

System for Flow Rate Regulation with Pulse-Width Modulation

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Abstract — In article describes the concept of the flow control system for ozone-oxygen mixture, using the principles of pulse-width modulation. The basic equation for calculation of the system measurement channel are given. Experimental studies of such air channel system and its performance characteristics are describes. The possibility of using flow control system ozone-oxygen mixture in medical ozone is shown.

Keyword — control system, discharge chamber, flowrate control, ozone generator, pulse-width modulation.

I. INTRODUCTION

The method of ozone-oxygen mixture (OOM) medical application is named the ozonotherapy. This method is widely use in surgery, urology, gynecology, dermatology, dentistry, venereology, otolaryngology, pulmonology, etc. It can be used in stationary clinics, hospitals, home health care [1-4]. All this terms imposes specific requirements for medical ozone generators: universality, reliability in continuous operation, the ability to work from a variety of oxygen sources.

Efficiency of the procedures to this method strongly depends on the dosage effects, which is determined by the concentration of ozone in the OOM and its flow rate. In this case the therapy impact can be carried out by the parenteral ozonization, distilled water, saline or oil. Today at prevailing medical-technical requirements regulating range of ozone concentration in OOM is from 0,1 to 80 mg/l with error not exceeding 10 %, the range of flow control OOM is 0,1 to 1 l/min at 10 % error.

In modern medical ozonators the ozone is produced by electrophysical method using volume barrier discharge. Problem of precise adjustment of ozone produced in this way is the subject of numerous papers [5, 6].

Gas flow or volumetric flow rate of OOM in medical ozonator can be regulating in different ways [7]. For this purpose are used valve systems, reducer of the pressure, and control system with a discrete set of apertures.

One of the advanced directions in the regulation of the flow of OOM is to use the method, based on the pulse-width modulation of the gas flow in the pneumatic path of ozonator. This system has a low weight, dimensions and cost parameters at high precision adjustment [8].

The aim of this work is a theoretical justification for using the method of pulse-width modulation of the gas flow in the medical

ozonator, development construction principles of the system automatically controlling the flow of OOM using this method.

II. FLOW CONTROL SYSTEM

The developed scheme of pneumatic control system tract with control system is shown on Fig. 1. The input to pneumatic tract oxygen is supplied from an oxygen gas bottle or oxygen network of medical institutions. To reduce the pressure of oxygen to the operating value and its stabilization in the pneumatic tract used pressure regulator (PR). However the point of stabilization of pressure is strongly dependent on the rate of gas flowing through it, especially for flow regulating the method with the use of the pulse-width modulation. When turning the electro-magnetic valve (EMV) flow rate varies from zero to full open state, and hence the value of point stabilization of pressure also varies.

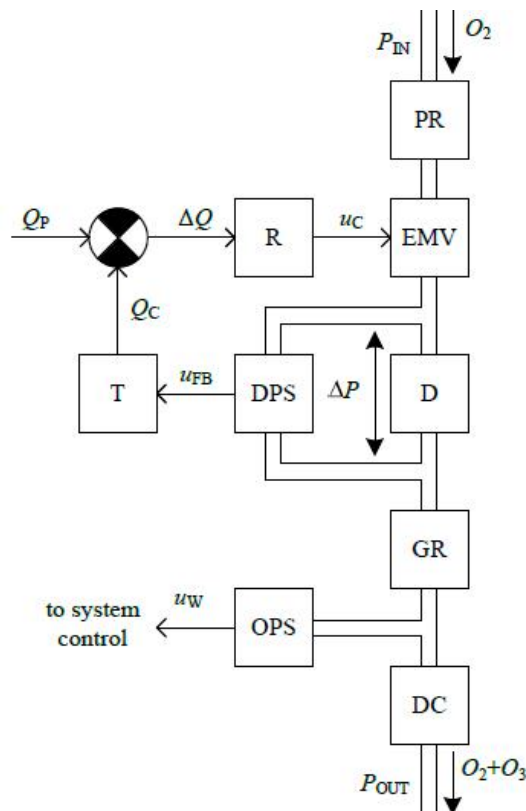


Fig. 1. Scheme of pneumatic control system tract with control system.

PR output connected to EMV, through which performed the pulse-width modulation of the flow of oxygen. Pulse widths into control signal formed by regulator (R) for each period of the PWM. Pulse width values are calculated based on setting signal Q_p and feedback (coming from the transducer (T)).

