APPLICATION OF BIPOLAR PLASMA DISCHARGE OVER THE LIQUID SURFACE FOR WATER PURIFICATION FROM CHEMICAL AND BACTERIAL POLLUTION

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The paper presents the results of development of a high-voltage pulse generator that provides formation of a bipolar low-temperature plasma discharge above the liquid surface. The generator is constructed after the scheme with an inductive energy store and, as a such energy store, a high-voltage inductor (Ruhmkorff coil) is used. The generator provides an adjustable pulse repetition frequency from 70 to 500 Hz with a voltage amplitude up to 300 kV at a current amplitude up to 4 A. The generator was tested by the formation of a plasma discharge above the water surface. It is shown that such a discharge provides an effective purification of water from chemical (chloroform, etc.) and bacterial (Esherichia coli, Candida albicans et al.) pollution.

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INTRODUCTION

Recently, interest in the research of discharges above the liquid surface has increased significantly. This is not only because of the variety of related processes occurring in the gas above the liquid surface, in the liquid itself, and at the liquid-gas interface [1]. In the first place, this interest is due to a physicochemical effect of discharge upon the liquid, which enables an effective purification of water from chemical and bacteriological pollution [2]. For this, in most cases, high-voltage unipolar pulses with amplitudes up to 30 kV at a pulse duration $\tau \leq 200$ ns are used [2, 3]. We might reasonably expect the discharge with a variable polarity at higher electric voltage amplitudes to effect more essentially.

There are known different schemes for high-voltage pulses formation [4], in which energy from the primary power supply (Fig. 1) is delivered to the energy store, and then, transferred to the load by using a commutation device. Both capacitors and inductors can be used as energy store.

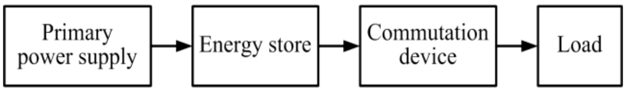

Fig. 1. Simplified diagram of a high voltage generator with an energy store

The purpose of the work is to develop a high-voltage pulse generator that provides a bipolar plasma discharge above the liquid (water) surface with $U_{max} \leq 300$ kV, $\tau \leq 50$ ns and pulse repetition frequency from 70 to 500 Hz.

1. EXPERIMENTAL

A simplified diagram of the generator with an inductive energy store is shown in Fig. 2. The diagram includes the energy store itself (transformer Tr) and a current interrupter. Energy storage occurs at a smooth increase in current passing through the primary winding of the transformer Tr.

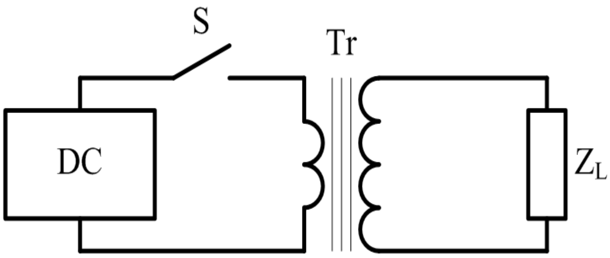

Fig. 2. Simplified diagram of a high voltage generator with an inductive energy store (DC – power supply; S – current interrupter; Z_L – generator's load)

A high-voltage inductor (Ruhmkorff coil) is used as a transformer. At a supply voltage of 12 V, it allows us to receive high voltage pulses up to 300 kV.

In the developed generator, two MOSFETs (metal-oxide-semiconductor field effect transistor) are used as a current interrupter (commutation device) in the transformer's primary winding. The MOSFET is controlled by a driving oscillator built on the NE555P chip (multifunctional precision timer).

The block diagram of the generator is shown in Fig. 3.

The power supply of the generator is a supply with regulated from 14 to 30 V DC voltage which is applied to the transformer's primary winding through the oscillator powered through a voltage stabilizer to ensure the stability of a control signal. A load, that is a discharge gap of the plasma reactor, is connected to the transformer's secondary winding (Fig. 4).

