

В ходе составления модели были учтены факторы, которые влияют на изменение температуры на выходе котла и на выходе целого участка, такие как расход газа, теплотворная способность природного газа и объемный расход воды.

2. Разработана система синхронизации работы при расположении котлов в виде условного «кольца». При таком расположении была рассмотрена ситуация, при которой подавалось возмущение в виде изменения нагрузки. В результате исследования получена реакция целой системы, с отклонением средней температуры, выдаваемое котлами в сеть, которая составляет величину, равную 0,14 °C.

#### Литература

- Boisvert, P. G. Fuel sparing: Control of industrial furnaces using process gas as supplemental fuel [Text] / P. G. Boisvert, A. Runstedtler // Applied Thermal Engineering. — 2014. — Vol. 65, № 1–2. — P. 293–298. doi:10.1016/j.applthermaleng.2013.12.047
- Davoudi, M. The major sources of gas flaring and air contamination in the natural gas processing plants: A case study [Text] / M. Davoudi, M. R. Rahimpour, S. M. Jokar, F. Nikbakht, H. Abbasfard // Journal of Natural Gas Science and Engineering. — 2013. — Vol. 13. — P. 7–19. doi:10.1016/j.jngse.2013.03.002
- Berghout, N. Techno-economic performance and challenges of applying CO<sub>2</sub> capture in the industry: A case study of five industrial plants [Text] / N. Berghout, M. van den Broek, A. Faaij // International Journal of Greenhouse Gas Control. — 2013. — Vol. 17. — P. 259–279. doi:10.1016/j.ijggc.2013.04.022
- Liu, H. Optimization of PEM fuel cell flow channel dimensions – Mathematic modeling analysis and experimental verification [Text] / H. Liu, P. Li, K. Wang // International Journal of Hydrogen Energy. — 2013. — Vol. 38, № 23. — P. 9835–9846. doi:10.1016/j.ijhydene.2013.05.159
- Tucakovic, D. Possibilities for reconstruction of existing steam boilers for the purpose of using exhaust gases from 14 MW or 17 MW gas turbine [Text] / D. Tucakovic, G. Stupar, T. Zivanovic, M. Petrovic, S. Belosevic // Applied Thermal Engineering. — 2013. — Vol. 56, № 1–2. — P. 83–90. doi:10.1016/j.applthermaleng.2013.03.028
- Rusinowski, H. Hybrid model of steam boiler [Text] / H. Rusinowski, W. Stanek // Energy. — 2010. — Vol. 35, № 2. — P. 1107–1113. doi:10.1016/j.energy.2009.06.004
- Bujak, J. Optimal control of energy losses in multi-boiler steam systems [Text] / J. Bujak // Energy. — 2009. — Vol. 34, № 9. — P. 1260–1270. doi:10.1016/j.energy.2009.05.005
- Стопакевич, А. А. Системный анализ и теория сложных систем управления [Текст] / А. А. Стопакевич. — Одесса: Астропринт, 2013. — 380 с.
- Демченко, В. А. Автоматизация и моделирование технологических процессов ТЭС и АЭС [Текст] / В. А. Демченко. — Одесса: Астропринт, 2001. — 305 с.
- Прохоренков, А. М. Параметрический синтез регуляторов теплоэнергетических объектов с использованием информационного подхода [Текст] / А. М. Прохоренков, Н. М. Качала // Вестник Мурманского государственного технического университета. — 2011. — Т. 14, № 4. — С. 704–711.

#### СИНХРОНІЗАЦІЯ ДИНАМІКИ ОДНОТИПНИХ КОТЛІВ, ЩО ПРАЦЮЮТЬ НА ЗАГАЛЬНУ МАГІСТРАЛЬ

Розроблена сучасна оптимальна система управління, яка виконує функції як синхронізації роботи котлів, так і стабілізації їх синхронної поведінки при реакції на збурення, пов'язане зі зміною навантаження споживачів. Синхронізовано три однотипних котла типу ПТВМ-50, які складають основу сучасних теплових котельень у районах міст України.

**Ключові слова:** синхронізація, однотипні котли, система управління, стабілізація, магістраль, збурення.

*Слободян Іван Васильевич, кафедра автоматизації теплоенергетических процесов, Одеський національний політехнічний університет, Україна, e-mail: vanichka2008@gmail.com.*  
*Ложечников Вадим Феликсович, кандидат технічних наук, доцент, кафедра автоматизації теплоенергетических процесов, Одеський національний політехнічний університет, Україна.*  
*Стопакевич Алексей Аркадьевич, кандидат технічних наук, доцент, кафедра автоматизації теплоенергетических процесов, Одеський національний політехнічний університет, Україна.*

*Слободян Іван Васильович, кафедра автоматизації теплоенергетических процесів, Одеський національний політехнічний університет, Україна.*  
*Ложечников Вадим Феліксович, кандидат технічних наук, доцент, кафедра автоматизації теплоенергетических процесів, Одеський національний політехнічний університет, Україна.*  
*Стопакевич Олексій Аркадійович, кандидат технічних наук, доцент, кафедра автоматизації теплоенергетических процесів, Одеський національний політехнічний університет, Україна.*

*Slobodian Ivan, Odessa National Polytechnic University, Ukraine, e-mail: vanichka2008@gmail.com.*  
*Lozhechnikov Vadim, Odessa National Polytechnic University, Ukraine.*  
*Stopakevych Oleksii, Odessa National Polytechnic University, Ukraine*

UDC 681.511.4:621.9.048.4

DOI: 10.15587/2312-8372.2016.86081

Savelenko G.,  
Ermolaev Y.,  
Yuriev V.

## OPTIMIZATION OF ARC IGNITION PROCESS FOR MACHINES OF ARC DIMENSIONAL MACHINING

*Досліджені процеси в електроерозійній камері типу АМН-1 в момент запалювання електричної дуги на верстаті розмірної обробки дугою. Наведено характер зміни тиску робочої рідини в електроерозійній камері. Запропоновано значення величини тиску, при якому системою автоматичної подачі при підведенні електрода-інструмента до заготовки забезпечується автоматична зміна швидкості з максимальної до робочої.*

**Ключові слова:** автоматична система, розмірна обробка дугою, тиск робочої рідини, швидкість подачі, електрод-інструмент, запалювання дуги.

