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Measurement of impulsive ultrasonic fields generated by an electrical discharge

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Introduction

The powerful electrical discharges in gases and liquids are sources of acoustic and ultrasonic fields, which are used for various applications, such as a sonar, measurement of physical properties of substances, calibration of ultrasonic transducers [1-3]. Very powerful sparks also can be used in a water cleaning equipment to disintegrate particles of organic materials. The physical mechanism of this process is not known exactly in spite of a clearly positive result. There is an assumption that the essential influence in a quality of this process is due to the acoustic field, generated by a spark in a treated liquid. The main difference from the applications mentioned above is that an electric discharge and generation of acoustic wave takes place in air, but the wave propagates through the boundary air/liquid into water.

The purpose of this work is to investigate the characteristics of the acoustic fields in liquids excited by an electric spark in adjacent gaseous medium and to evaluate the possible mechanisms influencing disintegration of molecules in organic substances.

Description of the acoustic wave excitation conditions

According to preliminary experimental investigations the best cleaning effect is achieved when the electrodes of a spark generator are positioned near the water surface and a discharge develops along the boundary air/ liquid (Fig.1).

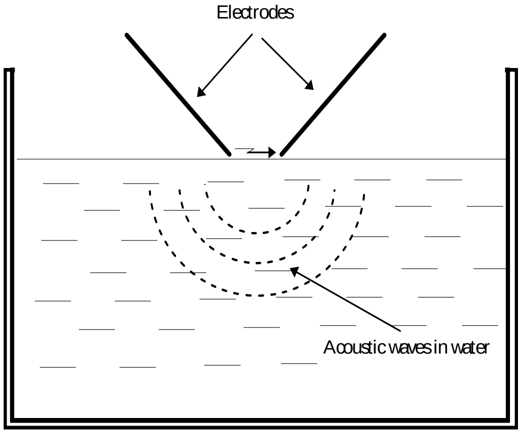


Fig.1. **Generation of acoustic waves in a liquid by an electrical discharge**

The acoustic waves are generated by a spark during fast expansion of the gases in the discharge zone and they propagate into water through the boundary air/ liquid. In the water cleaning equipment short (1 -3 μs) powerful spark discharges are used, which possess an electrical power density 1 - 5 MW/ cm^3.

At such energy levels in the liquid non-linear acoustic waves are excited, spatial-temporal shape of which is changing during their propagation. For example, the harmonic wave generated at the excitation point after some distance transforms into the shock wave with a very high spatial gradient of an acoustic pressure (Fig.2). The pressure difference in the shock wave between points separated only by 0.1 μm can exceed 50 MPa.

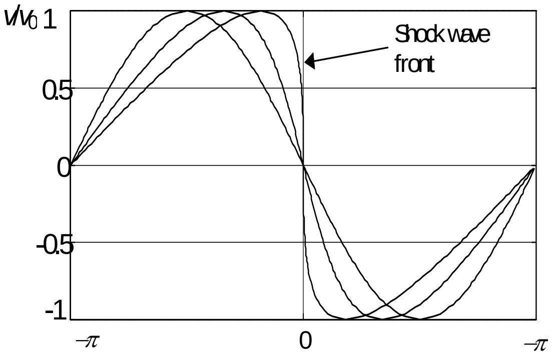


Fig.2. **The shape of non-linear acoustic wave after excitation and at some distance after spreading. (v/v_0 - normalized wave amplitude)**

The wave develops into the shock wave at the distance *l* , which depends on the excitation level, the angular frequency ω and non-linear properties of the medium [4-6]:

$$l = \frac{c_0^2}{\omega v_0\left(1+\frac{B}{2A}\right)}, \qquad (1)$$

where c_0 is the ultrasound velocity in the liquid, v is the particle velocity in the wave, *A* and *B* are the constants, characterizing non-linear properties of the liquid. For distilled water B/A=5.0. For other liquids such

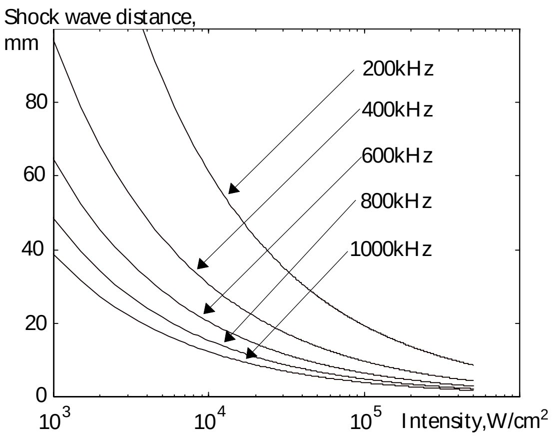


Fig.3. **The shock wave distance versus sound intensity at the various frequencies**

as water with dissolved salts the non-linear parameter B/A is bigger.