The process of measuring oxygen flow rate based on the measurement of differential pressure ΔP on the diaphragm (D), representing the narrowing device. Value of the differential pressure ΔP detects the differential pressure sensor (DPS), which is connected between the input and output D. In pneumatic tract diaphragm installed immediately after the EMV, and mounted on a "pneumatic island".

The dependence of flow rate Q on the differential pressure ΔP at the diaphragm, in the pulse-width modulation mode is determined by the equation [9]:

$$Q = \alpha \cdot \varepsilon \cdot S \sqrt{\frac{2}{\rho} \cdot \Delta P}, \quad (1)$$

where α – expansion coefficient of oxygen during the diaphragm; ε – flow coefficient; S – area aperture of a diaphragm; ρ – oxygen density.

Volume pulses of gas supplied to the gas receiver (GR), which smooth out pulsations the flow. Gas receiver is connected to the input of the discharge chamber (DC), wherein the ozone is synthesized directly. Exit discharge chamber is actually output ozonator that connects to the pneumatic load(L). Status monitoring pneumatic tract during its operation to the load carried out by overpressure sensors (OPS). Sensor is set on abstraction between the gas receiver and discharge chamber, which can detect breakage and block load. Warning signal u_w transmit to the control system for further processing.

III. RESEARCH AND DISCUSSION

For providing research was assembled test unit which composed: a pneumatic tract (PT), a gas bottle (GB) with compressed air, reducer, rheometer (R) control gas flow, various types of loads (L) and microprocessor system control (MSC) (Fig.2).

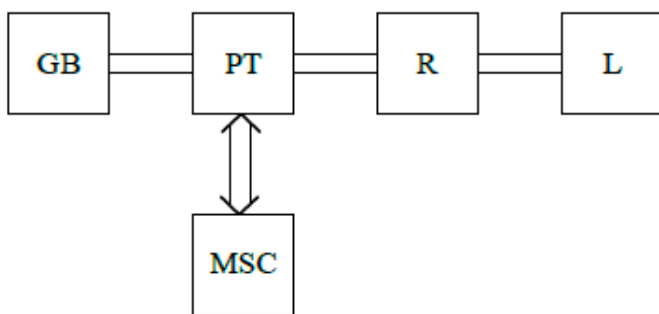


Fig. 2. Pneumatic tract test unit.

Elements of the test unit connected by plastic tubes. As the load of the pneumatic tract perform bottle with saline for bubbling, and the connection path of varying lengths. Perturbing factors which influence the pneumatic tract are pressure change P_{IN} at the entrance of pneumatic tract and load pneumatic

resistance. Changes of these parameters have a direct impact on flow rate value of gas through the pneumatic tract. Revealing character the effect of changes disturbing factors on the flow rate was carried out without feedback signal. Filed reference signal value $Q_p = 1,0$ l/min at the input of the regulator converted to pulse width τ_1 . The reaction of changes the flow rate per pulse PWM is shown in Fig. 3.

Due to inertia of EMV flow changing, which proportional to the differential pressure at the diaphragm, flow controlling by PWM will have a shape different from that of the control pulses u_c (Fig. 3).

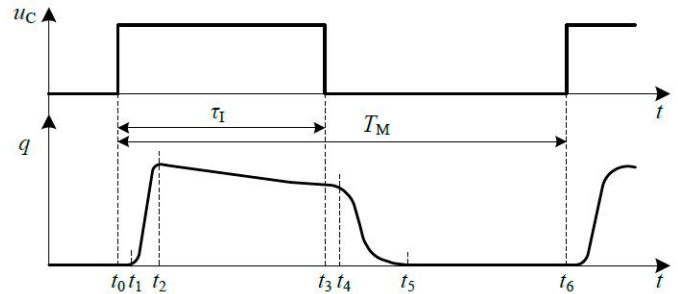


Fig. 3. The reaction of changes the flow rate per pulse PWM.

Forming the wave front τ_1 at the moment t_0 EMV stays closed for a further time interval until the moment t_1 , when the value of the magnetic induction will be sufficient for opening the EMV. On the interval t_1-t_2 the valve opens, which leads to increased flow through the pneumatic channel. Interval t_2-t_3 corresponds to the open state of the valve, but the gas flow rate is not constant, it decreases as the pressure equalization between the inlet and the outlet of the diaphragm.

At the time of forming the cutoff of pulse τ_1 (Fig. 3 moment of time t_3) appears self-induction EMF, which maintains the open state EMV until moment of time t_4 . On the time interval t_4-t_5 valve closes and the flow of gas through it completely stops.