### 1. Introduction

To improve the technical and economic indicators of machine parts production by arc dimensional machining

there are important measures to reduce production costs. This is achieved by increasing productivity and reducing production costs. Increase of dimensional machining process performance is possible not only while reducing the

machining time by creating a quasi-optimal machining regimes, but also by reducing the feed time of the electrode-tool to the workpiece. This will reduce the specific consumption of electricity for operation by reducing idling time and time of the breaks, which occur in the event of breakage of stationary arc or short circuit of arc. Also, reducing the cost of operation is possible while reducing the number of breakages or damage of the working surface of the electrode-tool.

It is known that increasing the rate of the electrode-tool in its feed to workpiece is increase the force of impact between them that occurs during arc ignition stage. The moment of arc ignition is accompanied by a sharp increase in current strength - there is a short circuit current. Since the feed systems of the electrode-tool have inertia that in the moment of arc ignition it is possible maximum shock load between the electrode and the workpiece. Damage and chipping of the working surface of the electrode-tool are usually caused by compressive force arising from shock loads that exceed the critical toughness of the electrode-tool.

Therefore, in the control systems of electrode-tool feed rate for arc ignition there are following methods:

- Feed rate is limited by automatic control system of the value, at which the shock loads on the electrode-tool will create a compressive force less then critical values.
- Feed rate relies on the experience and skills of the operator.

When using the first or second method it is important to define the moment for switching from high to working rate of the electrode-tool.

In this regard, it is actual a research aimed at finding ways to improve the automatic control system of electrode-tool feed. In developing appropriate technical solutions it is necessary to consider their use for automatic control systems with hydraulic or electromechanical drives of electrode-tool feed.

## 2. The object of research and its technological audit

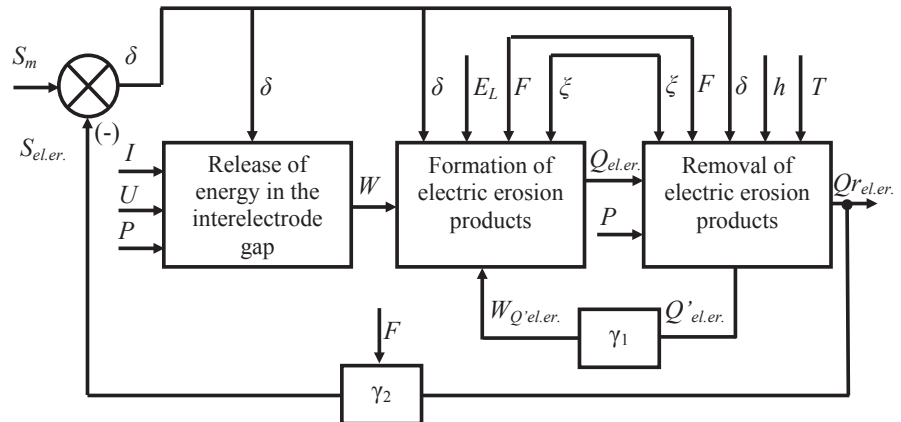
The object of this research is the process of arc dimensional machining. Dimensional machining takes place in a closed chamber during combustion of stationary electric arc between the electrode-tool and the electrode-workpiece in a transverse flow of the working fluid.

One of the problem areas in the process is to determine the value of interelectrode gap in the absence of electric arc combustion between the electrodes. Maintaining a given interelectrode gap by automatic control system of electrode-tool feed occurs after arc ignition.

The value of linear movement of the electrode-tool is used as an input parameter of control object at existing arc dimension machines. In the output of the control

object there are erosion products that are removed by working fluid.

To determine the effect of disturbing factors on the control object let's consider dimension machining that occurs in the combustion chamber during electrical arc combustion in a transverse flow of working fluid. Functional scheme of arc dimensional machining is shown in Fig. 1.



**Fig. 1.** Functional scheme of arc dimensional machining:  $S_m$  — linear electrode movement by feed drive;  $S_{el.er.}$  — the value of electric erosion of machine part;  $\delta$  — interelectrode gap;  $I$  — electric arc current;  $U$  — arc voltage;  $P$  — working fluid pressure at the inlet interelectrode gap;  $W$  — thermal energy of electric arc;  $F$  — machined area;  $E_L$  — thermal properties of electrodes;  $\xi$  — dielectric properties of the working fluid;  $h$  — the depth of machining;  $T$  — temperature of the working fluid;  $Q_{el.er.}$  — electric erosion products (process performance  $mm^3/min$ );  $Q_{r,el.er.}$  — share of removed electric erosion products;  $Q'_{el.er.}$  — share of unremoved electric erosion products;  $W_{Q'_{el.er.}}$  — thermal power input for reduction and destruction of unremoved electric erosion products;  $\gamma_1$  — feedback factor, which takes into account the thermal power input  $W_{Q'_{el.er.}}$ ;  $\gamma_2$  — feedback factor for electric erosion of the machine parts

The input values of  $I, U, P$  are the main components that characterize the thermal power  $W$ , released in interelectrode interval [1, 2]. From [1, 3] it is known that the value of arc current  $I$  characterize the quantitative component of the process (process performance), the pressure of working fluid  $P$  characterizes the qualitative component of the output products (roughness of the machined surface), and the nature of the arc voltage changes  $U$  characterizes the state of the process — its sustainability. Therefore,  $I$  and  $P$  values are set and technologically over time of machining and usually can be adjusted manually by the operator.

Interelectrode gap  $\delta$  is formed from the difference between the linear movement of the electrode-tool and linear electric erosion. The value of linear electric erosion is obtained from the value characterizing the amount of generated and removed electric erosion products that reduced to the machined area  $F$ , which reflects the feedback factor  $\gamma_2$ .

As the number of unremoved electric erosion products it is difficult to determine the state of the object and process performance. Therefore, in practice to determine the process performance, one or more process parameters are used: arc voltage, arc current, their ratio, pressure of working fluid and other.

