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BIOMEDICAL ELECTRONICS AND SIGNAL PROCESSING

A New Technology of Bactericidal Processing of Koch's Bacillus on the Basis of Pulsed Electromagnetic Radiation

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Abstract— **The technology of bactericidal and sterilizing processing of Koch's Bacillus on the basis of pulsed electromagnetic ultraviolet (UV) radiation has been proposed. This technology is based on the pulse method of bactericidal processing of objects with low-temperature plasma using pulse sterilizer developed by the authors. The mathematical model of generating broadband pulsed radiation by the source of powerful optical radiation, based on the technique of charged particles accelerator, has been developed. The structure of the electromagnetic radiation source of the high-intensity optical range has been presented. The research of the bactericidal effect of pulsed UV radiation on Koch's bacillus has been conducted.**

Keywords—capacitive storage; forplasma; magneto-plasma compressor; hard ultraviolet; pulse sterilizer; biomedical technologies; bactericidal and sterilizing processin; Koch's bacillus

I. Introduction

Nowadays, there are chemical and physical means of controlling pathogens of infectious diseases that are found in the air, on the surface of various objects, indoors and so on [1-7]. Application of chemical methods for sterilizing objects of various physical nature along with the use of the necessary equipment is a potential danger itself, since various chemical reactions that lead to changes in physical-chemical and biological properties of the processed objects can be initiated [1], [2].

Thermal methods of processing objects in their various modifications are considerably energy-intensive, require very expensive equipment and do not always provide the necessary level of decontamination of the processed objects [3-5].

Existing radiation-based sterilization methods involving various types of ionizing radiation (X-ray, gamma radiation) cause deep bulk modifications in the chemical structure of the processed objects and result in the formation of by-products of chemical compounds with specific biological properties [6], [7].

Wide range of perspectives for carrying out highly effective sterilization is opened by the electro-physical method, which is based on the use of UV radiation, characterized by a significant bactericidal action.

For bactericidal processing involving optical radiation of the UV range, the sources with gas-discharge mercurial lamps of continuous effect are used [8]. Such a method presupposes that for the effect of sterilization, processing should last for several hours in order to achieve the necessary dose, at which decontamination level of 99.9% is observed. Considering the low - efficiency factor of bactericidal lamps, which does not exceed 0.06, the overall efficiency does not exceed several percents. Moreover, presence of mercury vapor and its compounds in lamp bulbs is a very dangerous factor, which complicates their use and further disposal [8].

Sources of pulsed electromagnetic radiation of gigawatt power level are characterized by high biological efficiency [9]. Such sources are based on the technique of high-intensity accelerators of relativistic electron beams and plasma. Depending on the type of electrodynamic structures, antennas and ways of their perturbation, sources can generate narrowband radio pulses of the microwave range, or ultra-wideband non-sinusoidal pulses of short duration. On the basis of plasma sources it is possible to obtain pulses of optical, in particular, ultraviolet radiation [9-12].

The influence of radiation on living organisms can be dual: thus, under certain conditions, it can have an obvious positive effect, which contributes to the intensification of life processes, cell growth, and increased resistance to various factors – the so-called vital radiation (from the Latin word vitae – life); on the other hand, a considerable sterilizing bactericidal effect is possible leading to destruction of living microorganisms – pathogens of diseases [10], [12].

The technology proposed by the authors, in this paper, is based on the pulse method of bactericidal processing using magneto-plasma compressor (MPC). An MPC is currently considered to be the most highly effective source of impulse effect [13]. A magneto-plasma compressor (MPC) is suggested as a source of UV radiation [14] with a bactericidal effect on tubercle bacillus.

The coaxial type MPC contains a high-power capacitive energy storage device based on a pulse capacitor. The latter is fundamental because it allows saving in the spectrum of

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radiation the part of hard ultraviolet which is most harmful to bacteria, but is absorbed by glass casing of closed-discharge lamps. This allows effective suppression of the most dangerous microorganisms, such as Koch's bacillus and others. The strongest influence of ultraviolet radiation in terms of its bactericidal effect is achieved at wavelengths of λ=253-265 nm [15].

II. A Mathematical Model for Generation of Broadband Pulsed Radiation

Effects of high-intensity pulses on various objects are carried out using radiation sources based on the technique of high-intensity accelerators of charged particles. On the basis of such technology, generators of microwave radiation are implemented, which, when using different electrodynamic structures, allow the generation of radio pulses with a carrier frequency in the centimetre wavelength range. Elements of the high-voltage technique of electron accelerators underlie the construction of ultra-wideband (UWB) radiation of a non-sinusoidal form of nano- and subnanosecond duration [13].

