https://doi.org/10.46813/2023-148-141

DEVELOPMENT OF MICROPROCESSOR BASED CONTROL SYSTEM FOR LOW-TEMPERATURE PLASMA STERILIZER WITH ULTRASONIC CAVITATION

G.P. Opaleva[1], I.E. Garkusha[1,2], A.V. Taran[1], S.P. Gubarev[1], M.I. Zolototrubova[1], V.A. Makhlai[1], P.M. Vorontsov[3], Yu.P. Gnidenko[2]

[1]National Science Center "Kharkov Institute of Physics and Technology", Kharkiv, Ukraine;
[2]V.N. Karazin Kharkiv National University, Kharkiv, Ukraine;
[3]Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv, Ukraine
E-mail: avtaran@ukr.net

The programmable controller for ozone-plasma sterilizer for programmatic operation of the units and continuous monitoring of the sterilization process has been developed. The design of the controller is based on the model of the PIC18F series microcontroller of the XLP family. The software that ensures the operation of the plasma sterilizer (control and monitoring of parameters) is written in a specialized C++ software in the MPLAB IDE processing environment under the Windows 10 operating system.

PACS: 52.70.Ds; 52.70Kz

INTRODUCTION

In the conditions of russian aggression, as well as appeared pandemics, like COVID-19, there is an urgent need to develop modern methods of cold sterilization. Among these methods, one of the most prospective is the technology of low-temperature plasma sterilization [1 - 4]. The use of plasma sterilizers significantly reduces the time (up to 20…30 min) for sterilization of medical instruments. It is also important to avoid using high temperatures [5 - 7]. Cold sterilization using the novel plasma technologies is promised to be a very safe and efficient method of sterilization and disinfection.

Plasma sterilizer is a complex device, which includes a number of blocks and units. An important factor is the optimization of the design of each developed element. Considering the complexity of the device and the interaction of their individual units and blocks, the need for their intelligent control and monitoring in an automated mode becomes obvious. The listed requirements can be implemented by using a high-performance integrated single-chip microcontroller as the basis of the developed sterilizer program control device. Today, such controllers include products of world leaders in the production of integrated microcontrollers under the trademark STM and Microchip Technology Inc (USA).

The aim of the present research is to develop a programmable controller for ozone-plasma sterilizer with a dielectric barrier discharge reactor. In addition, it is necessary to control the ultrasonic cleaning equipment and ensure the control of the operation of the sterilizer units in automated mode.

1. EXPERIMENTAL SETUP

The plasma sterilizer itself is designed for low-temperature pre-sterilization cleaning and sterilization of surgical and dental instruments, as well as products made of plastic and other non-heat-resistant materials. Sterilization of the processed material is carried out in a sealed bath with built-in ultrasonic emitters, in circulating distilled water saturated with ozone.

In order to optimize the design of the ozone reactor and to test blocks and units of plasma sterilizer, a software and hardware complex for diagnosing ozone sterilizers was developed and installed. With the help of modernized testing line based on CAMAC platform; optimal technical solutions are developed for correct operation of the sterilizer being developed (Fig. 1).

Fig. 1. Modernized testing line based on CAMAC platform

Fig. 2 shows a front pannel of the sterilizer. Below are some technical characteristics of the sterilizer: chamber volume – 2.5 l, ozone concentration in the air mixture (minimum) – 22 mg/l, ozone concentration in water (minimum) – 6 mg/l, ultrasonic generator power – (50) W, air consumption – 0.2 l/min. sterilization operating temperature – 5…28ºC, maximum sterilization cycle time – unlimited, rated supply voltage – 220 V ± 10%, power consumption 190 W, operating time at maximum humidity 98% – 200 h, dryer recovery time (option) – no more than 8 h. The block diagram of the sterilizer is shown in Fig. 3.

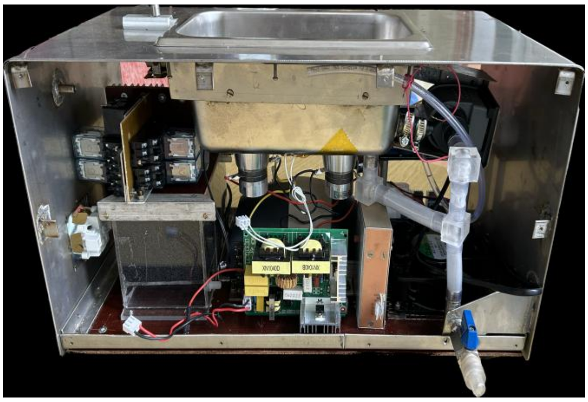

Fig. 2. Plasma sterilizer (front panel)