In [1] the functional power dependence is given. It helps to determine the process productivity using parameters of arc current and pressure of the working fluid:

$$q = kI_{arc}^\alpha P_{stat}^\beta, \tag{1}$$

where  $q$  — process performance;  $k$  — dimension factor;  $I_{arc}$  — current strength of electric arc, A, limited by cross-

sectional area of the electrode-tool (given technologically), determines the machining performance and thus, in fact, reflects the quantitative side of the process;  $P_{stat}$  – flow static pressure,  $P_a$ , determines the quality of machining (roughness, depth of heat-affected zone, accuracy) and, thus, essentially reflects the qualitative aspect of the process;  $\alpha$  and  $\beta$  – exponents of power.

The size of the gap is determined by the arc voltage. The stability of the arc voltage typically determines the stability of the process. Therefore, in practice the state of arc dimensional machining is determined by the effective values of the current  $i(t)$ ,  $u(t)$ ,  $p(t)$ . They are considered as output parameters of control object, creating value of the state vector  $\dot{X}$ .

Simplified functional scheme of control object takes the form shown in Fig. 2.

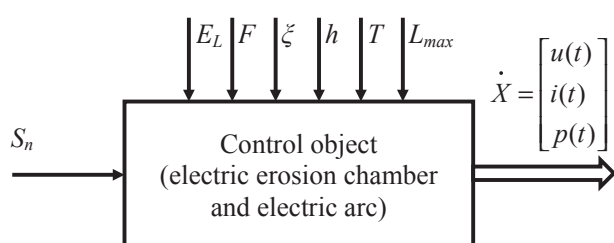


Fig. 2. Simplified functional scheme of control object:  $L_{max}$  — maximum length of the evacuation route for erosion products

The objective of the control system of considered object is the automatic selection of the feed rate, at which there is maximal machining performance while maintaining the defined quality indicators of the machine part. Since in research it is investigated only part of arc machining process, the objective of the automatic control system can be defined as automatic choice of feed rate, at which the electrode-tool feed to the electrode-workpiece is achieved in the absence of an electric arc combustion in minimum time.

The distance between the electrodes is usually not determined before arc ignition, and the state of the process is determined at the time of arc ignition by arc voltage drop of the arc source to the short circuit voltage. This situation creates uncertainty of electrode-tool position toward the electrode-workpiece. Increase of the electrode-tool feed rate leads to time reduction for electrode feed, which is especially important for electromechanical feed systems, but the shock increase on the working surface of the electrode-tool is increased.

The process scheme is shown in Fig. 3.

The scheme works as follows. Working fluid 14 through pipeline 13 is pumped by hydraulic pump 11 in the electric erosion chamber 6. Through the front interelectrode gap in the direction from the periphery to the center of the electrode-tool 5 working fluid is removed through the central channel of the electrode-tool. After checking the sealing of electric erosion chamber, a voltage is applied from the source 4 to the electrode-tool and electrode-workpiece 7.

Automatic control system 3 after voltage appearing on the interelectrode gap is driven the mismatch error between task voltage and arc voltage and control of electric motor operation 2, which using mechanical feed part 1 moves the electrode-tool. Moving electrode-tool decreases interelec-

trode gap to zero, i.e. electrode-tool touches the electrode-workpiece. This changes the voltage in interelectrode gap from the voltage of power supply idling to short circuit voltage. The automatic feed control system commands to the lift of the electrode-tool from the workpiece. During the lift of the electrode-tool interelectrode gap is created, in which electric arc is ignited. Its length is further supported at a given level by changing the feed rate of the electrode-tool. Overpressure of working fluid is created in the chamber due to the hydrodynamic resistance in the interelectrode gap. The pressure in the chamber is controlled by a pressure gauge 8 and is regulated by the valve 10, which returns excess of working fluid into the reservoir 15. Working fluid removes erosion products form interelectrode gap, which then accumulate in the filter 9, and working fluid is drained into the reservoir 15.

Usually, visual observation of the object is conducted, using the instrument by parameters: arc current and arc voltage, pressure of working fluid in the chamber, depth of immersion of the electrode-tool in the electrode-workpiece.

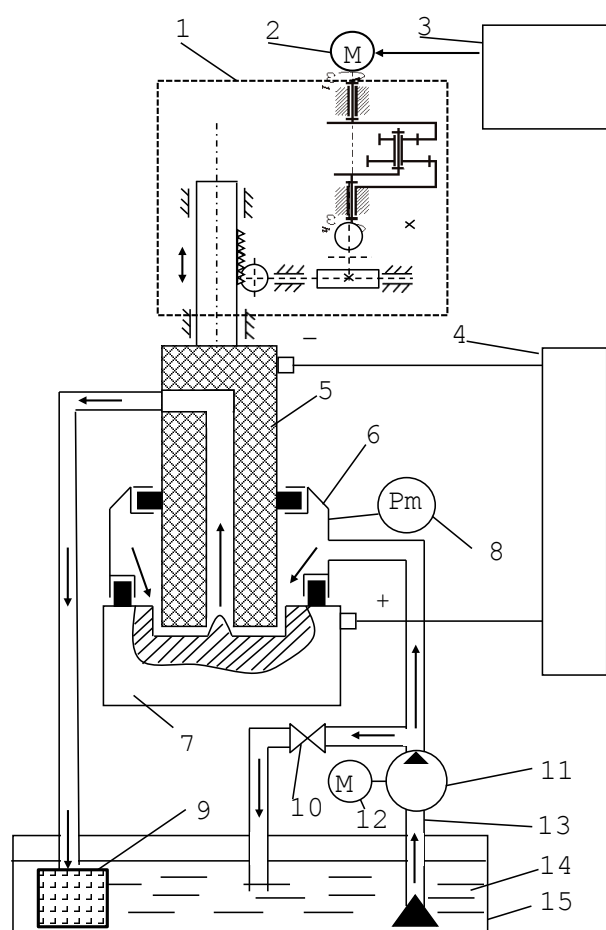


Fig. 3. Process scheme of arc dimensional machining

Automatic feed system of existing dimensional machines like «ARC» stabilizes parameter: arc voltage. Operator observes other above-mentioned parameters. Operator changes automatic feed system, which, in turn, affects the machining. Therefore, the main direction of control process improvement is to reduce the subjective effects (qualifications and experience of the operator) for machining of the machine parts. The most important should be considered

the automation of operations assigned to the operator. This will increase the efficiency of the process as a whole and reduce the operator load.