Elements of accelerating technology underlie the construction of sources of powerful optical radiation. The most powerful sources of electromagnetic radiation of artificial anthropogenic nature are pulse voltage generators based on the technology of accelerators of charged particles [16].

For defining the parameters of pulse sterilizer (discharge current, pulse discharge duration, momentary power) let us consider the circuit (Fig. 1), which consists of a condenser with a capacity C, parasite inductivity L and plasma resistance R ($R \sim 10^{-2}$ Ω and lower),

The first condition of the work of the circuit "Fig. 1" is condenser charge to voltage U_c. After shorting key K there is a condenser discharge, the character of which depends on the parameters L, R and C.

For circuit analysis "Fig. 1" let us work out an equation for momentary current:

$$i = \frac{U_c}{\omega L} e^{-\delta\tau} \sin \omega\tau, \qquad (1)$$

where $\delta = \frac{R}{2L}$ is a coefficient of attenuation, $\omega = 2\pi / \sqrt{LC}$ is oscillation frequency.

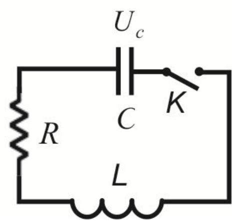


Fig. 1. Circuit of the oscillatory contour with resistance R

Then momentary meaning of voltage on condenser equals

$$u = \frac{U_C}{\omega\sqrt{LC}} e^{-\delta\tau} \sin(\omega\tau + \varphi), \qquad (2)$$

where $tg\varphi = \frac{2\omega L}{R}$.

Consequently, when the condition

$$R < 2\sqrt{\frac{L}{C}}, \qquad (3)$$

is satisfied, the discharge is oscillating, the oscillation amplitude decreases according to the exponential law with the coefficient of oscillation attenuation.

On the basis of the constructed time dependences $i(t)$ and $u(t)$, one can construct a dependence of instantaneous power, which is calculated as:

$$p(t) = i(t) \cdot u(t) \qquad (4)$$

As a result of the simulation process, the authors obtained the dependence of discharge current upon the stored energy and charge voltage of accumulator. For condenser with typical parameters: maximal voltage $U_{\max}$ = 8 kV; capacity is C=288 µF, inductivity is L=10 nH. For increasing the resource of MPC the condenser is used in under- charged mode, under which the meaning U_c ≈ 4 kV.

In "Fig. 2" is shown the dependence of the value of momentary current discharge, which calculated in accordance with (1). Analysis of dependence shows, that under resistance R=9 mΩ, which corresponds to the condition (3) the peak value of momentary current equals I=294.7 kA while the length of current pulse t=11 µs, which corresponds the maximal value of momentary capacity P=889.4 MW.

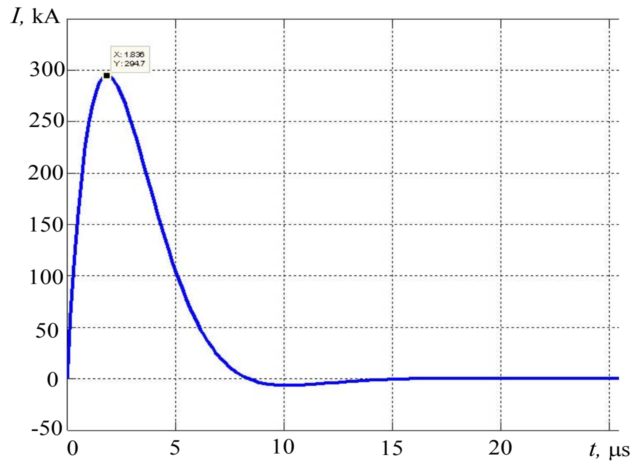


Fig. 2. Dependence of current discharge of the condenser

III. Functional Block Diagram of the Pulse Sterilizer Based on the MPC

In the work suggests the functional block diagram of pulse sterilizer of high- effectiveness based on the magneto-plasma compressor. It contains high- energy capacitive bank of energy based on the pulse condenser and the MPC of the open type "Fig. 3" [13]. The last one is obligatory as it allows saving in the spectrum of radiation the part of ultraviolet, which is the most harmful for bacteria, but it is absorbed by a glass casing of the lamps of closed digit.