From consideration process of formation flow follows that regulating characteristic is a nonlinear. This is caused the finite time of rise and fall flow rate when triggered EMV, as well as the duration of the time interval the open state.

For gas flow adjustment at range 0,1 – 1,0 l/min by method PWM selected f_M modulation constant frequency equal to 5 Hz. To ensure the necessary regulation accuracy of 10 % in the whole range of flow clock frequency of PWM f_{CLK} is 2 kHz.

Research results of the flow rate depending from the control pulses width τ_1 are presented graphically in Fig. 4.

Nominally regulating characteristic can be divided into four sections. Plot I (*a-b*) (minimum values of the control pulse duration) due to half-opening EMV and is characterized by high steepness depending $q(\tau_1)$. Since the EMV has a finite response time, the regulation cannot be shorter than the value a .

Plot II (*b-c*) is transitional, and its length is substantially dependent on the differential pressure at the inlet and outlet EMV.

Regulation on the plots I and II characteristics is impractical since EMV work in undesired mode, which can lead to significant deviation from the predetermined and actual flow.

Plot III (c-d) is an operating portion of the characteristic and has a linear character depending flow rate on the control pulse width.

Plot IV (d-e) indicates the mode of operation in which the EMV does not provide a complete closing the pneumatic path channel. This leads to decrease the steepness of the control characteristic. At the moment d pulse becomes equal to the period PWM and the valve remains permanently open.

Fig.4 and Fig.5 shows the regulating characteristics EMV in the system (Fig. 1) at input pressures and pneumatic loads normalized during ozone therapy procedures. Analysis of these dependences showed that the change in pressure from 150 kPa to 50 kPa at a constant control pulses width (τ_1) leads to decrease in flow rate by 65%. Changing the pneumatic load also affects the flow: connection to the long connection path (1 m) reduces flow rate by 7%, and the connection standard bottle with saline – by 17%.

Research indicates shows an exclusive need to apply automatic control systems to ensure correct gas flow values. Perturbation factors take influence both on the gas flow and the electromagnetic valve function.

Effect of perturbation factors in the pneumatic tract of on the deviation of the gas flow value is determined by the feedback signal. Signal is taken from DPS in the form of voltage level proportional to the pressure difference ΔP at the diaphragm. Changing voltage at the output of the sensor has the same character as the change in flow rate (see Fig. 2). Calculated average value of the voltage with DPS for the PWM period proportional to the average value of the differential pressure ΔP . Transducer (T) converts values of the reference and feedback based on the equation (1). Deviation of the flow rate ΔQ is defined as a difference between the current and the predetermined values. The deviation signal ΔQ supplied to the regulator for correcting the pulse width control u_C PWM (Fig. 1).

Based on feedback signal from DPS, which is proportional to the difference pressure ΔP , the average voltage during one period of the PWM is calculated. The value of the feedback signal is recorded discretely and saved in the array until the end of the period, after which calculated by the equation:

$$U_{CP} = \frac{1}{n} \cdot \sum_{i=1}^n \sqrt{U_{FB i}}, \quad (2)$$

where n – number of measurements per PWM period equal f_{CLK}/f_M .

Provide generally valid values of the current flow rate is achieved by using Q_C sampling frequency of the signal from DPS equal to PWM clock frequency. Here the value of the current flow rate is calculated in transducer by the equation:

$$Q_T = k \cdot U_{CP}, \quad (3)$$

where k – total coefficient of the constants appearing in the expression (2).

Value of the coefficient k can be assumed to be constant, but possible technological scatter in the manufacture of pneumatic tract can make significant deviations in the calculation of the current flow rate. To avoid this drawback of pneumatic tract is calibrated at $P_{IN} = 100$ kPa and the absence of resistance at the output.

In the pneumatic tract provide flow rate equal $Q = 1$ l/min and measured the average values diaphragm differential pressure. The obtained data is used for correcting of coefficient k , which is used for further calculations of the current flow rate in the transducer (T).

