DOI: https://doi.org/10.15407/techned2020.05.080

HIGH VOLTAGE PLANT WITH 3 MW PULSE POWER FOR DISINFECTION FLOW OF WATER BY NANOSECOND DISCHARGES IN GAS BUBBLES

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The processes in the discharge circuit of a powerful high-voltage pulse installation with three multi-gap spark gaps operating in parallel are experimentally investigated. Oscillograms of voltage and current pulses at the load in the form of three reactors are obtained with running water. The discharge processes are compared when using in the discharge circuit three multi-gap dischargers and three reactors connected in parallel, on the one hand, and one such discharger and one reactor on the other. The regimes of synchronous discharges in gas bubbles were obtained in three reactors, which ensured the complete inactivation of the E.coli in water with an initial concentration of 10^6 CFU/cm3 (CFU is a colony-forming unit). References 5, figures 4, table 1.

Keywords: nanosecond discharge in a gas bubble, a high-voltage pulse plant, pulse power, a spark discharger (gap), disinfection of water in a stream, a reactor - a discharge unit.

Introduction. The disinfection and purification of water by electric discharges have been the subject of growing research interest in recent years [1, 2]. It was experimentally shown that with an increase of the input power the water purification rate has increased however, the energy efficiency has decreased [3]. It was shown in [3] also that with an increase in the current density over the permissible one the process of quenching of OH radicals with a characteristic lifetime of ≈1 ms intensifies. Therefore, to create industrial plants for water purification and disinfection, it is necessary to increase the total power introduced into the load (reactors) by distributing it between the reactors so that the current density and power in each discharge unit do not increase. Thus, with an increase in plant productivity, the number of electrical discharge nodes (reactors) should increase. In this case, one high-voltage pulse generator can operate on such a number of several reactors whose total impedance is $Z_{tot} \geq 2Z_g$, where Z_g is the internal impedance of the generator.

The purpose of this work is to create a high-voltage pulse installation for disinfecting water in a stream using nanosecond discharges in gas bubbles with a rated pulse power of up to 3 MW and experimental study with its help the possibility of complete inactivation of indicative microorganisms with a high initial concentration in the water, that must be disinfected.