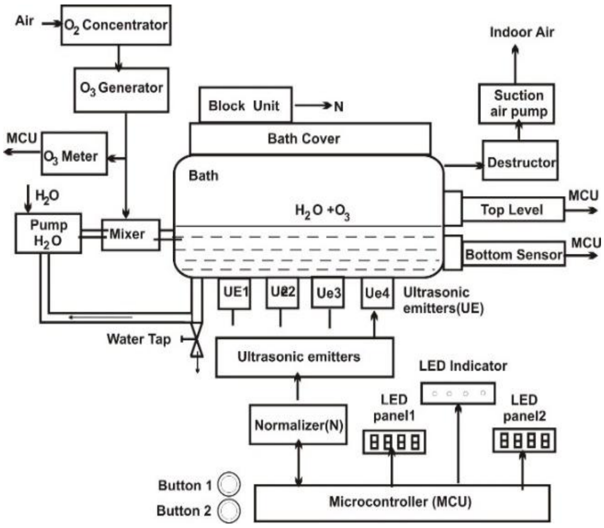

Fig. 3. The block diagram of the sterilizer

The sterilization process takes place in an ultrasonic bath with distilled water saturated with ozone. The combined action of ozone and ultrasonic cavitation significantly increases the efficiency of sterilization of products. Water cooling contributes to higher ozone concentrations.

2. RESULTS AND DISCUSSION

The programmable controller must ensure that the sterilizer performs the operations protocol for a specific scenario and material. In this case, the controller must ensure the implementation of the following functions:

- setting the parameters of the sterilizer operation algorithm;
- setting the parameters of ultrasonic treatment;
- setting the parameters of the required ozone concentration;
- setting the system purge time;
- operational control and management of the technological process in an automated mode, including indication of current modes;
- cyclic reading of meters, data processing;
- implementation of the necessary blocking;
- process completion signaling;
- giving an alarm signal in case of an emergency situation;
- ensuring the operation of the sterilizer in a remote mode in the event of a possible short-term evacuation of service personnel (for example, in connection with civil defense activities);
- the possibility of forming an archive of technological processes and an event log.

The design of the controller is based on the model of the PIC18F series microcontroller of the XLP family. A distinctive feature of this family with a sufficiently high performance is low power consumption. This makes it possible to consider the development of a non-volatile controller option as an option, taking into account the real situation with the power supply. In cases of a temporary power outage, the controller stores the current process parameters in memory. When the power supply is restored, the current situation is analyzed and the suspended technological process is resumed according to the optimal algorithm.

The microprocessor controller of the ozone sterilizer structurally consists of a control board, an indication panel and a stabilized DC power supply. The control board contains: an integrated microcontroller, a quartz oscillator, a stabilizer, a matching device, an optical isolation device, controls, a sound piezo emitter, internal and external connectors, a programming connector, a COM-port connector. On the indication panel there are: two 4-decade 7-segment LED indicators, – 4-discrete LED indicators. Discrete LED indicators visualize the current state of the sterilization process: ozone generation, ultrasonic cleaning, water pumping, air purge. One of the 4-decade 7-segment LED indicators shows the current time of the sterilization process in a countdown. The second is the time of ozone generation, ultrasonic cleaning or air purge according to the LED indicators. There is an option to connect a 2-line LCD alphanumeric display instead of two 7-segment LED panels.

The power supply of the ozone sterilizer controller is carried out from a separate stabilized voltage source +5 V. The power supply of the stabilized voltage source is carried out from the AC network with a voltage of 220 V 50 Hz. Power consumption is less than 5 W.

When developing a controller for a plasma sterilizer, it is necessary to take into account the main features of the operation of a sterilizer with a dielectric barrier discharge reactor:

- the duration of the sterilization process – up to 90 min;
- periodic switching on and off of ultrasonic emitters;
- the ability to adjust the duty cycle of switching on and off ultrasonic emitters;
- the ability to adjust the time of blowing the ozone-air mixture through the destructor;
- activation of the sound alarm.

An audible alarm notifies the completion of the sterilization process or the occurrence of an emergency situation. The block diagram of the microprocessor controller of the plasma sterilizer is shown in Fig. 4.

All processes in the sterilizer are controlled by a microprocessor module implemented on the basis of an integrated single-chip microcontroller PIC18F46K20. The microprocessor is clocked by the built-in programmable generator Oscillator Module. The indication panel (Indicator Panel) reflects the current operating modes of the sterilizer.