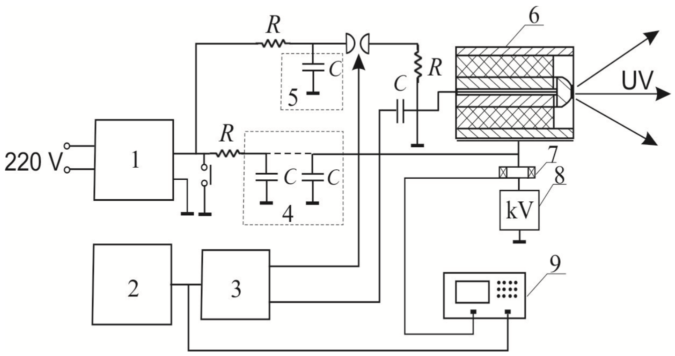


Fig. 3. Functional block diagram of the pulse sterilizer based on the MPC

In "Fig. 3" such signed are taken: high voltage rectifier (1); pulse generator (2); initiation block (3); high - voltage capacitive bank *C* (4); capacity bank *C* (5) for initial forplasma; magneto- plasma compressors (6); Rogowski coil (7); kilovoltmeter (8); oscillograph (9).

The most important peculiarity of MPC is making plasma focus (PF) - the field of shock condensed forplasma in end part of the accelerator, which in fact is the source of powerful pulsed electromagnetic radiation and blast wave, whose front is depicted in "Fig. 4" [13]. Photo of the source MPC discharge is shown in "Fig. 5".

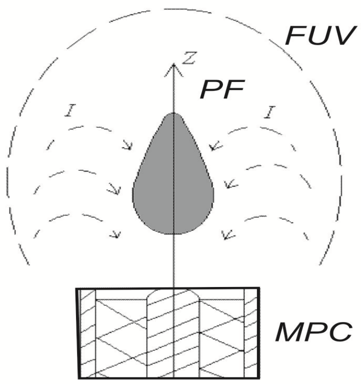
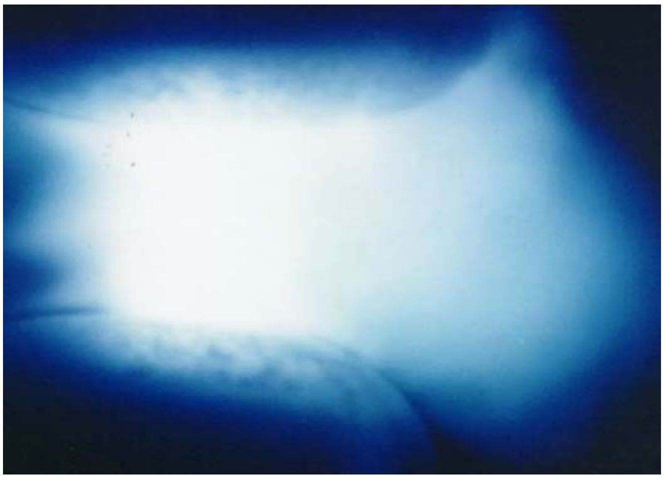


Fig. 4. Distribution of a field and electric current in the MPC

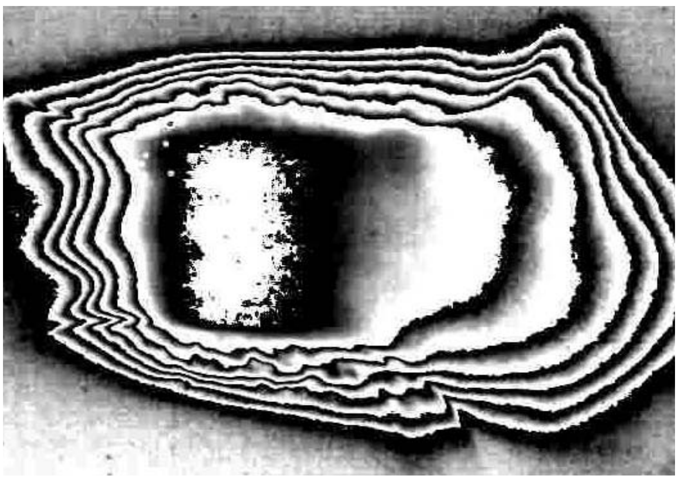
Experimental research showed, that the area of PF is formed on the distance of 0.5 – 1.5 cm from the cut of electrodes of MPC. The temperature of plasma in the area of PF depends on the value of current and energy, which is put up into the discharge and can change in the wide range from 10^4 to 10^7 K.

