High-speed diagnostic pulsewise-periodic of electric discharge in a water

Victor A. Kolikov, Mikhail E. Pinchuk*, Anatoly G. Leks, Philipp G. Rutberg
Institute for Electrophysics and Electric power of RAS
191186, Russia, St.-Petersburg, Dvortsovaya emb., 18

ABSTRACT

The results of research of pulsewise-periodic discharge in a water with a periodic time from 10 Hz up to several kHz, duration of discharge impulse 1-50 μs, current amplitude 10-100 A, current rise rate from 10^6 A/s to 10^8 A/s are presented.

The optical diagnostic of electric discharge in a water is carried out by the high-speed miniature 9-frame image converter camera K-011, one frame camera NanoGate-1 and the spectrograph with ICCD. The camera K-011 allows to register up to 9 frames with an exposition up to 0.1 μs and time between frames up to 0.1 μs. The exposure time of NanoGate-1 is up to 10 ns. The registration of spectra can be carried out with an exposition up to 5 ns. The program complex allows to record of a series of discharge impulses.

The main discharge parameters was determined by this high-speed optical diagnostics: discharge channel temperature, velocity of channel expansion, compression waves dynamic was determined. The feature of the channel formation were detected in unipolar mode of discharge and in oscillate mode.

Keywords: image converter camera, high-speed spectroscopy, discharge in water

1. INTRODUCTION

In the different technical applications the electric discharges in water are widely used [1,2]. The pulsewise-periodic discharges with duration 1 - 20 μs and energy in an impulse 0,2 - 1,0 J, rate of current rise of $10^5 \div 10^9$ A/s and with frequency of consecution 50 - 100 Hz are most effective and easily implemented in technical use [3]. The pairs of a spearhead - plane or spearhead - spearhead electrodes are optimal for realizing such discharge system with a interelectrode gap about 10 mm and diameter of a spearhead electrode of 1 mm.

However a powerful electric discharges applying in the technical applications requires the solution of difficult technical problems [1-3]. At increasing of input energy into discharge impulse the technical difficulties are accrued avalanchely. One of basic reasons is the impossibility of making of a long-term working discharge chamber. The powerful discharge creates major dynamic stresses, first of all on an electrode assembly, that gives in its destruction. There are also problems in making of long-term working high-voltage powerful generator and hydraulic system of continuous action.

Above mentioned limitations the pulsewise – periodic discharge with a small energy input in an impulse (~ 1 J) is dispossessed. And a usage of the discharges of such parameters becomes commercially favourable [3].

At the present time electrophysical and hydrodynamical properties of electric discharges in water were investigated in many work [1-4]. The effective mathematical models for description of such discharges are designed. At the same time, the deficiency of data of experimental researches with usage of diagnostics with the time and space resolution is felt.

In this paper we show the research result of diagnostic of electric pulsewise-periodic discharge in a water with a periodic time from 10 Hz up to several kHz and duration of discharge impulse 1-50 μs.

* Ph. + 7 (812) 3151757, fax + 7 (812) 5715056, e-mail rutberg iperas.spb.su

27th International Congress on High-Speed Photography and Photonics,
edited by Xun Hou, Wei Zhao, Baoli Yao, Proc. of SPIE Vol. 6279,
62795C, (2007) · 0277-786X/07/$15 · doi: 10.1117/12.725381

2. EXPERIMENTAL SET UP

The discharge investigations were conducted in the discharge chamber, that is a model of the device destining for practical usage. The time of continuous operation of the device is stipulated, first of all, reserve of an electrode material, as interelectrode gap during working is incremented because of erosion of electrodes, and it is necessary automatically support interelectrode distance. To a lesser degree, the resource of installation is determined by resourceof operation of other devices and units of installation. In this installation the interelectrode gap is supported to fixed value by the special device, that deliver an electrode wire into the discharge chamber. The scheme of electrodischarge installation is shown on fig. 1. All experiments we made in one discharge chamber, but we used several high voltage generators for power supply to achieve other regime of discharge. We used copper and steel electrode.

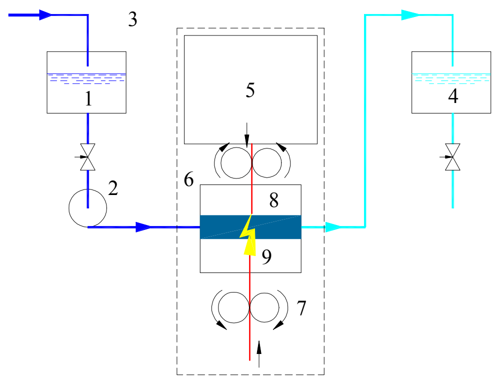

Fig. 1. The installation diagram. 1, 4 - tank with water, 2 – pump, 3 – electrodischarge block, 5 - high-voltage generator, 6 – electrodischarge chamber, 7 - feed mechanism of a spearhead electrode, 8, 9 - electrodes.