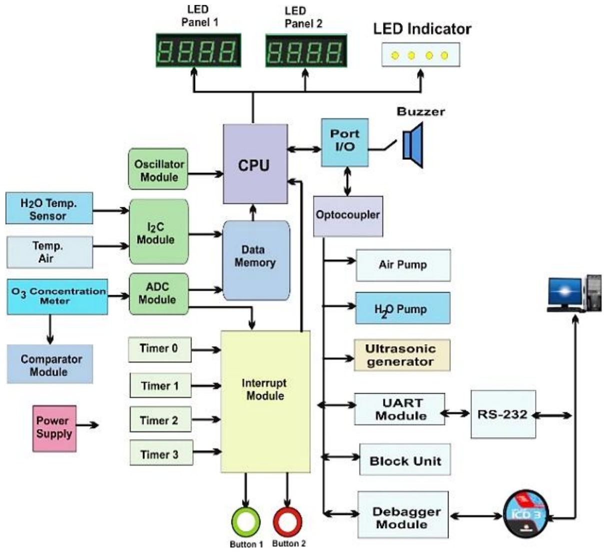

Fig. 4. The block diagram of the microcontroller

Pressing the "Power" button turns on the power supply that supplies voltage to the controller and the cooling fans of the ozone reactor. Using the buttons "1" ("Parameter setting") and "2" ("Process"), the required operating modes are set and the sterilizer is controlled.

Pressing button "1" starts the sterilizer program. From the Data Memory module, pre-set parameters for the upcoming sterilization process are read. The Top Water Level / Bottom Water Level sensors are interrogated and the required level of distilled water in the bath is checked. If it is lacking, the Buzzer piezo emitter sounds an audible signal and displays the flashing information "H_2O" on the LED Panel.

The Block Unit bathroom lid lock is switched on. The suction air pump turns on Suction Air Pump. Power is supplied to the external oxygen concentrator. By pressing the button "2" the ozone generator Ozone Generator turns on. The generator operation parameters are set before the start of the process programmatically using the interactive menu. The current ozonation time is displayed on LED Panel 1 in a countdown format.

The oxygen-air mixture from an external oxygen concentrator enters the generator, where part of the oxygen in the air is converted into ozone in a barrier discharge. From the generator, the ozone-air mixture is fed into the mixer, where the water is saturated with ozone.

Simultaneously with the Ozone Generator, the H_2O water pump is turned on. In the Mixer unit, the ozone-containing air flow from the ozone generator is mixed with distilled water. Then the ozonated water enters the bath. The pump ensures constant circulation of the resulting mixture through the bath with the material to be processed.

Simultaneously with the Ozone Generator, the Ultrasonic Generator ultrasonic cleaning system starts to work. Four Ultrasonic Emitters are connected to the output of this generator.

Under the action of ultrasonic cavitation, the processed material is cleaned and the ozonated water is actively mixed, which contributes to the penetration of ozone into narrow cavities of the sterilized products. The effect of ultrasound causes the water to heat up. To prevent the decrease in the ozone concentration in the water, the controller periodically turns off the ultrasonic emitters when the water temperature reaches the upper set limit. Periodic switching on and off of the ultrasonic emitter according to the selected program occurs until the end of sterilization. The current ultrasonic cleaning process time is displayed on the LED Panel 2 in a countdown format.

After the set sterilization time has elapsed, the generator power supply is turned off and ozone generation stops. The timed by the controller process of purging the remaining ozone from the bath begins. The purge time is displayed on the LED Panel 2. The ozone-air mixture, with a constantly decreasing ozone concentration, enters the destructor, where ozone decomposes. The end of the sterilization process occurs at the command of the microcontroller timer programmatically. After the end of the purge of the bath, an audible alarm is activated, announcing the end of work. The corresponding message "End" is displayed on LED Panel 2.

Using the UART microcontroller module and the MAX232 serial integrated driver, a COM port is implemented that supports the exchange protocol and the RS-232 interface. At the end of the complete sterilization cycle, at the command of the microcontroller, the entire array of data characterizing the sterilization process carried out is automatically sent via the serial RS-232 interface to the local network computer to document the sterilization sessions with their certification. The possibility of forming a log of emergency situations is provided.

The microcontroller is equipped with a Debugger Module, an in-circuit programming module that allows you to write programs to the controller's memory and edit them through an external connector without opening the device. For these purposes, the ICD-3 programmer-debugger (Microchip Co.) is used.

Fig. 5. Programmer (top) and printed circuit board with microcontroller (bottom)

Fig. 5 shows the programmer and the mounted printed circuit board of the microcontroller control unit. The software that ensures the operation of the ozone sterilizer (control and monitoring of parameters) is written in a specialized C++ software in the MPLAB IDE processing environment under the Windows 10 operating system.