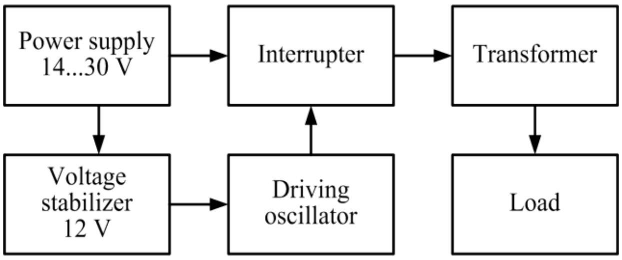

Fig. 3. Block diagram of a high voltage pulse generator

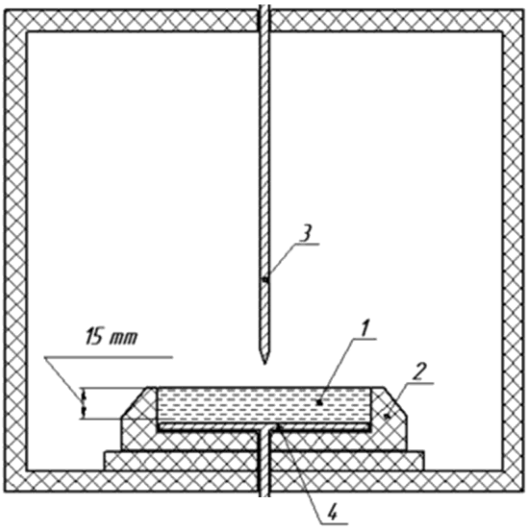

Fig. 4. Plasma reactor: 1 – liquid; 2 – cell;
3 – pointed metal electrode; 4 – flat electrode

2. EXPERIMENTAL RESULTS

The circuit diagram of a high-voltage pulse generator is shown in Fig. 5. A voltage stabilizer for driving oscillator supply is made on the chip IC1.

The driving oscillator is built on the chip IC2 that discharges the capacitor C1 when the voltage across it has reached a certain level. Capacitor C1 charging occurs according to the linear law given by the current stabilizer. A current stabilizer is built on the transistor VT1, the crystal stabilizer diode VD1 of 4.7 V, and resistors R1, R2, and R3. The variable resistor R3 provides control of the current value at the capacitor C1 charging, the time of its charging to a specified voltage and, consequently, the pulse repetition frequency. Then a signal from the capacitor C1 goes through the buffer stage, built on the transistor VT2, to the transistors VT3 and VT4 which control the current in the transformer‘s Tr primary winding. As the capacitor C1 is charging, the current through the transformer‘s Tr primary winding gradually increases. When a prescribed level on the capacitor C1 is reached, the transistors VT3 and VT4 block and that results in arising of a self-induced EMF in the transformer‘s primary winding. The magnitude of this EMF depends on the current through the transformer‘s primary winding at the instant when the transistors VT3 and VT4 are blocking , and on the time interval of their blocking. In this case, a high voltage pulse is induced in the transformer‘s Tr secondary winding.

Current in the discharge gap of the plasma reactor is controlled by a voltage drop across the resistor R15 (see Fig. 5), and voltage in the discharge gap is controlled by a voltage drop across the resistor R28, which is a part of the high-voltage resistive voltage divider R16 – R28. These signals from R15 and R28 are delivered to the digital oscilloscope DO and recorded by it.

Figs. 6 and 7 show the oscillograms of voltage and current in the discharge gap "metal tip – liquid surface" at atmospheric pressure for one of generator modes. In Fig. 6, oscillograms represent the periodicity in change of the discharge electrical characteristics. According to them, voltage across the gap is bipolar (i.e. changes its sign during the period) and duration of the period is ≈ 5 ms that corresponds to a frequency of ≈ 200 Hz.

High bipolar voltages in the discharge gap and large discharge currents are observed during short time intervals $\tau < 50$ ns. They are recorded by an oscilloscope (see Fig. 7) with much shorter sweep duration than for the oscillograms shown in Fig. 6.