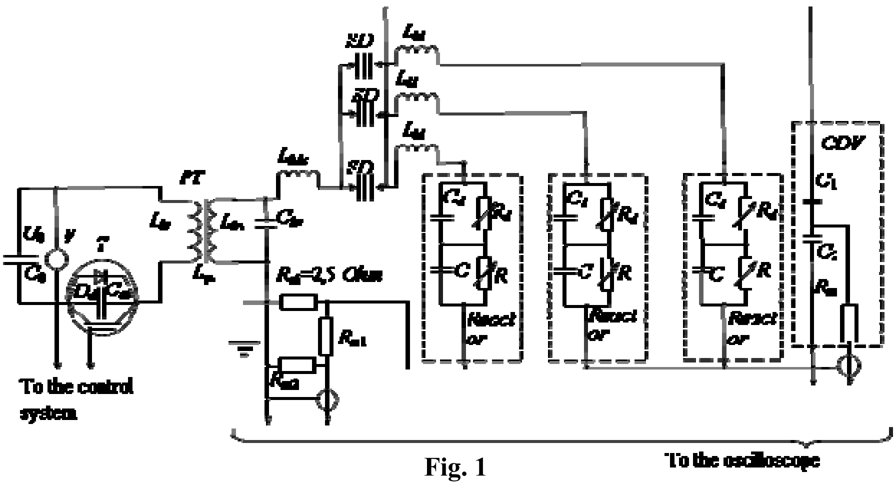

Fig. 1

Distinctive features of the experimental plant. The electrical circuit of the installation (without a pump and compressor) is shown in Fig. 1. In Fig. 1 capacitance C_0=4230 µF (9 TAMICON 470 µF capacitors, 450 V in parallel) is charged from the network (220 V, 50 Hz) through a diode bridge (not shown in Fig. 1) to voltage U_0 according to [4]. V is a voltmeter. The switch is a transistor switch T, consisting of four parallel-connected IGBT - transistors of the type IRG4PH50UD. Switching energy is carried out when the transistors are in the process of opening in the switch T. The duration of the open state of the key T is 110 µs. D_d are the reverse diodes of the IGBT key built into transistors; $C_{ec} \geq 1$ nF is the capacitance of the "emitter-collector" of the IGBT key; R_{sh} is the resistance of the measuring shunt; R_{m1}=300 Ohm, R_{m2}=60 60 Ohm - matching shunt resistances, R_{sh}=2.5 Ohm; C_1, C_2 are the capacitances of the high-voltage and low-voltage arms of the capacitive voltage divider CDV ($C_1 \approx 2{,}7 \times 10^{-12}$ F, C_2=20,4×10^{-9} F, division ratio $k_d \approx 7650$) with matching resistance R_m=50 Ohm; $C_d \ll C_{ec} \ll C_0$. In the electri-

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cal circuit of each of the three discharge nodes (reactors) C_d, R_d are the capacitance and nonlinear active resistance of the discharge gap in the gas bubble, and C, R are the capacitance and nonlinear active resistance of the water layer between the discharge gap (*DG*) and the grounded electrode. The pulse transformer *PT* is represented by the magnetization inductance L_μ and the leakage inductances L_{lv}, L_{hv} of the primary and secondary windings of *PT*, respectively. L_{hdc} is the inductance of a high-voltage discharge circuit (excluding *PT* and inductances of L_{ld} reactors). C_{hv} is the peaking capacity, *SD* is the peaking multi-gap spark discharger (*MG SD*). The capacitance C_{hv}=150 pF is composed of six KVI-2 capacitors with a capacity of 100 pF each for a voltage of 20 kV.

The disinfecting effect of the created plant with three discharge units and three peaking *MG SD*s operating in parallel was experimentally verified in this work. Spark dischargers (spark gaps) operate in the air at atmospheric pressure. The discharge nodes provide discharges in gas bubbles in the water.

The method based on pulsed electric discharges in gas bubbles inside water is one of the most promising methods for disinfection and purification of water. The discharges generate a series of high-intensity factors, including OH radicals, atomic oxygen, ozone, hydrogen peroxide, broadband radiation that contains ultraviolet light, and other factors that disinfect and purify water. The method can be used for the preparation of drinking water, for disinfection and purification of water in swimming pools, municipal water, wastewater, the water of various industries, etc. Fig. 2 shows a block diagram of the plant implementing this method. The plant consists of a low-impedance generator *1* of high voltage pulses, compressor *2*, pump *3*, pipeline *4* with a diameter of D=40 mm with running water, made of insulating material. The plant includes also three branch pipes *5* with a diameter of D_{bp}=40 mm, through which insulation hollow cases *6* without a bottom are inserted and fixed there. Cases 6 are made combined with high-voltage conductors – pointed electrodes *7* in isolation and with tubular gas pipelines *8*. The plant contains also a grounded electrode *9* in each of the three discharge units. This electrode is made in the form of a metal cylindrical ring with a hole in its side surface for the location of the case *6* in the pipeline *4*. Каждый разрядный узел состоит из электрода *7* в твердой изоляции, кончик которого не изолирован, корпуса 6 з характерным внутренним линейным размером S=2,8 см, газопровода *8*, электрода *9* и слоя воды внутри трубопровода *4* под патрубком *5* и около него. Each discharge unit consists of an electrode *7* in solid insulation, the tip of which is not insulated, a case *6* with a characteristic internal linear size S=2,8 cm, a gas-pipe *8*, an electrode *9* and a water layer inside the pipe 4 under and around the branch pipe *5*. The branch pipes *5* may have caps (Fig. 2 not shows caps) with the possibility of gas outlet after discharges in gas bubbles. Wherein, the outflow of water through the caps on the branch pipes *5* is impossible. A pump *3* pumps water into a pipe *4* from a water source *10*. The distance between adjacent branch pipes is d≈300 mm. The flow rate of water and gas from the compressor is adjustable. The composition of the gas may be different. The flow of water can be carried out by gravity from a source of water *10*.