The electrical parameter are measured by a voltage probe with logarithmic amplitude limiter and current probe, connected to a 200 MHz oscilloscope. When breakdown occurs the current fast rises and the voltage drop. We use the current rise for triggering of our diagnostics.

The high-speed digital photography of electric discharge in a water is carried out by the high-speed miniature 9-frame image converter camera K-011 [5] and NanoGate-1 [6]. The camera K-011 allows to register up to 9 frames with an exposition up to 0.1 μs and time between frames up to 0.1 μs. The camera NanoGate-1 allows to register only one frame per one snot but with an exposition up to 10 ns and more high resolution.

The recording of spectrums is carried out by a spectrograph with ICCD. The collecting objective assemble light from fixed place of discharge volume on the tip of fiber bundle. The fiber bundle brings the collected light into a 0.127 m imaging spectrograph MS127i [7], equipped with three gratings (300, 600, 1200 g/mm). The spectra was detected by ICCD iStar DH720-18F-03 [8]. The registration of spectra can be carried out with an exposition up to 5 ns.

The experimental diagnostic techniques schematically are presented on fig. 2. The photos of experimental installation and high-speed diagnostic devices are shown on fig. 3.

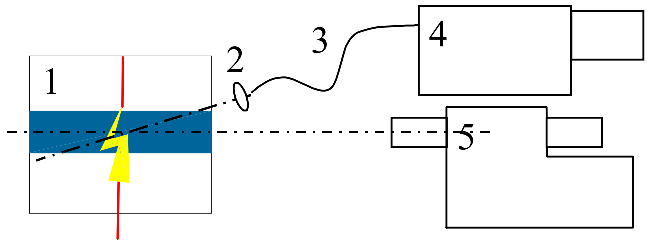

Fig. 2. Schematic drawing of diagnostic techniques: 1 – discharge chamber, 2 – collecting lens, 3 – fiber bundle, 4 - imaging spectrograph with ICCD, 5 - high-speed digital cameras.

a b

Fig. 3. General view of installation (a); 1 – discharge chamber. High-speed miniature 9-frame image converter camera K-011 (b - on high); imaging spectrograph MS127i with ICCD DH720-18F-03 (b – on down).

3. EXPERIMENTAL RESULTS

The typical oscillograms of a discharge current and voltage are shown on fig. 4. To the moment of the interelectrode gap breakdown, at 32 µs, the prebreakdown stage will precede, during which one, per time about 5 µs up to the moment of a breakdown, the current increases from 0 A to 7 A at a voltage increasing up to 35 kV (the oscillogram of a voltage has restriction on 1700 V). Since the moment of a breakdown and forming of an electric channel the current increases up to a maximum - 43 A at 8 µs thus the shape of a current is close to sine wave, the voltage on the gap monotonically decreases from 1 kV to zero at a mean of a voltage drop on a gap about 700 V. The pulse length is 20 µs. The input electrical energy during an impulse is about 0.4 J.

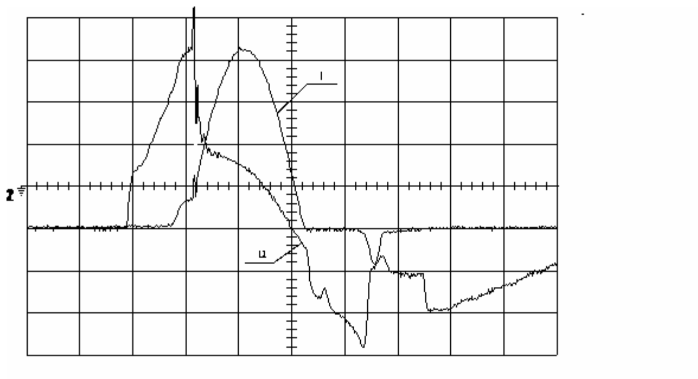

Fig. 4. Oscillograms of current and voltage on discharge impulse. I - current 10 A/div., U – voltage 400 V/div., time 10 µs/div.

Depending on input energy into discharge and velocity of its input, the motion of boundary of the discharge channel gives in occurrence in a fluid of a compression waves of different intensity. Photos of discharge evolution for different speeds of energy entrance for unipolar mode of discharge and in oscillate mode are presented on figures 5-7.

The initial phase of the discharge is accompanied by formation of a shock wave, at the front which one shapes cavity bubbles. It specially is well visible in a fig. 8. In more late stages of the discharge the bubbles are disintegrated with persistence. The velocity of expansion of a shock wave, in an initial stage of the discharge coincides expansion of a light discharge column. The velocity of expansion of light channel is kept approximately constant in a given range of current rise rate and input energy and it is ~2.0×10^4 m/s. The steady-state light channel diameter of the discharge in all cases is about ~1 mm.