Fig. 5. Photo of the source MPC discharge

In the ultraviolet range with the help of the corresponding filters of the UVG-6 "Fig. 6, a" and UVG -8 "Fig. 6, b" types (UVG – abbr. *ultraviolet glass*) the discharge channel which generates powerful dense radiation is observed [16], [17].



a)



b)

Fig. 6. Photos of high-current discharge of MPC taken with the use of ultraviolet filters: UVG-6 (a); UVG-8 (b)

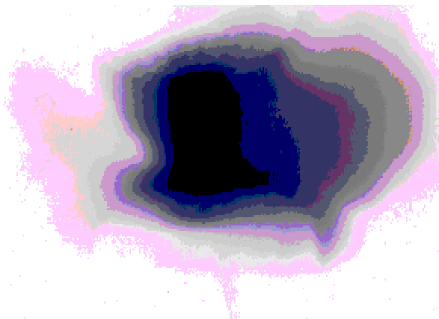
In the visible range of the spectrum, the MPC discharge has the form (Fig. 7) when using optical filters of DG-2 types "Fig. 7, a" and YGG-17 "Fig. 7, b" (DG - abbreviation dark glass, YGG – yellow- green table).

The highest-temperature discharge zone is localized near the end of the central electrode and it is spindle-shaped, which is peculiar to plasma focus formation. Moreover, the discharge is accompanied by the powerful blast wave at the end of plasma accelerator and intensive sound wave which is typical for powerful electric discharge [13].

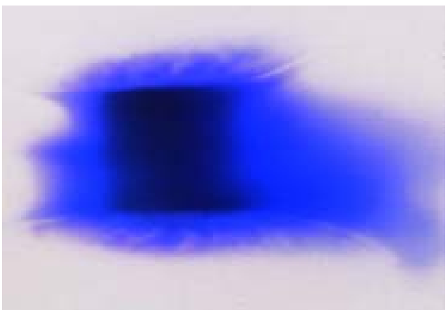
The described effect allows calculating the weight of plasma which is involved in the processes of compression and radiation. By means of weighing the dielectric bushing before and after the 50^{th} operation of MPC in the optimal mode (C_Σ=288 μF; U=3 kV), the measurement of the plasma-forming substance gave, as a result, approximately 0.5 mg/pulse.

IV. The Experimental Result of Bactericidal Effect of Pulsed UV Radiation on Koch's Bacillus

The pulse sterilizer contains a magneto-plasma compressor of the open type that allows saving in the spectrum of radiation the part of hard ultraviolet (UV) which is most harmful



a)



b)

Fig. 7. Photos of high-current discharge of MPC taken with the use of visible spectrum filters: DG-2 (a); YGG-17 (b)

to bacteria. The quantity characterizing bactericidal radiation is a bactericidal flow. The value of bactericidal flow $\Phi_{\hat{a}\chi}$ (W) can be calculated taking into account the relative spectral bactericidal efficacy by the formula [5]:

$$\hat{O}_{\hat{a}\chi} = \Delta\lambda \sum_{205}^{315} \Phi_{\lambda} S(\lambda), \quad (5)$$

where 205 - 315 – the range of wavelengths of bactericidal radiation, nm; Φ_{χ} – the value of the spectral density of the radiation flow, W/nm; S(λ) – the value of relative spectral bactericidal efficacy; Δλ – width of spectral addition intervals, nm.

The effectiveness of exposure of microorganisms to radiation, or bactericidal (antimicrobial) efficacy, is the level of reduction of microbial contamination of the air or any surface after its exposure to ultraviolet radiation. This value is calculated as a percentage – the ratio of the number of dead microorganisms to their initial number before exposing to radiation. Bactericidal efficacy mainly depends on the radiation dose [13], [15]:

$$D_{UV} = I \cdot t, \quad (6)$$

where I – the average intensity of radiation; t – the time of exposure, s.

The intensity of UV radiation of a magneto-plasma compressor is calculated as follows:

$$D_{UV} = \frac{W}{4\pi r^2}, \quad (7)$$

where W – the power of bactericidal UV radiation, W/m^2; r – distance along the normal from the middle of the emitter to the calculation point, m;

The survival rate of microbial colonies exposed to bactericidal radiation is exponentially dose-dependent:

$$S = e^{kD_{UV}}, \quad (8)$$

where k – decontamination (inactivation) constant, depending on a certain type of microbial colonies.

The study of the bactericidal effect of pulsed ultraviolet radiation of high power created by a magneto-plasma compressor was carried out by exposing the Koch's bacteria (tubercle bacillus) to this type of radiation. In this case, the dose equal to the total density of UV radiation energy $D=nW_n$ was determined by the number of discharges of the pulse sterilizer, since the density of the radiation energy in the pulse did not change.