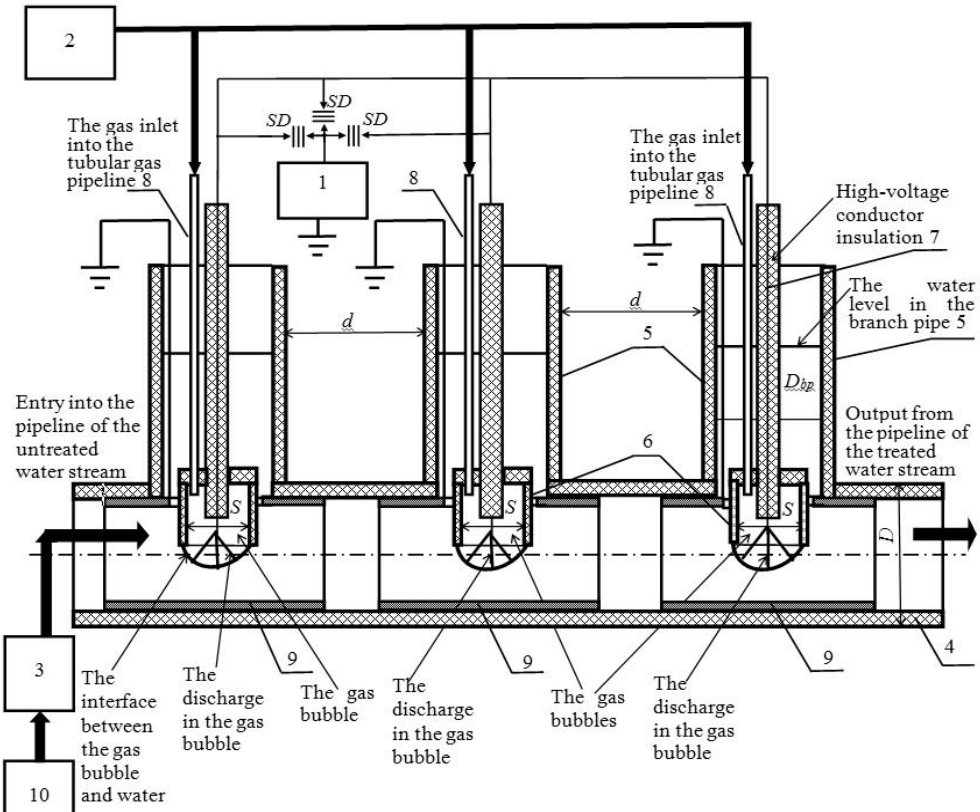


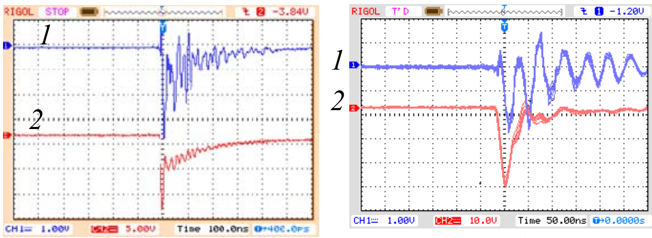
Fig. 2

The fundamental difference between this plant and the device in [4] is the presence of three *MG SD*s working in parallel, and three separate discharge units on water treatment in the stream. The operation of the dischargers in parallel is complicated by the short connection of their main electrodes to each other, to which three water treatment units are connected. Such a connection provides a guaranteed connection of each MG discharger to any discharge unit. However, such a connection increases the likelihood of operation only one or two out of three spark dischargers at the overheating of the electrodes in the *MG SD*s. To avoid overheating, each *MG SD* is cooled by a separate fan.