### 3. The aim and objectives of research

*The aim of research* — to optimize the process of electrode-tool feed rate at the arc ignition and, thus, reduce shock loads to the electrode-tool. This will reduce time of technological operations and reduce the damage likelihood of the working surface of the electrode-tool.

To achieve this aim it is necessary:

1. Set the technological parameters, by which it is advisable to control feed rate of the electrode-tool until the arc ignition.
2. Determine the limiting value of the selected process parameter, which determine changes of the feed rate.
3. Formulate optimality criterion of arc ignition process on the machines for arc dimensional machining.

### 4. Literature review

The process of arc dimensional machining (ADM) as a means of electrical discharge machining (EDM) is introduced and developed in the laboratory «Arc dimensional machining» with the assistance of the departments «Metal forming and special technology» and «Automation of technological processes» of Central Ukrainian National Technical University (Kropyvnytskyi, Ukraine). So the most of scientific papers on the technological features of this method and its automation are written by scientists of this University [1–10], but issues of this study aren't considered in periodicals. This is due to the specific of machining method in relation to other forms of electrical discharge machining, including:

- Working fluid is pumped in a sealed electric erosion chamber and removed through a technological channel of the electrode-tool. Channel is created so that the electric arc burns in a transverse flow of working fluid.
- Electric arc is powered by a power source with sharply falling current-voltage characteristics.
- Stationary electric arc burns during machining.

In scientific publications considerable attention is paid to optimize process parameters and their influence on the relative roughness of the manufacturing surface and machining performance in related technologies:

- Electric erosion (electric discharge) machining (EDM) [11].
- Electric arc machining (EAM, SEAM) [12–14].
- Blasting erosion arc machining (BEAM) [15, 16].
- Arc dimensional machining (ADM) [1–10].

Published papers over the last few decades in electric erosion machining technology are reviewed and areas of research are given in the article [11]. These areas have the following structure:

- 20 % of works consider the principle of EDM machines;
- 19 % of works explore the impact of powder additives as a part of the working fluid to change of the properties of machined surface;
- 18 % of works explore the ways to optimize the machining process parameters;
- 16 % of works explore servo control at electrode-tool feed;

- 10 % of works explore the ways of recognizing pulses: work, short circuit and idling;
- 9 % of works consider the impact of major (duration of work pulse and pauses, arc current rate) and disturbing parameters on the electric discharge machining;
- 5 % of works explore multi-spark electrode-tools;
- And only 3 % of the works investigate automatic control systems of electric discharge machining process.

Based on this analysis we can conclude that the scientific publications pay little attention to works by automating the electric discharge machining process.

In [12] the block diagram of the experimental unit for electric arc machining is considered. The methods and design solutions to determine the state of arc discharge in the interelectrode gap are given. In [13] technological scheme of short electric arc machining (SEAM) is examined and dependence of process parameters on the depth of machining and feed rate of the electrode-tool are shown. In [14] design features of electric arc power source for SEAM machines are reviewed and studied.

In [15, 16] electric erosion BEAM process is considered, namely, the design features of the electrode-tool, technological process parameters and the results are achieved: machining performance, roughness of machined surface, electrode-tool discharge.

In [4, 5] the method of arc dimensional machining is disclosed. The conditions for creation and properties of the arc in the cross flow of the working fluid are described.

In [6] machining method of cavities, in particular grooves, is proposed. Obtained mathematical models allow to predict the specific performance, power consumption, back lash and relative wear of graphite electrode-tool.

In [8] substantiation of technological scheme for forming of carbide roll lateral surface by arc dimension machining method is done. Analytical relationships of technological characteristics of machining regimes and geometrical parameters are established.

In [9] the controller of automatic stabilization system of arc dimensional machining is considered. An algorithm of process stabilization is proposed.

In [10] a method of automatically stability determination of arc dimensional process is given. Combustion interval, in which it can get a stable process, is proved.

As a result of the search it is found that expressed objectives of the study were not considered in the scientific literature, and the feed rate of the electrode-tool with no arc combustion often given by the manufacturer of the control system such that at the arc ignition in the impact time, impact torque acting on the electrode-tool is not exceed its toughness.

Thus, the research results suggest that electrode-tool feed is in conditions of undervalued feed rate. To reduce the time of electrode-tool feed to the electrode-workpiece it should:

- Feed should be at the maximal rate.
- Before electric arc ignition it is necessary to switch over to a working feed rate.

### 5. Materials and methods of research

Research was conducted at the electric erosion machine type AMN-1 with electromechanical electrode-tool feed drive based on a complete high-precision drive ESHIM-1. A mixture of kerosene and oil «Industrial-12» is used

as the working fluid in the ratio 1:1; material of the electrode-tool (ET) was graphite MPG 7; material of the electrode-workpiece (EW) was metal E 235-C (Fe 360-C) according to ISO 630:1995. There were technological limitations by current strength in the range of 50 to 100 A and the static pressure of the working fluid at the inlet in interelectrode gap  $P_{st} = 0,6 \dots 1,8$  MPa. In all of the experiments that are highlighted in this paper the reverse polarity of the electrodes were used («+» on ET, «-» on EW).

Oscillogram record of process parameters were performed by measuring complex, built on the basis of data collection microsystem mDAQ-12 and software PowerGraphProfessional. Features of measuring complex are reviewed in [17]. Used sensors are presented in Table 1.

Input variable parameters of the process are the feed rate of the electrode-tool. Output parameters are pressure of the working fluid at the inlet in electric erosion chamber, current and arc voltage.

The study was based on the method proposed by the authors of [18]. To control the process of electrode-tool feed we used automatic control system considered in [9].

