric pulse generator. Parameters of installation are: output water flow
from 0 (without water flowing) to 2 l/min, electric pulses with a duration of 1–20 μs, energy in pulse of \( \leq 1 \) J, and a repetition rate of 1–150 Hz. Water inlet was diameter of 10 mm. In the chamber quartz windows were installed for optical diagnostic. Diameter of copper electrode was 0.5 mm and interelectrode gap of axisymmetric electrode system “wire to wire” from 1 to 10 mm was varied. A scheme of the experimental setup is shown on figure 1.

![Figure 1. Experimental setup](image)

To study the hydrodynamic structure of the shock waves, the optical diagnostic installation using direct shadow method with a time resolution of 5 ns and a spatial resolution of 0.1 mm was designed and developed. Gas-discharge xenon lamp was used as backlight source for shadow method. Shadow image registration was made by 16-frames high-speed CCD camera Cordin-222-16 with exposure times down to 5 ns. In condition of high electromagnetic level of interferences from electrodischarge installation we were compelled to make original system of synchronisation, based on fast optocouplers, with diagnostic devices. Diagnostic system was started by synchrosignal from special digital filter considering rather small reduction of voltage on discharge gap, signalling about the breakdown beginning. The dead time from synchrosignal to image exposition start was about 50 ns. So this system allowed to record series of images for subsequent independent discharges just from its beginning breakdowns.

Power supply with energy recuperation was specially designed and made for intelligent regulation of input energy level into the discharge gap [11]. Turning on of the transformer with saturating core in the circuit of the load (with water gap) allows to limit a current in the discharge gap at the main channel stage of the discharge and to return energy on a storage capacitor in the source. And regulation of input energy into discharge channel can be make by change of feedback factor in recuperation energy level. Current and voltage oscillograms at input energy into interelectrode gap of 0.15 J and 0.35 J are presented on figure 2. And respectively, for example, it is possible to provide optimal energy input for generation of a shock wave.

![Figure 2. Current and voltage curves. Energy in pulse: (a) – 0.15 J, (b) – 0.35 J.](image)
3. Experimental results

Shock wave velocities were measured for different energy input into discharge and for different interelectrode gaps. Typical shadow image is shown on figure 3. A shock wave place changing was measured from frame to frame and the shock wave velocity was calculated at different time from water breakdown by this measurements.

![Figure 3. Shadow image of discharge at 2 μs after breakdown (interelectrode gap of 7 mm): 1 — anode, 2 — cathode, 3 — shock wave from anode, 4 - shock wave from cathode, 5 — discharge channel.](image)

The pictures of streamers with different structures of three varieties: from the anode, from the cathode, and from both electrodes simultaneously (figure 4a) were obtained at initial stage of the gap breakdown. In most of the cases, the shock waves were formed near to the ends of electrodes and have similar velocities. But shock waves were formed by forming main discharge channel (figure 4c), not streamers.

![Figure 4. Shadow image of discharge gap at stage of formation main discharge channel. Time between frames is 100 ns.](image)

Images on figure 3 showed two spherical shock waves forming near the ends of the electrodes. And at an very early stage their velocity was ~1×10^4 m/s. The initial stage of shock wave formation is characterized by local extreme parameters of substance. Pressure behind the shock wave front at speed of ~10 km/s according to [12] corresponds to pressure 1.2×10^{11} GPa. After ~500 ns in the far Fraunhofer zone both waves merged in visually one quasispherical wave with velocity of ~1.5×10^3 m/s. Dependencies of shock wave velocity versus time are presented on figure 5 for other
different parameters. This data correspond to the results obtained previously under similar conditions [13].

At an initial voltage rising before breakdown (that corresponds to increasing of an interelectrode gap) corresponds increasing in number of streamers and also embeded energy into an interelectrode gap is increased at stage of forming main discharge channel. So shock wave intensity is increased too. An increasing of power at constant energy in an pulse leads to growing in an amplitude of pulse pressure [7]. In this system the current steepness practically doesn’t depend from the storage (and input) energy. And energy in a shock wave at the less energy in an pulse is same as one at more energy (figure 5b). Shock wave intensity was increased by growing of interelectrode gap (figure 5a).

**Figure 5.** Shock wave velocity vs time after breakdown: (a) — Energy in pulse of 0.35 J, interelectrode gap: $\Delta$ - 1.7 mm, $\square$ - 7 mm; (b) — Interelectrode gap of 7 mm. Energy in pulse: $\Delta$ - 0.15 J, $\square$ - 0.35 J.

4. Conclusion

Thus, although a shock wave intensity is grown at increasing of a pulse steepness and a general pulse energy. Nevertheless, general energy reduction in a pulse doesn't lead to considerable reduction of
shock wave intensity. On length of some millimetres from the discharge channel intensities of shock waves for different energy in pulse are became approximately equal and shock waves degenerated into weak wave. The formation of shock waves occurs at the stage of formation main discharge channel, and there is insignificant influence of a further energy input into channel at the main discharge stage.

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5. References
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