The dependencies of this distance versus the ultrasound intensity at the different frequencies are presented in Fig.3.

The thickness of the shock wave front is given by [4]:

$$\delta = \frac{b}{\varepsilon\rho v} \approx \frac{\lambda}{\mathrm{Re}_a}, \qquad (2)$$

where

$$\mathrm{Re}_a = \frac{\varepsilon}{\pi}\frac{\rho v\lambda}{b}$$

is the acoustic Reynolds numberand ε is the parameter characterizing non-linearity of the liquid. For example, at $v = 20\mathrm{m/s}$, $p = 30\mathrm{MPa}$, the spatial prolongation of the shock wave front is $\delta \approx 0.2\mu\mathrm{m}$, that is, it is comparable with dimensions of smallest particles of organic materials in polluted water. It means, that these particles can be destroyed by a pressure gradient.

The description of the experiment

The purpose of the experimental investigation was to evaluate the temporal shape and frequency ranges of the excited ultrasonic signals in liquid and to determine a spatial distribution of the acoustic fields. The initial experiments were carried out at low acoustic intensity levels, which do not exceed a range of linear acoustics.

Fig.4. **The experimental set-up used for investigation of impulsive acoustic pulses in water excited by an electric spark**

The experimental set-up used for measurements is shown in Fig.4

The acoustic pulses in water were picked up by a wide-band hydrophone, digitized by the digital oscilloscope HP54645A with the sampling rate 200 MHz and transferred to a Pentium type personal computer for further processing. In order to eliminate the influence of directivity of the hydrophone the small acoustic transducer was used in measurements. The diameter of the active surface of the transducer was 1 mm and the central frequency 4 MHz. The calculated directivity patterns of the transducer used for measurements at various frequencies are presented in Fig. 5. The distances are presented in millimeters.

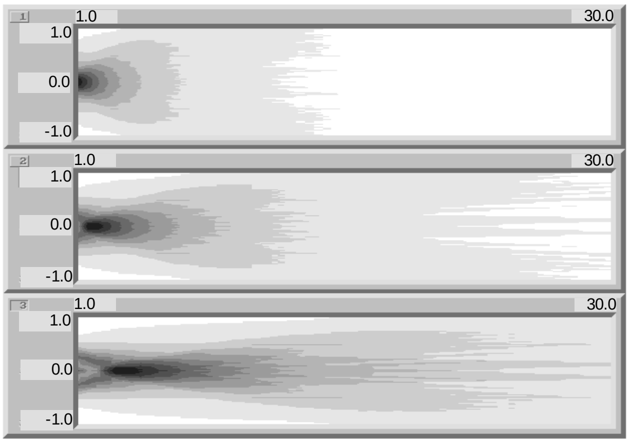


Fig.5. **Directivity patterns of the hidrophone at the frequencies 5, 10 and 20 MHz correspondingly**

The experimental results

The acoustic signal measured under described above conditions and the corresponding frequency spectrum are presented in Fig.6.