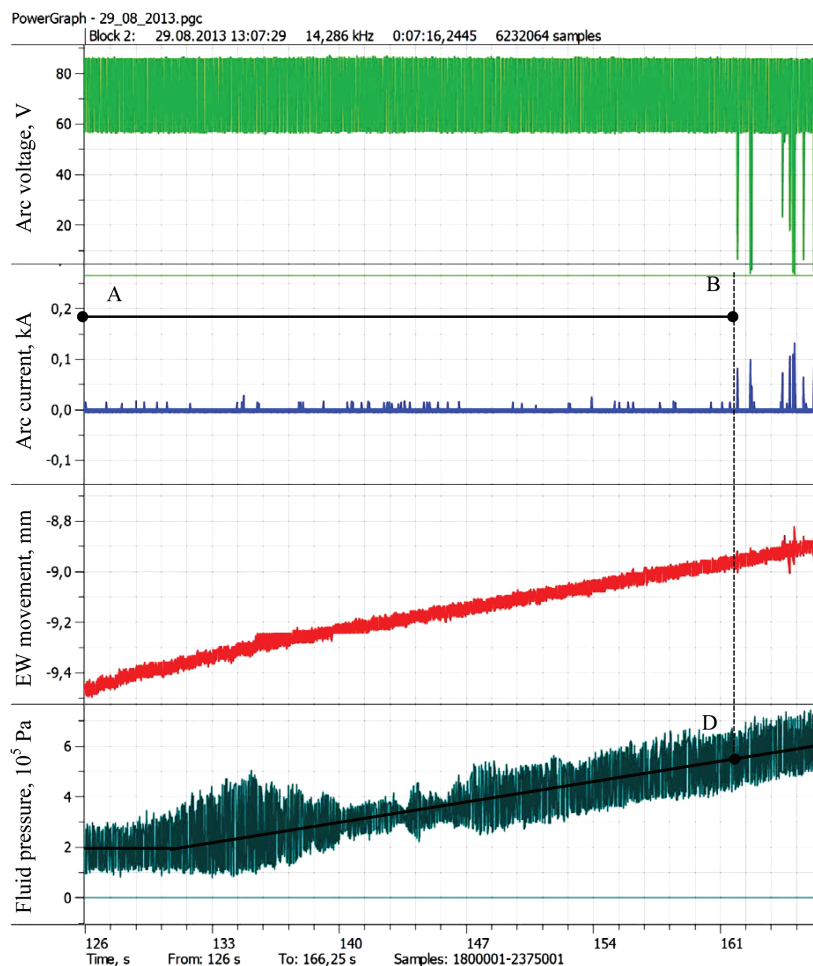


Fig. 4. Typical oscillograms of technological parameters of ignition process in electric arc chamber AMN-1

Table 1

The use of sensors in the measuring channels

The name of the channel	Sensor or interface unit	Fig №
Arc voltage	Block of signal normalization	Fig. 4, Fig. 7
Arc current	Shunt75ШСММ3	Fig. 4
Linear movement of the electrode-tool	Linear movement sensor CLPR13-25 (Megatron)	Fig. 4
Pressure of working fluid	Pressure sensor of 628CR series	Fig. 4, Fig. 7
Tachogenerator voltage	Block of signal normalization	Fig. 7
Arc current	Linear current sensor LF 305-5/SP11	Fig. 7

## 6. Research results

A typical process of working fluid pressure change during arc ignition is shown in Fig. 4.

Arc voltage channel displays the idling voltage of the power source to the arc ignition (segment AB, Fig. 4) and is uninformative to determine interelectrode gap. Arc current is absent before arc ignition. Minor current pulses in the interval AB (Fig. 4) in the channel is a signal of induced noise in the measurement system. Moving channel of the electrode-tool displays the value of linear movement of the electrode-tool.

Hydrodynamic resistance is changed at electrode-tool feed in the interelectrode gap, which leads to pressure changes of the working fluid in the electric erosion chamber, as shown in Fig. 4.

In this example, the ignition process began at the pressure of the working fluid within 0,45...0,65 MPa (0,55 MPa after treatment of values by median filter, point D on the working fluid pressure oscillogram). The magnitude of hydrodynamic resistance is influenced by many factors: area and geometry of manufactured surface, length of the evacuation route of erosion products and other.

As a result of studies it is found that using cylindrical electrode: the electrode outside diameter – 16 mm, hole inside diameter – 8 mm (exterior of the electrode-tool is shown in Fig. 5, a) and machining depth – 1–3 mm (exterior of the electrode-workpiece after machining is shown in Fig. 5, b) ignition process began at a pressure of working fluid within 0,19...0,8 MPa.

The pressure value of the working fluid at a rate of 0,18 MPa was set as the threshold of automatic control system triggering for changing the feed rate of the electrode-tool. Oscillograms of parameters for arc dimensional machining at feed rate control of the electrode-tool before arc ignition are shown in Fig. 6.

In oscillogram (Fig. 6) segment AB – corresponds to the feed time of the electrode-tool at high feed rate, segment CD – corresponds to the feed time at a working feed rate, segment NM – start of the arc ignition.

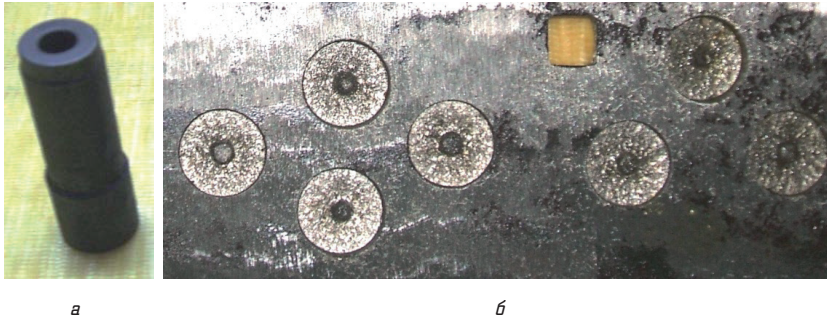


Fig. 5. Exterior: a — electrode-tool; b — machine part (electrode-workpiece) after machining