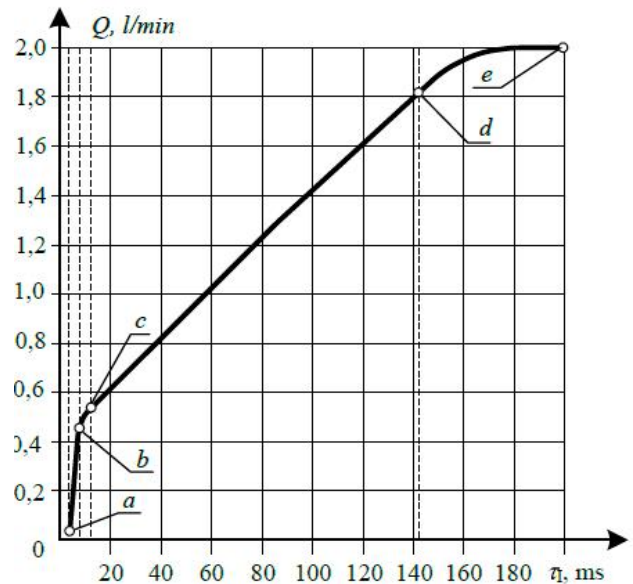


Fig. 4. Research results of the flow rate depending from the control pulses width.

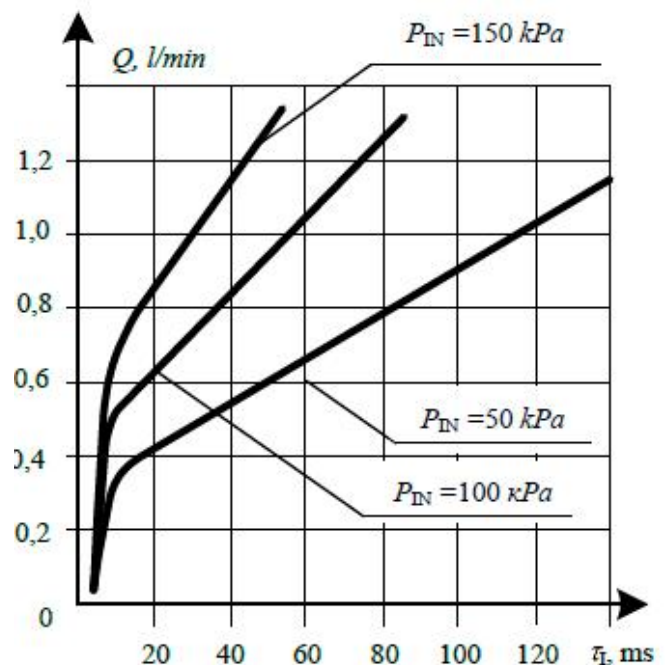


Fig. 5. The regulating characteristics EMV at various input pressures.

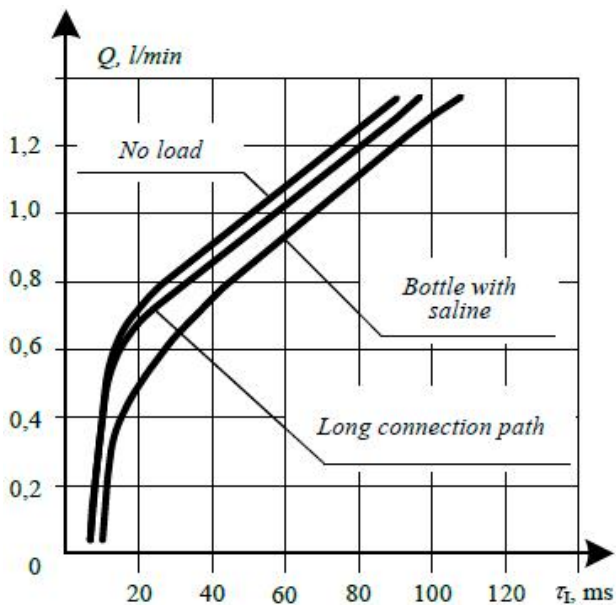


Fig. 6. The regulating characteristics EMV in the system at various load.

Research working off pneumatic tract with automatic regulation system produced at a given flow rate $Q_p = 1,0$ l/min. Changes pressure at the inlet of pneumatic tract was varied from 45 kPa to 150 kPa.

In providing research of automatic regulation system maintained the flow rate at a predetermined level. Timing diagrams feedback signal changes in one PWM period are shown in Fig. 7.

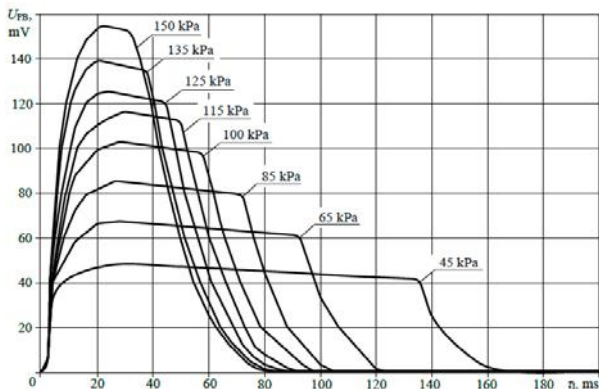


Fig. 7. Timing diagrams feedback signal changes in one PWM period.