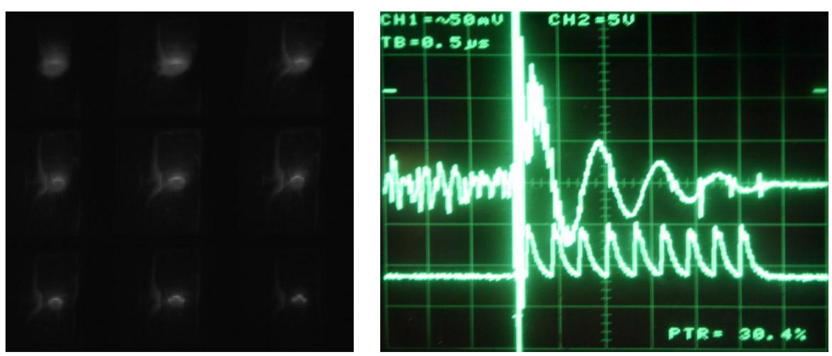

Fig. 5. Discharge evolution: Frames from left to right and from the top downward. On an oscillogram from above current pulse, from below frame pulses from high-speed camera (the impulse top corresponds to an exposure time, time between impulses to a pause between frames). The high-speed camera K-011. Maximum current ~ 30 A. Current rise rate ~10^8 A/s. Interelectrode gap 10 mm. I - current 10 A/div, time 0.5 µs/div.

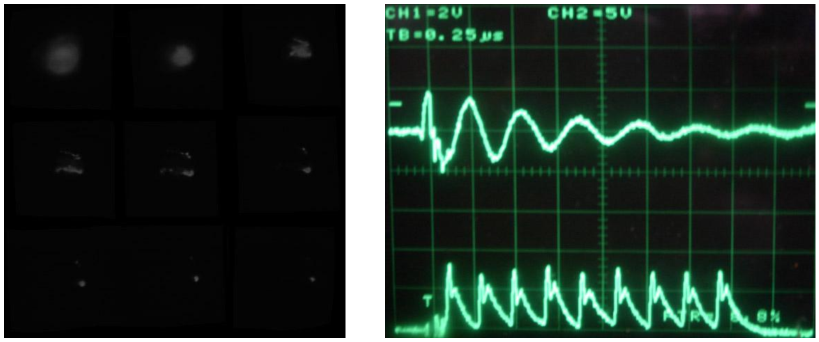

Fig. 6. Discharge evolution: Frames from left to right and from the top downward. On an oscillogram from above current pulse, from below frame pulses from high-speed camera (the impulse top corresponds to an exposure time, time between impulses to a pause between frames). The high-speed camera K-011. Maximum current ~ 40 A. Current rise rate ~10^8 A/s. Interelectrode gap 10 mm. I - current 40 A/div, time 0.25 μs/div.

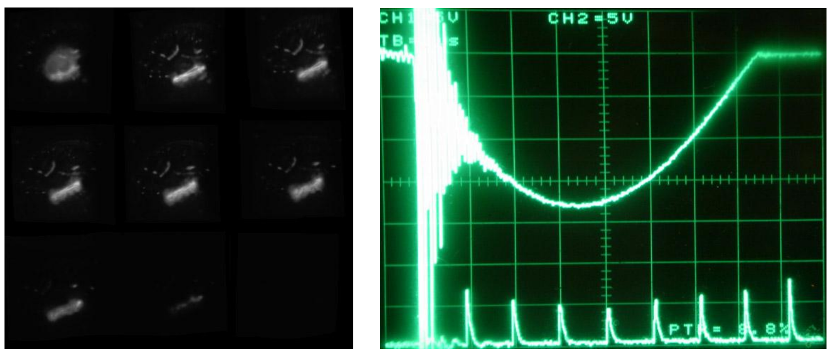

Fig. 7. Discharge evolution: Frames from left to right and from the top downward. On an oscillogram from above current pulse, from below frame pulses from high-speed camera (the impulse top corresponds to an exposure time, time between impulses to a pause between frames). The high-speed camera K-011. Maximum current ~ 35 A. Current rise rate ~5×10^6 A/s. Interelectrode gap 10 mm. I - current 10 A/div, time 2 μs/div.