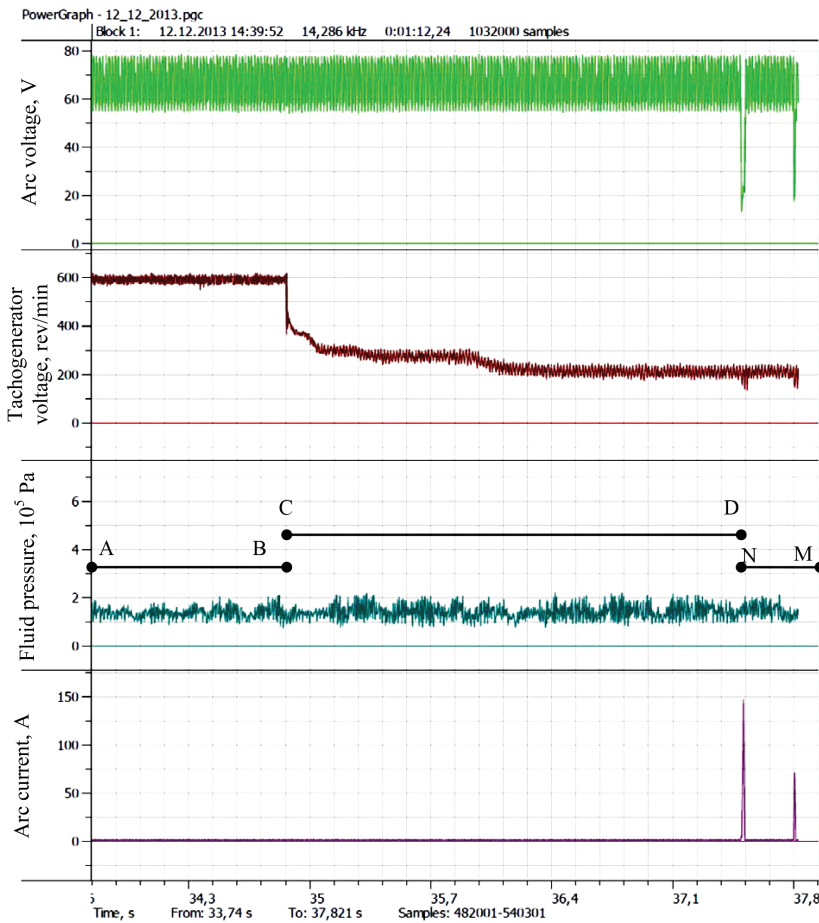


Fig. 6. Oscillograms of research parameters

Let's formulate a functional of process optimization of arc ignition  $K$ :

$$K = f(t_p, V_{max}), \tag{2}$$

where  $t_p$  — feed time of the electrode-tool to the workpiece, s;  $V_{max}$  — linear feed rate, mm/s.

Feed time has negative feedback, because decrease of time  $t_p$  increases the value of the vector  $K$ . Feed rate has positive feedback and restricted by the technical data of feed engine. In the considered feed system the maximum linear feed rate of electromechanical system is 0,807 mm/s and working — 0,0616 mm/s. The amount of time delay of the drive control systems and

the time of the transition process is about  $T_z = 0,04$  s.

Let's write an optimality criterion:

$$\begin{aligned} t_p &\Rightarrow \min; \\ V_{max} &< V_{critical}, \\ V_{critical} &= \frac{\delta_{lim}}{T_z}, \end{aligned} \tag{3}$$

where  $V_{critical}$  — critical rate of impact of the electrodes;  $\delta_{lim}$  — limiting inter-electrode gap in which switching is performed with maximum feed rate to the working automatic control system (for this version  $\delta_{lim}$  is within 0,8...1 mm).

Let's verify the condition

$$V_{max} < V_{critical}.$$

$$V_{critical} = 0,8/0,04 = 20 \text{ mm/s.}$$

Since  $V_{max} \ll V_{critical}$  ( $0,807 < 20$ ) condition is satisfied, so the system at the electrode-tool feed at the maximum rate will be adjusted optimally.

The feed rate of the electrode-tool before implementation of proposed algorithm for rate control in ACS was threefold increased work rate and was 0,1848 mm/s. When the distance between the electrode-tool and the electrode-workpiece was 5 mm, feed time was 27 seconds and after optimization — 7 seconds. Feed time (at 5 mm) was decreased by 20 seconds.

As shown in Fig. 4, combustion process of stationary electric arc is after combustion process of non-stationary arc. Automatic control system of the electrode-tool feed rate stabilizes the electric arc parameters, creating optimal interelectrode gap and further process occurs at steady arc combustion, as shown in Fig. 7.

Stabilization system of electric arc parameters in this article is not considered.

This result suggests the possibility of improving existing control systems of electrode-tool feed by entering additional feedback channel in the controller on the pressure of working fluid at the inlet in interelectrode gap. This will suggest with a little change of algorithm to increase performance by reducing feed time of the electrode-tool to the workpiece. It is also necessary to take into account the benefits of reducing impact torque on the electrode-tool at the moment of arc ignition, as the rate, thus, is equals working rate, not electrode-tool feed rate.

Experimental researches were conducted to test the proposed solutions. They are proved its efficiency. Damage or breakage of the electrode-tool wasn't observed during 50 tests using proposed method.

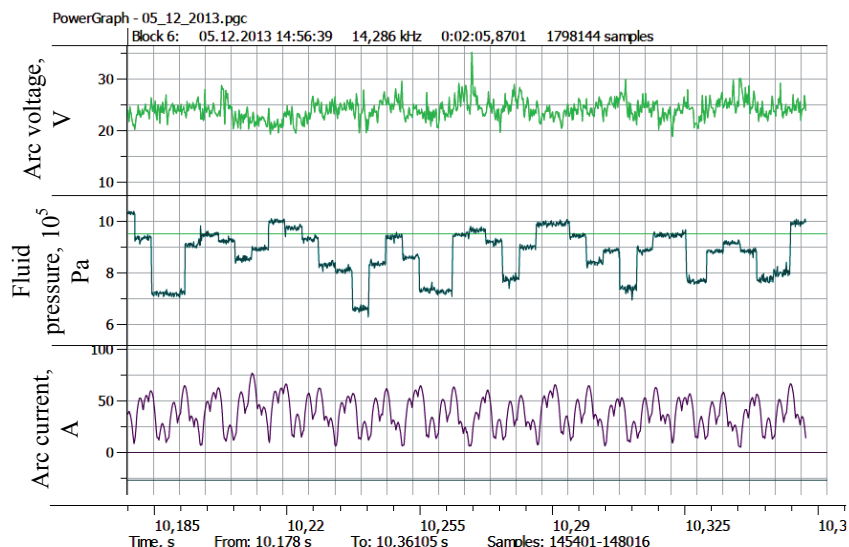


Fig. 7. Oscillograms of stationary process of arc dimensional machining

## 7. SWOT analysis of research results

**Strengths.** The proposed method can reduce the feed time of the electrode-tool in the work zone. At the implementation of the proposed method as an additional automatic control subsystem in the part of the base automatic control system of the electrode-tool feed the load on the operator and accordingly its influence on the machining is decreased.