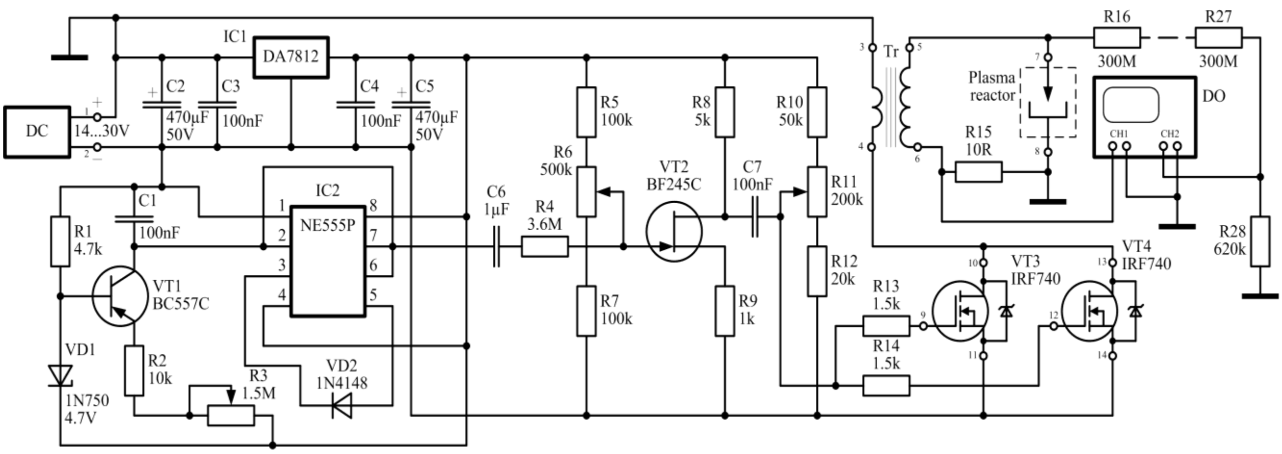

Fig. 5. Circuit diagram of a high-voltage pulse generator

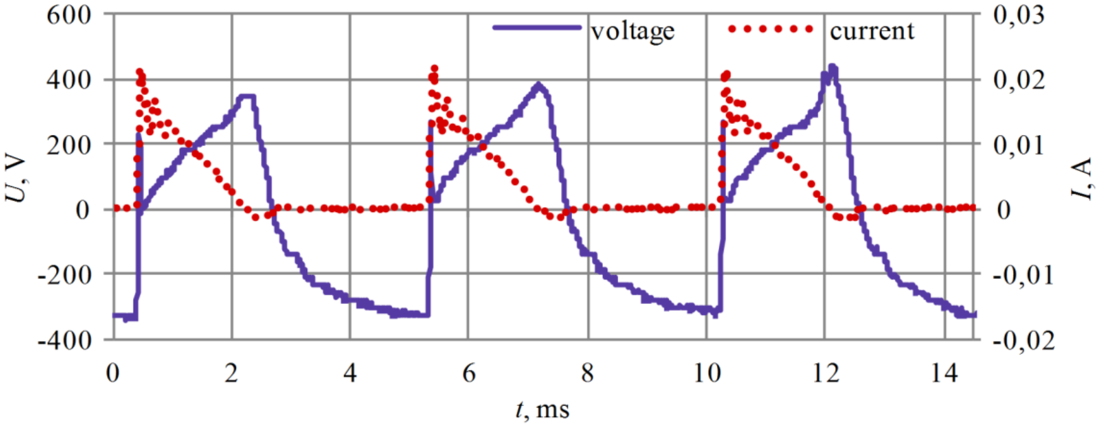

Fig. 6. Oscillograms of voltage and current in the discharge gap (periodic signal)

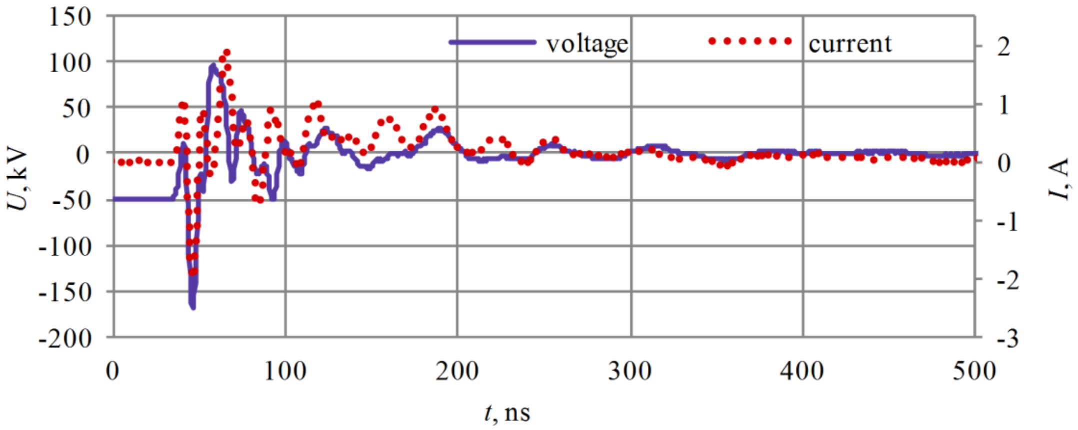

Fig. 7. Oscillograms of voltage and current in the discharge gap (during discharge initiation)

The image of a discharge, formed in the plasma reactor under such conditions, is shown in Fig. 8. The discharge "spreads" over the liquid surface that might indicate its nonlocal effect on the liquid.