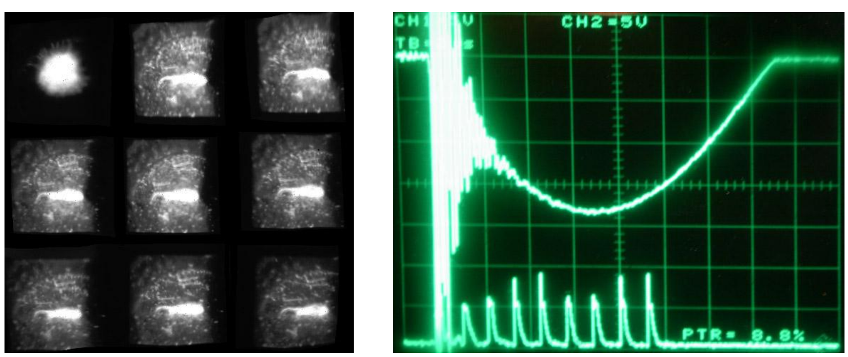

Fig. 8. Discharge evolution: Frames from left to right and from the top downward. On an oscillogram from above current pulse, from below frame pulses from high-speed camera (the impulse top corresponds to an exposure time, time between impulses to a pause between frames). The high-speed camera K-011. Maximum current ~ 40 A. Current rise rate ~5×10^6 A/s. Interelectrode gap 10 mm. I - current 10 A/div, time 2 μs/div.

By the analysis of one hundred frames made in a maximum of the first half-period of a current, we set, that in 10 % of cases simultaneously there are more than one channel in the discharge (6 discharges with two channels, 4 discharges with three channels, fig. 9). The configurations with several channels are steady, in that the sense, that the some formed discharge channels exist all time of a half-wave of a current impulse. On a following half-wave a place of a breakdown and the shaping of the channel does not correlate with a place and form of the discharge channel, that was just before.

Fig. 9. Other different realization of discharge channel formation. Parameters of experiments corresponds to fig.6. The exposition – 10 ns. And the moment of exposition synchronizes to moment of maximum current at the first half-wave. High-speed camera – NanoGate-1. Spectral range of filming is 600-700 nm.

The spectral measurings were conducted for the discharge with electrodes from copper or steel with a coopering at current amplitude 30-50 A, a voltage drop on gap 700-900 V; of a pulse length 20 µs; interelectrode gap 3-5 mm.

The radiation spectrums (fig. 10) of the discharge represent a continuum with a dip in the range 500-600 нм and bright maximum at 650 nm, on which one the line spectrum is superimposed. The continuum was identified as Stark broadening of a lines of a Balmer series of hydrogen, line spectrum - as lines of atoms of the electrode material. Such character of a spectrum at absence reabsorption in a continuum (the plasma is optically transparent) has allowed [9] to estimate an electron concentration in discharge plasma by a Stark broadening of a line H_α, which one has equal to $2.0\pm0.5\times10^{17}$ cm^{-3}, and by a Stark broadening of a line H_β - $4.5\pm1.0\times10^{17}$ cm^{-3}. Temperature of the discharge channel is $(10\div20)\times10^3$ K.

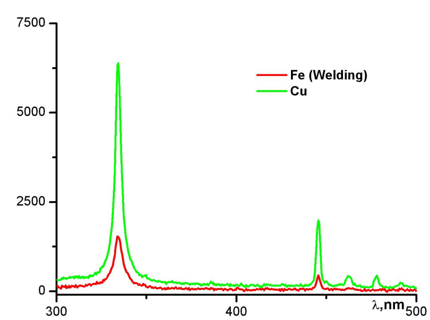

Fig. 10. The fragment of time-integral spectrum from center of interelectrode gap.

4. CONCLUSIONS

The phenomenology of the pulsewise-periodic discharge in a water with a periodic time from 10 Hz up to several kHz and duration of discharge impulse 1-50 µs with current amplitude 10-100 A, current rise rate from 10^6 A/s to 10^8 A/s was investigated by the made high-speed optic diagnostic. The estimations of main parameters of the discharge were made.

Work is partially supported by the Russian Fund of Basic Researches (the grant № 05-02-16033, 05-02-19-804-MФ-a, 05-08-01125, 06-08-00028) and the grant of the President of the Russian Federation (the grant № NSh-885.2003.2 and MK-2052.2005.8).

REFERENCES

1. *Theory and Practice of Electrogidravlic Effect.* Miscellany, Naykova Dumka, Kiev, 1978 (in Russian).
2. N.M. Beskaravainy, V.V. Dihta, V.G. Kovalev and V.V. Tulskii. *Aplication gidrodinamic of electroexplosion.* Naykova Dumka, Kiev, 1992 (in Russian).
3. V.L. Goryachev, Ph.G. Rutberg and V.N. Fedioukovitch. "About some properties of pulsewise-periodic discharges with pulse energy of ~1 J in water," *High Temp.* **34**(5), 757-760 (1996).
4. A. Descoudres, Ch. Hollenstein, G. Walder and R. Perez. "Time-resolved imaging and spatially-resolved discharge machining plasma," *J. Phys. D: Appl. Phys.* **38**, 4066-407 (2005).
5. http://www.bifocompany.com
6. http://www.videoscan.ru
7. http://www.lot-oriel.com
8. http://www.andor-tec.com
9. G. Grim. Plasma spectroscopy. Atomizdat, Moskow, 1969.