**Weaknesses.** Research was conducted for the electrode-tool of working profile: circle, square, polygon with one technological hole (diameter of 6 mm or more) for pumping the working fluid.

**Opportunities.** In the related electric erosion machining technologies: EDM, EAM, SEAM, BEAM it is possible to optimize the feed of the electrode-tool to the workpiece using proposed method, but for this task it is necessary to conduct additional researches, which take into account the peculiarities of machining methods.

**Threats.** The technical backwardness of automatic control systems of ADM machines in relation to global manufacturers of EDM machines (e. g., Sodick (Japan), MITSUBISHI ELECTRIC (Japan), AGIE (Switzerland), EROWA (Switzerland), etc.) complicates their market distribution.

## 8. Conclusions

1. On the basis of these studies it is concluded that the arc ignition point is optimally determined using technological parameters – working fluid pressure at the inlet of interelectrode gap.

2. Threshold of the working fluid pressure was experimentally determined and was 0,18 MPa.

3. Formed optimality criterion of arc ignition process ensures minimal time for electrode-tool feed by the maximum permissible feed rate. Experiments confirmed its effectiveness. At a distance of 5 mm between the electrode-tool and the electrode-workpiece feed time is decreased by 20 seconds.

## References

- Nosulenko, V. I. Rozmirna obrabka metaliv elektrychnoi duhoiu [Text]: Abstracts of Theses ... Dr. Tech. Science: 05.03.07 / V. I. Nosulenko; Kirovograd State Technical University. – Kyiv, 1999. – 36 p.

- Meshcheriakov, G. Physical and Technological Control of Arc Dimensional Machining [Text] / G. Meshcheriakov, V. Nosulenko, N. Meshcheriakov, V. Bokov // CIRP Annals – Manufacturing Technology. – 1988. – Vol. 37, № 1. – P. 209–212. doi:10.1016/s0007-8506(07)61619-9
- Nosulenko, V. I. O fizicheskoi prirode, ob obshchem i otlichiih, tehnologicheskikh vozmozhnostiah elektricheskikh razriadov i klassifikatsii sposobov elektrorazriadnoi obrabotki metallov [Text] / V. I. Nosulenko // Elektronnaia obrabotka materialov. – 2006. – № 1. – P. 4–14.
- Nosulenko, V. I. Razmernaia obrabotka metallov elektricheskoi dugoi [Text] / V. I. Nosulenko // Elektronnaia obrabotka materialov. – 2005. – № 1. – P. 8–17.
- Nosulenko, V. I. Elektricheskaiia duga v poperechnom potoke sredy-dielektrika kak istochnik tepla dlia novyh tehnologii [Text] / V. I. Nosulenko // Elektronnaia obrabotka materialov. – 2005. – № 2. – P. 26–33.
- Bokov, V. M. Elektroduhove frezeruvannia [Text] / V. M. Bokov // Konstruiuvannia, vyrobnytstvo ta ekspluatatsiia silskohospodarskykh mashyn. – 2015. – Vol. 45, Part 2. – P. 180–188.
- Nosulenko, V. I. Rozmirna obrabka elektrychnoi duhoiu otvoriv skladnoho konturu [Text] / V. I. Nosulenko, V. V. Yuriev // Zbirnyk naukovykh prats Kirovohrads'koho natsionalnoho tekhnichnoho universytetu. Tekhnika v silskohospodarskomu vyrobnytstvi, haluzeve mashynobuduvannia, avtomatyzatsiia. – 2015. – Vol. 28. – P. 70–73.
- Sisa, O. F. Rozmirna obrabka elektrychnoi duhoiu bichnoi poverkhni tverdospalnoho prokatnoho valka [Text] / O. F. Sisa // Konstruiuvannia, vyrobnytstvo ta ekspluatatsiia silskohospodarskykh mashyn. – 2014. – Vol. 44. – P. 153–159.
- Savelenko, G. Development of software and hardware device of automated system of the process stabilization of arc dimensional processing [Text] / G. Savelenko, Y. Ermolaev, O. Sobinov, V. Gutsul // Technology audit and production reserves. – 2015. – № 1/3 (21). – P. 22–28. doi:10.15587/2312-8372.2015.36244
- Savelenko, G. The method of automatic determination of arc sizing machining process stability [Text] / G. Savelenko // Eastern-European Journal of Enterprise Technologies. – 2015. – № 1/5 (73). – P. 9–13. doi:10.15587/1729-4061.2015.36226
- Pawade, M. M. A Brief Review of Die Sinking Electrical Discharging Machining Process towards Automation [Text] / M. M. Pawade, S. S. Banwait // American Journal of Mechanical Engineering. – 2013. – Vol. 1, № 2. – P. 43–49. doi:10.12691/ajme-1-2-4
- Zhang, M. An independent discharge status detection method and its application in EAM milling [Text] / M. Zhang, Q. Zhang, L. Dou, G. Zhu, C. Dong // The International Journal of Advanced Manufacturing Technology. – 2016. – Vol. 87, № 1–4. – P. 909–918. doi:10.1007/s00170-016-8537-0
- Zhou, J. P. Study on Rules in Material Removal Rate and Surface Quality of Short Electric Arc Machining Process [Text] / J. P. Zhou, C. H. Liang, W. J. Teng, Y. Xu, B. S. Zhou // Advanced Materials Research. – 2008. – Vol. 33-37. – P. 1313–1318. doi:10.4028/www.scientific.net/amr.33-37.1313
- Zhou, J. P. The NC Power Supply Design of Large Current and Wide Frequency Pulse in Short Electric Arc Machining [Text] / J. P. Zhou, C. H. Liang, Y. Xu, B. S. Zhou // Applied Mechanics and Materials. – 2013. – Vol. 278-280. – P. 1051–1055. doi:10.4028/www.scientific.net/amm.278-280.1051
- Zhao, W. A Novel High Efficiency Electrical Erosion Process – Blasting Erosion Arc Machining [Text] / W. Zhao, L. Gu, H. Xu, L. Li, X. Xiang // Proceedings of the Seventeenth CIRP Conference on Electro Physical and Chemical Machining. – 2013. – Vol. 6. – P. 621–625. doi:10.1016/j.procir.2013.03.057