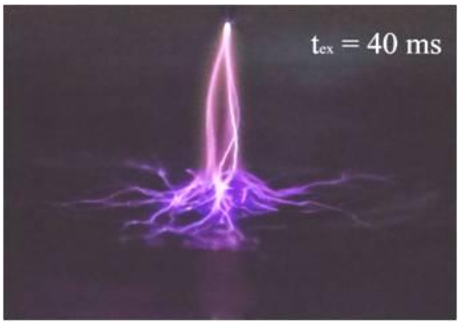

Fig. 8. Photo of discharge in the discharge chamber. Exposure time – 40 ms; thickness of the liquid in the cell – 15 mm; distance between the pointed electrode and the liquid surface – 10 mm

The constructed bipolar high-voltage pulse generator was tested by processing water with a 280 ppm initial content of dissolved chloroform. Concentration of CHCl3 in solutions, before and after processing, was determined by gas chromatography-mass spectrometry using the Agilent 7890AGCSystem.

After processing at U = 75 kV, I = 0.5 A during 20 min, chromatographic and mass spectrometric studies showed that the chloroform content decreased by 67 %, i.e. there is a significant destruction of chloroform molecules in water. Processing of water with various microorganisms (for example, Esherichia coli, Candida albicans et al.) results in complete bactericidal purification of water [5] at the initial bacterial content ranging from $1.5{\cdot}10^8$ to $1.5{\cdot}10^9$ CFU / ml.

CONCLUSIONS

A simple generator of high-voltage bipolar pulses is developed and, as an inductive energy store, the Ruhmkorff coil is used in it. The generator produces pulses with $U_{max} = 300$ kV, $\tau \le 50$ ns and pulse repetition frequency from 70 to 500 Hz.

Electronic control of the current interrupter in the Ruhmkorff coil primary circuit provides good repeatability of high-voltage pulses.

An adjustable DC supply, in the primary circuit of the energy store (Ruhmkorff coil), and electronic control of the current interrupter make it possible to regulate the high-voltage amplitude over a wide range.

Application of the developed high-voltage bipolar pulse generator to produce a low-temperature plasma discharge above the liquid surface has demonstrated a high efficiency of detoxification and disinfection of water.

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ИСПОЛЬЗОВАНИЕ БИПОЛЯРНОГО ПЛАЗМЕННОГО РАЗРЯДА НАД ПОВЕРХНОСТЬЮ ЖИДКОСТИ ДЛЯ ОЧИСТКИ ВОДЫ ОТ ХИМИЧЕСКИХ И БАКТЕРИАЛЬНЫХ ЗАГРЯЗНЕНИЙ

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Представлены результаты разработки импульсного высоковольтного генератора, обеспечивающего формирование биполярного низкотемпературного плазменного разряда над поверхностью жидкости. Генератор построен по схеме с индуктивным накопителем энергии, в качестве которого используется высоковольтный индуктор (катушка Румкорфа). Генератор обеспечивает регулируемую частоту следования импульсов 70...500 Гц с амплитудой напряжения до 300 кВ при амплитуде тока до 4 А. Проведено опробование работы генератора при создании плазменного разряда над поверхностью воды. Показано, что такой разряд обеспечивает эффективную очистку воды от химических (хлороформа и др.) и бактериальных (Esherichia coli, Candida albicans и др.) загрязнений.

ВИКОРИСТАННЯ БІПОЛЯРНОГО ПЛАЗМОВОГО РОЗРЯДУ НАД ПОВЕРХНЕЮ РІДИНИ ДЛЯ ОЧИЩЕННЯ ВОДИ ВІД ХІМІЧНИХ ТА БАКТЕРІАЛЬНИХ ЗАБРУДНЕНЬ

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Наведено результати розробки імпульсного високовольтного генератора, що забезпечує формування біполярного низькотемпературного плазмового розряду над поверхнею рідини. Генератор побудований за схемою з індуктивним накопичувачем енергії, що використовується як високовольтний індуктор (котушка Румкорфа). Генератор забезпечує регульовану частоту проходження імпульсів 70...500 Гц з амплітудою напруги до 300 кВ при амплітуді струму до 4 А. Проведено випробування роботи генератора при створенні плазмового розряду над поверхнею води. Показано, що такий розряд забезпечує ефективне очищення води від хімічних (хлороформа та ін.) та бактеріальних (Esherichia coli, Candida albicans та ін.) забруднень.