In order to increase the convenience of using the sterilizer and improve safety, it is planned to equip the control controller with a wireless interface and a meter for the maximum allowable ozone concentration in the working room. Such refinement will help to minimize the time spent by operational personnel in the zone of potential risk associated with the aggressive environment of the generated ozone.

CONCLUSIONS

The developed microprocessor device based on a high-speed integrated microcontroller allows carrying out a stable regulated technological monitoring of ozone sterilization in accordance with the entered program. With the help of a microprocessor controller, operational control of the operation of the ozone sterilizer units and control of the necessary parameters is provided.

Software development and debugging tools are available from open sources from the manufacturer of integrated microcontrollers (Microchip Technology Inc.). This allows to quickly edit the developed application software and adapt the operation of the ozone sterilizer to the actual conditions of the process.

ACKNOWLEDGEMENTS

The research was supported by the National Research Foundation of Ukraine "Science for the Recovery of Ukraine in the War and Post-War Periods", Grant № 2022.01/0001. Three members of the team of authors are grateful to the Simons Foundation Program: Presidential Discretionary-Ukraine Support Grants, Award № 1030288.

REFERENCES

1. A. Sakudo, Y. Yagyu, T. Onodera. Disinfection and Sterilization Using Plasma Technology: Fundamentals and Future Perspectives for Biological Applications // *Int. J. Mol. Sci.* 2019, v. 20, issue 20, p. 5216. doi: 10.3390/ijms20205216.
2. V. Taran, I. Garkusha, Yu. Gnidenko, V. Krasnyj, A. Lozina, A. Taran, O. Chechelnitskyi, V. Starikov, S. Starikova. Portable ozone sterilization device with mechanical and ultrasonic cleaning units for dentistry // *Review of Scientific Instruments*. 2000, v. 91, p. 084105. https://doi.org/10.1063/1.5145279.
3. K.K. Jyoti, A.B. Pandit. Ozone and cavitation for water disinfection // *Biochemical Engineering Journal*. 2004, v. 18 (1), p. 9-19. doi: 10.1016/S1369-703X(03)00116-5.
4. V.S. Taran, I.E. Garkusha, V.V. Krasnyj, A.S. Lozina, A.V. Taran, V.V. Starikov, S. Starikova. Ozone sterilization system for processing of small-sized dental instruments // *Journal of Biological Physics and Chemistry*. 2020, v. 20, p. 86-88.
5. A.S. Lozina, I.E. Garkusha, A.V. Taran, A.V. Klosovskij, O.G. Chechelnitckij. Evaluation of ozone generation in surface dielectric barrier discharge with pulsed power supply // *High Temperature Material Processes.* 2021, v. 25, 2, p. 9-16
6. A.S. Lozina, I.E. Garkusha, A.V. Taran, O.G. Chechelnitskij, P. Vorontsov, Y. Gnidenko, S.A. Shypilov, I.N. Bolduriev. Multifunctional DBD Based Ozone Sterilizer with Ultrasonic Cavitation for Low Temperature Treatment of Medical Tools // *Plasma Medicine*. 2021, v. 11 (2), p. 55-61.
7. V.S. Taran, V.V. Krasnyj, A.S. Lozina, A.V. Schebetun. Devices for pre-sterilization treatment of endoscopes by ozone and ultrasound // *Problems of Atomic Science and Technology. Series "Plasma Physics".* 2014, № 6, p. 230-232.

Article received 17.09.2023.

РОЗРОБКА МІКРОПРОЦЕСОРНОЇ СИСТЕМИ КЕРУВАННЯ НИЗЬКОТЕМПЕРАТУРНИМ ПЛАЗМОВИМ СТЕРИЛІЗАТОРОМ З УЛЬТРАЗВУКОВОЮ КАВІТАЦІЄЮ

Г.П. Опалева, І.Є. Гаркуша, А.В. Таран, С.П. Губарєв, М.І. Золототрубова, В.О. Махлай, П.М. Воронцов, Ю.П. Гніденко

Розроблено програмований контролер озоноплазмового стерилізатора для автоматичної роботи вузлів і постійного моніторингу процесу стерилізації. Конструкція контролера базується на моделі серії PIC18F сімейства XLP. Програмне забезпечення для роботи плазмового стерилізатора (контроль і моніторинг параметрів) написано на спеціалізованій мові C++ у середовищі обробки MPLAB IDE під управлінням операційної системи Windows 10.