16. Zhao, W. S. High-speed Electrical Arc Machining Based on Hydrodynamic Arc Breaking Mechanism [Text] / W. S. Zhao, L. Gu, H. Xu, L. Li, X. L. Xiang // *Electromachining & Mould.* — 2012. — Vol. 300, № 5. — P. 50–54. — Available at: \www/URL: [http://en.cnki.com.cn/Article\\_en/CJFDTOTAL-DJGU201205012.htm](http://en.cnki.com.cn/Article_en/CJFDTOTAL-DJGU201205012.htm)
17. Savelenko, G. V. Study workflow dimensional processing of arc on a machine with electromechanical drive [Text] / G. V. Savelenko, Y. A. Ermolaev // *Computer-integrated technologies: education, science and industry.* — 2014. — № 14. — P. 164–169.
18. Method for determining moment of arc ignition and change of movement mode at idling of electrode-tool of machine for size processing by stationary arc [Text]: Patent 110050 Ukraine, МРК (2006.01) В23Н 7/26. В23Н 7/32. В23Н 1/02. В23Н 7/18. G05В 13/02. H05В 7/152 / Savelenko H. V., Yermolaev Y. O.; assignee: Kirovograd State Technical University. — Appl. № a201311270. Filed 23.09.2013. Publ. 10.11.2015. Bull. № 21. — 3 p.

#### ОПТИМИЗАЦИЯ ПРОЦЕССА ЗАЖИГАНИЯ ДУГИ НА СТАНКАХ РАЗМЕРНОЙ ОБРАБОТКИ ДУГОЙ

Исследованы процессы в электроэрозивной камере типа АМН-1 в момент зажигания электрической дуги на станке размерной обработки дугой. Приведен характер изменения давления рабочей жидкости в электроэрозивной камере. Предложено значение величины давления, при котором системой автоматической подачи при подводке электрода-инструмента к заготовке обеспечивается автоматическое изменение скорости с максимальной до рабочей.

**Ключевые слова:** автоматическая система, размерная обработка дугой, давление рабочей жидкости, скорость подачи, электрод-инструмент, зажигание дуги.

**Савеленко Григорій Володимирович**, викладач, кафедра економіки та підприємництва, Центральноукраїнський національний технічний університет, Кропивницький, Україна, e-mail: [savelenko@mail.ru](mailto:savelenko@mail.ru).

**Єрмолаєв Юрій Олексійович**, кандидат технічних наук, доцент, кафедра автоматизації виробничих процесів, Центральноукраїнський національний технічний університет, Кропивницький, Україна.

**Юр'єв Віталій Віталійович**, аспірант, кафедра обробки металів тиском та спецтехнологій, Центральноукраїнський національний технічний університет, Кропивницький, Україна.

**Савеленко Григорій Владимирович**, преподаватель, кафедра экономики и предпринимательства, Центральноукраїнський національний технічний університет, Кропивницький, Україна.

**Єрмолаєв Юрій Алексеевич**, кандидат технических наук, доцент, кафедра автоматизации производственных процессов, Центральноукраїнський національний технічний університет, Кропивницький, Україна.

**Юрьев Виталий Витальевич**, аспирант, кафедра обработки металлов давлением и спецтехнологии, Центральноукраїнський національний технічний університет, Кропивницький, Україна.

**Savelenko Gregory**, Central Ukrainian National Technical University, Kropyvnytskyi, Ukraine, e-mail: [savelenko@mail.ru](mailto:savelenko@mail.ru).

**Yermolaev Yuriy**, Central Ukrainian National Technical University, Kropyvnytskyi, Ukraine.

**Yuriev Vitaly**, Central Ukrainian National Technical University, Kropyvnytskyi, Ukraine

UDC 681.3

DOI: 10.15587/2312-8372.2016.86768

**Blintsov V.,  
Hrytsaienko M.**

## IMPROVEMENT OF THE MANAGEMENT OF MATERIAL AND TECHNICAL RESOURCES OF WATER CLEANING PROJECTS FROM EXPLOSIVE OBJECTS

*Запропоновано процесну модель управління проектами роботизації завдань очищення акваторій від вибухонебезпечних об'єктів. Дана модель знаходиться в складі підмоделі управління базовими роботизованими підводними завданнями, які реалізують безпечні технології очищення акваторій, а також підмоделі управління базовими завданнями щодо ефективного застосування спеціальних засобів морської робототехніки, що утворює теоретичну основу для підвищення ефективності управління проектами захисту акваторій від надзвичайних ситуацій техногенного та природного характеру.*

**Ключові слова:** морська акваторія, вибухонебезпечний предмет, підводний робот, управління матеріально-технічними ресурсами проектів.

### 1. Introduction

Cleaning of the territories and waters from explosive objects is one of the priorities of «State Program of population and territory protection from emergency situations of technogenic and natural character for 2013–2017 years» approved by the Law of Ukraine on June 7, 2012 № 4909-VI. For the territorial waters of Ukraine urgency of this task is due to the need to do in safe areas of the Black and Azov seas, waters of marine transport routes and waters

of inland transport routes (navigable rivers) containing explosive objects of WWII and fighting in the postwar period.

Material and technical support of water cleaning objects from explosive objects (EO), unlike similar land-based works, involves the use of divers and is characterized by increased risk to their lives. This is due to poor visibility under water, EOs mud accumulation, complexity of their classification and evaluation of technical condition. In addition, the complex process is a primary search, detection