Fig. 3 shows a photo of three *MG SD*s working in parallel (Fig. 3, *a*) and a photo of a pipeline for treating water in a stream with three branch pipelines, three discharge units and an end valve (Fig. 3, *b*). The multi-gap spark dischargers provide nanosecond fronts of voltage and current pulses in the load - in reactors with discharges in gas bubbles in the water and layers of water under the bubbles.

a **Fig. 3** ***b***

Experimental results. Fig. 4 shows the waveforms of voltage pulses (curves *1*) and current (curves *2*) for a variant of operation of a plant with one reactor and one *MG DS* (Fig. 4, *a*) and for a variant with three reactors connected in parallel and with three *MG DS*s included in parallel, (Fig. 4, *b*). When using three reactors in parallel, the active resistance of load decreases approximately three times, the total capacity of the water layers in the reactors increases, the oscillation period increases (see Fig. 4), and the quality factor of the discharge circuit increases compared to using of one discharge unit (reactor). Therefore, the amplitude of the oscillations on the voltage waveform increases, they occur closer to a zero line. The oscillation period increases due to an increase in the total capacity of the water layers between the discharge gaps (DGs) with discharges in gas bubbles and grounded electrodes. The amplitude of the current pulse increases more than twofold with a decrease in its duration at the base by about 5 times (from 250 ns to 50 ns). It is necessary to take into account the increase in the switching time of the *MG SD*s with a decrease in the total load resistance - the active and capacitive resistance of the water layers in three reactors connected in parallel and the resistance of the emerging discharge channels in gas bubbles that connected in series with the corresponding water layers in the reactors (see Fig. 1). The shape of the current curve from aperiodic with superimposed oscillations in Fig. 4, *a* transforms into a triangular shape in Fig. 4, *b*, close to the shape of the critical discharge. In Fig. 4, *b*, several waveforms of voltage and current are superimposed on each other to show the repeatability of the signals. An experimental check at a pulse repetition rate of more than 2000 pulses/s showed the reliable operation of three *MG SD*s in parallel with pulse current amplitudes up to 100 A and pulse voltage amplitudes at the discharge units of about 30 kV. The characteristic pulse durations, in this case, were 20–30 ns (see Fig. 4). The rated power *Pp* of the plant in the pulse when working on three reactors in parallel is up to $P_p \approx Up*Ip$=30000 V*100A=3*10^6 W=3 MW.



a **Fig. 4** ***b***

After treating the water in the stream with discharges in gas bubbles, the pulses shown in Fig. 4, *b*, within 35 seconds at a pulse repetition rate of $f_{rpt} \approx 2400$ p/s, complete inactivation of E.coli bacteria was achieved. The results of the analyses are shown in the table. The seeding by indicative microorganisms - E.coli bacteria and analyzes of treated and control water samples were carried out in the specialized enterprise “Sanepidservice” (Kharkiv, UA). The initial seeding (bacterial concentration, number of bacteria per unit volume) of both the experimental and control samples was 10^6 CFU/cm^3 (CFU – colony forming units). This is a very high concentration, at least 100 times higher than the maximum concentration of E.coli bacteria in real dirty wastewater.

Name of indicator, units of measure	Regulatory documentation for test methods	Research result
Determination of total coliforms in drinking water or coli-index in pool water and wastewater		
Experimental sample E.coli 10^6 (CFU/cm^3) CFU - colonies forming units (water treatment by electric discharges in gas bubbles)	Methodical instructions # 10.2.1-113-2005 approved by the order of the Ministry of Health of Ukraine from 03.02.2005, No. 60	0
Control sample E.coli 10^6 (CFU/cm^3)		10^6

An important characteristic is the specific energy consumption of W_{sec} for disinfection [5]. To reduce the obtained value W_{sec}≈660 W*h/m^3 in this plant, at an initial concentration of E.coli of 10^6 CFU/cm^3, there is a significant reserve. If the initial concentration decreases by a factor of 100, a corresponding additional decrease in W_{sec} should be expected. The total concentration of E.coli in the treated (experimental) sample turned out to be zero, while in the control sample the concentration (the seeding) remained equal to 10^6 CFU/cm^3.