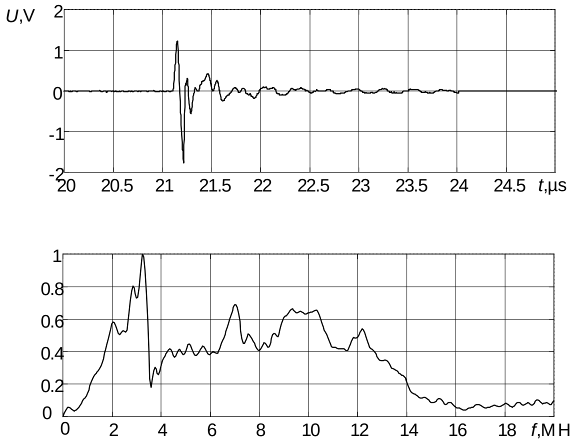


Fig.6. **The measured acoustic signal and its frequency spectrum in water**

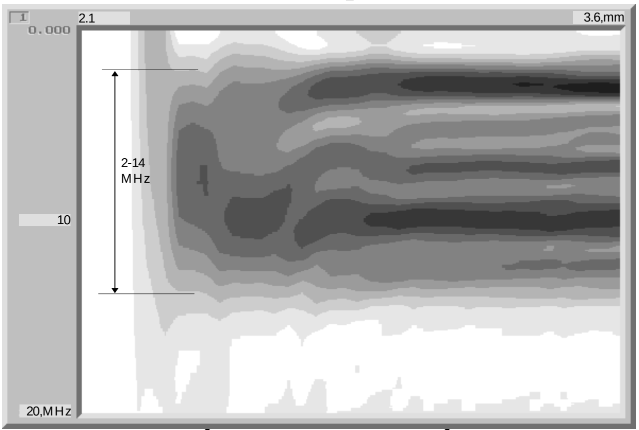
The results obtained indicate that the frequency range of the excited signals reaches 14 MHz. The frequency range 1-4 MHz corresponds to the resonant frequency of the hidrophone.

The features of the detected acoustic pulses are rather different at different time instants. From the temporal shape of the signal it can be concluded that the short pulse at the beginning corresponds to the shock wave pattern and another part are only echoes or interference of the main excited pulse. The essential properties of the signals excited can be revealed in a frequency domain using the concept of the two dimensional current spectrum:

$$S_c(\omega,t)=\int_{t_0}^{t_0+t} p(\tau)\cdot e^{-j\omega\tau}d\tau\ , \qquad (3)$$

where t_0 is the initial instant at which calculation of spectrum starts and t is continuously changing finishing instant. Such a spectrum shows an evolution of the spectrum in the time domain, enabling to estimate better origin and physical properties of the particular frequency components.

The current spectrum of the acoustic pulse, shown in Fig.6, is presented in Fig.7. The part of the spectrum between 0÷0.5 µs is due to the front of impulsive acoustic wave , propagating through the interface gas/ liquid. The rather strong components after the time instant 0.5 µs in the frequency ranges 2÷4 MHz , 7 MHz and 10÷12 MHz are due to the tail of the pulse, which most probably was caused by a non-uniform frequency response of the hydrophone used in the measurements. Hence, even at rather low excitation levels, corresponding to the range of linear acoustics, an electric discharge in gases excites very short acoustic pulses in water. At excitation levels producing significant non-linear effects, one can expect that the temporal and spatial duration of the pulses excited will be even shorter. That can explain the observed destruction of organic molecules in polluted water.



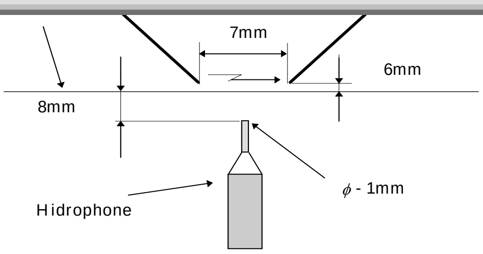


Fig.7. **The current spectrum of the acoustic pulse in water**

Conclusions

The electric discharge in air in a close vicinity to a boundary air/ water excites acoustic impulsive cylindrical waves in the liquid, temporal duration of which can be less than 40 -50 µs. In the frequency domain there are significant components in the range 3-14MHz.

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Elektrinio iðlydþio sukuriamø impulsiniø ultragarsiniø laukø charakteristikø matavimas

Reziumë

Analizuojamos netiesiniø impulsiniø laukø, atsiradusiø dël stipraus priepavirðio elektrinio iðlydþio, matavimo problemos. Pagrindþiamos netiesiniø laukø susiformavimo galimybës, pateikta tokiø laukø tyrimø metodika bei nusakomi reikalavimai, keliami matavimo aparatûrai. Apraðytieji eksperimentai su maþos galios iðlydþiais ávertina laikines ir daþnines suþadinto akustinio lauko charakteristikas.