To research the bactericidal effect produced by high-power pulsed UV radiation on tubercle bacillus an impulse sterilizer was put into an aluminum container, the size of which also allowed placing Petri dishes with test objects. Aluminum easily reflects UV radiation facilitating more effective irradiation of bacteria due to repeated wave reflection inside the container.

The daily bacterial culture was spread on the agar surface in Petri dishes and then the dishes were placed on the side surface of the container.

After irradiation, Petri dishes with the samples were closed in the container and sent to a medical laboratory to undergo microbiological analysis. The exposed samples were incubated in a thermostat for 24 hours at a temperature of 37 °C.

The results of the analysis showed that at $n = 10$ the growth of the colonies was not observed in the Petri dish. It testifies to the fact that pulsed UV radiation of such a dose has a bactericidal effect and leads to 100% destruction of tubercle bacillus. The graph of the dependence of the number *(N)* of tubercle bacillus colonies that survived after the experiment upon the radiation dose is shown in "Fig. 8".

To compare the effectiveness of the developed impulse sterilizer model, experimental sterilization of tubercle bacillus was carried out using a 230-Watt mercury lamp of a DRT-230 type. Experiments showed that the effect equal to 10 discharges of impulse sterilizer may be obtained at an exposure time of about 800 seconds. Total electricity consumption is $Wcons$=230·800=184 kJ. Electricity consumption in case of MPC use is defined by the values n, C, U_N. At n =10, $C \leq 300$ mF, U_N =3 kVt we obtain W=13.5 kJ. This implies that a 10-fold gain in energy consumption is achieved using the MPC.

Thus, the use of the impulse sterilizer developed by the authors can several times reduce the amount of electricity consumption. When using the proposed sterilizer for bactericidal processing of objects of different physical nature, there is no need to solve environmental problems associated with exploitation of mercury UV radiation sources. Moreover, pulsed UV radiation generated by impulse sterilizer does not cause any side-effects, except for creating some concentration of ozone in the atmosphere, which in its turn, is an additional sterilizing factor.

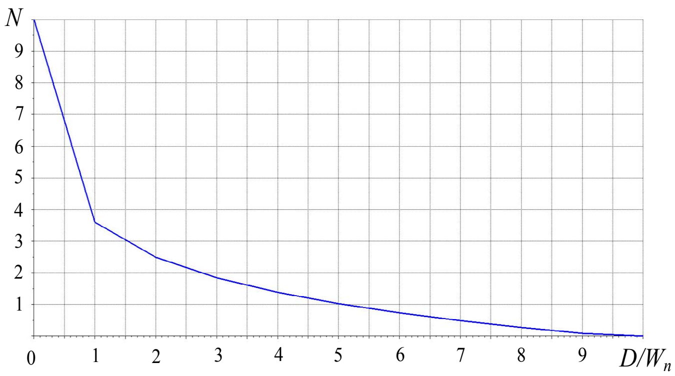


Fig. 8. The graph of the dependence of the number (N) of tubercle bacillus colonies that survived upon the radiation dose

V. Conclusion

In this paper, the authors have proposed a new technology of bactericidal and sterilizing processing of Koch's Bacillus on the basis of pulsed electromagnetic radiation, which is provided by the modern pulse sterilizer developed by the authors. It has been shown that a perspective method of limiting parasitic inductance of the discharge circuit consists in the implementation of the bus-less circuit connecting the elements of the power module and emitter. At the same time, using the open-type magneto-plasma compressor in the developed sterilizer [18], it is possible to maintain in the spectrum of radiation a part of hard ultraviolet that is the most harmful to microorganisms. This allows effective suppression of the most dangerous microorganisms, such as Koch's bacillus and others.

The conducted research of the bactericidal effect of pulsed ultraviolet radiation emitted from the sterilizer on tubercle bacillus showed that at the number of discharges n = 10 of the pulse sterilizer, 100% destruction of Koch's bacillus was achieved. In addition, at the expense of the efficiency factor of the pulse emitter, which is 70% (7.4% for UV), it was possible to significantly reduce (up to 10 times) the time of ultraviolet radiation and considerably reduce energy costs.

Thus, the investigation of the effect of pulsed UV radiation with a wide spectrum ($0.12 < \lambda < 0.3$) and a power from 2.5 to 3 MW on microbiological objects has shown: the increase in the intensity of radiation provides more effective than the typical sources of UV radiation (mercury lamps), sterilization at significantly lower doses of UV radiation.

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