Conclusions. The experimental high-voltage pulse plant with a rated pulse power of 3 MW was created and successfully tested, in which the disinfection of water in a stream is carried out using nanosecond discharges in gas bubbles. Complete inactivation of E. coli bacteria with an initial concentration of 10^6 CFU/cm3 in water (CFU - colony forming units) was achieved In the flow mode of treatment at a water flow rate of 120 l / h. The method of water disinfection using nanosecond discharges in gas bubbles is promising for industrial applications and can successfully replace or supplement ozonation and ultraviolet treatment.

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УДК 537.52:621.373

ВЫСОКОВОЛЬТНАЯ УСТАНОВКА ИМПУЛЬСНОЙ МОЩНОСТЬЮ 3 МВТ ДЛЯ ОБЕЗЗАРАЖИВАНИЯ ВОДЫ В ПОТОКЕ ПРИ ПОМОЩИ НАНОСЕКУНДНЫХ РАЗРЯДОВ В ГАЗОВЫХ ПУЗЫРЯХ

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Экспериментально исследованы процессы в разрядной цепи мощной высоковольтной импульсной установки с тремя многозазорными разрядниками, работающими в параллель. Получены осциллограммы импульсов напряжения и тока на нагрузке в виде трех реакторов с проточной водой. Проведено сравнение разрядных процессов при использовании в разрядной цепи трех многозазорных разрядников и трех реакторов, включенных в параллель, с одной стороны, и одного такого разрядника и одного реактора с другой стороны. В трех реакторах получены режимы синхронных разрядов в газовых пузырях, обеспечившие полную инактивацию E.coli в воде с исходной концентрацией 10^6 КОЕ/см^3 (КОЕ – колониеобразующая единица). Библ. 5, рис. 4, табл. 1.

Ключевые слова: наносекундный разряд в газовом пузыре, высоковольтная импульсная установка, импульсная мощность, искровой разрядник, обеззараживание воды в потоке, реактор – разрядный узел.

УДК 537.52:621.373

ВИСОКОВОЛЬТНА УСТАНОВКА ІМПУЛЬСНОЮ ПОТУЖНІСТЮ 3 МВТ ДЛЯ ЗНЕЗАРАЖЕННЯ ВОДИ У ПОТОЦІ ЗА ДОПОМОГОЮ НАНОСЕКУНДНИХ РОЗРЯДІВ У ГАЗОВИХ БУЛЬКАХ

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Експериментально досліджено процеси у розрядному колі потужної високовольтної імпульсної установки з трьома багатозазорними розрядниками, що працюють в паралель. Одержано осцилограми імпульсів напруги та струму на навантаженні у вигляді трьох реакторів з проточною водою. Проведено порівняння розрядних процесів під час використання у розрядному колі трьох багатозазорних розрядників і трьох реакторів, включених в паралель, з одного боку, та одного такого розрядника і одного реактора з іншого боку. В трьох реакторах одержано режими синхронних розрядів в газових бульках, які забезпечили повну інактивацію E.coli у воді з вихідною концентрацією 10^6 КУО/см^3 (КУО – колонієутворююча одиниця). Бібл. 5, рис. 4, табл. 1.

Ключові слова: наносекундний розряд в газовій бульці, високовольтна імпульсна установка, імпульсна потужність, іскровий розрядник, знезараження води у потоці, реактор – розрядний вузол.

Надійшла 28.02.2020
Остаточний варіант 03.05.2020