From the graphs clearly shows that at pressure decrease of air at the inlet pneumatic tract changes duration of the interval of time the open state of EMV, thereby providing a stabilizing the air flow rate.

Results of the tract research with automatic pneumatic regulation system without load and with connected to the output the bottle with saline or distributing long tract is shown in Fig. 8.

In general obtained control characteristic has a linear character and provides flow rate regulation in whole range with deviation not more than 4,8 %.

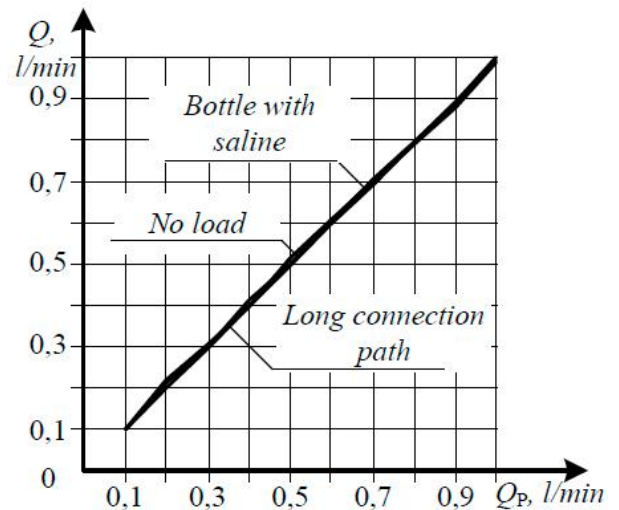


Fig. 8. Results of the tract research with automatic pneumatic regulation system.

IV. CONCLUSIONS

As a result it may be noted that the efficiency using of the method PWM for regulating flow rate of OOM in medical ozone generators has been confirmed with experimental research prototype model of the pneumatic tract with automatic control system.

Factual flow rate value of OOM did not differ from the defined, over an adjustable range, more than the allowable 10 % at the presence limit perturbations: by input (changes input pressure by $\pm 50\%$) and output deviations of the ozonator (all kinds of real pneumatic load).

REFERENCES

- [1] O.V. Maslennikov, K.N. Kontorshchikova. "Practical ozonotherapy: The Handbook". N. Novgorod: "Vector-TiS", 2003, p 52.
- [2] O.V. Maslennikov, K.N. Kontorshchikova. "Ozonotherapy: The Internal Diseases Handbook". N. Novgorod: "Vector-TiS", 2003, p 132.
- [3] G.N. Boyarinov, V.V. Sokolov. The ozonized cardiopulmonary bypass. N. Novgorod: "Pokrovka", 1999, p. 317.
- [4] A.A. Minenkov, R.M. Filimonov, V.I. Pokrovskiy. "Basic principles and tactics of ozonotherapy. The manual for doctors". Moscow: "PAIMS", 2001, p.40.
- [5] E.I. Sokol, A.V. Kipenskiy, A.A. Laschin. "About the features of controlling the concentration of ozone in medical ozone generators" // Materials of the scientific-practical conference. « New technologies of healing by preformed and natural ». Kharkiv: KMAPO, 2002, pp. 229-231.
- [6] A.V. Kipenskiy, E.I. Sokol, A.A. Laschin. "The development of medical ozone OM-80/1 and the results of its tests" // Herald of Physiotherapy and Health Resort. Evpatoria: EIRITS, 2006, № 5, pp76-78.
- [7] E.I. Sokol, A.V. Kipenskiy, V.V. Kulichenko, R.S. Tomashevskiy, T.M. Barkhotkina. "The Analysis of Technical Solutions for Medical Ozonators" // 2013 IEEE XXXIII International Scientific Conference Electronics and Nanotechnology (ELNANO). Kyiv, Ukraine, pp. 262-265, April 16-19, 2013.
- [8] A.V. Kipenskiy, V.V. Kulichenko, N.V. Mahonin. "Pneumatic electromechanical system of flow control ozone-oxygen mixture in medical ozone generator," Problems of automated electric drive. Theory and practice. Special issue, Kharkiv: NTU "KhPI", 2013, pp. 186 – 188
- [9] Krenlevskiy P.P. Flowmeters and amount counters: Directory. – 4th pub. reproc. and comp. – L.: Engineering, Leningrad. department, 1989. – p. 701.