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Prospects of combining electro-erosive and electrochemical processes in forming the holes of a small diameter in difficult-to-process materials

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Abstract. Implementation of modern methods in forming the surfaces of a small geometrical size in materials difficult to process allows putting into practice new technical solutions to designing different objects. Most technologies are based on using electro-physical methods of processing. The combination of processes with various physical nature in one method is considered to be perspective. So, the use of erosive and electrochemical processing to pierce the holes of small diameter is suggested. It is determined experimentally that the implementation of electro-erosive discharges in the inter-electrode gap during electrochemical piercing of the hole in stainless steel 12H18N10T by a hollow cathode, which is a tool having the external diameter of 0.46 mm, allowed increasing the piercing speed by 3.7 times compared to electrochemical processing. As a result, the hole taper reduced from 4.3° to 2.5° and the accuracy of duplicating the cathode increased. It was assumed that the further increase in the accuracy of forming the holes was possible by using the cathode with an electrically isolated side surface.

1 Introduction

Nowadays creating new and improving the existing methods of combined material processing in mechanical engineering is connected with toughening the requirements applicable to details used in up-to-date aircraft engineering, mechanical engineering, cosmic and medical equipment, nuclear, oil and gas equipment from both the standpoint of accuracy and quality, and the process productivity. Of special difficulty in processing are micro-objects which surface size does not allow using the traditional methods of forming the holes, particularly the method of mechanical cutting. The analysis of the modern situation in micro-processing allows assuming the increase in its share in the total production volume for the near future [1, 2]. The use of high-strength materials and alloys as construction materials is also a significant argument in choosing the methods of forming as an alternative to the mechanical processing. The solution to technological tasks in the

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micro-processing of details made of hard-to-machine materials is aimed at using the methods of hole forming based on electro-physical processes. Nowadays to solve such problems, electro-erosive [3], electrochemical [4], laser [5] and plasma [6] processing methods as well as their combinations are more and more applied in technological processes. A combined method of erosive-electrochemical processing is used rather effectively in forming the holes in hard-to-machine materials. It is more perspective in comparison with the traditionally used erosive and electrochemical piercing. The possibility of combining these processes in one method is explained by favorable conditions to implement them in the inter-electrode gap. The authors in Paper [8] claim that the description of electrolysis and the electrical discharge in the electrolyte is possible by using the uniform standpoints based on generalized physical and chemical statements. So, a multi-phase system “metal – plasma – gas – electrolyte” is formed in using a large amount of energy in the inter-electrode gap near the electrode, in which energy carriers are both ions and electrons. It determines the destruction of the processed material as a combined action of anode dissolution and the electric discharge.

The effect of combining electro-erosive and electrochemical processes should not be considered as summing up the results of their action. It is necessary to take into account the synergetic effect during processing. Despite the difficulty of processes taking place in the inter-electrode gap, the following mechanism of their action can be assumed. So, the electrolysis at a voltage applied to the inter-electrode gap and necessary for the anode dissolution is accompanied by gas emission at the electrodes, forming the gas-liquid layers near them. It results in boiling the electrolyte and forming the vapor phase. All this contributes to appearing the electrical discharge processes in the current-conducting environment at an applied impulse voltage. The action of electric discharges in the inter-electrode gap, in its turn, influences electrochemical processes. Electric discharges in the liquid contribute to the depassivation of the anode surface due to appearing hydrodynamic processes in the diffusion limitations of the electrochemical dissolution speed. The action of hydrodynamic processes in the electrolyte speeds up the extrication of the destruction products of the processed material from the processing zone and provides the influx of new portions of solution anions to the anode surface. In addition to speeding up the depassivation processes, the presence of heat effects because of the electric discharge action leads to increasing the electric conductivity in local electrolyte volumes, thus raising the speed of electrochemical reactions. Mutual influence of electro-erosive and electrochemical processes on one another determines the synergetic effect in the combined processing.

Significant results on implementing the erosive-electrochemical processing were achieved in practice [9]. To implement the combined method, several electrochemical copying piercing machines were modernized at the enterprises of the aircraft industry in order to process the combustion chamber details, to pierce lubricant holes in bearing rings, to perforate thin-walled and some other parts. The erosive-electrochemical processing was used most effectively in piercing the holes, providing the productivity increase by 5 - 10 times compared to the traditionally used electrochemical processing [10].

Despite the obtained results, the perspective of using the combined processing to pierce the holes of a small diameter (less than 1 mm) has not been studied yet. Paper [11] shows that there appear limitations of the mode parameters in implementing the process of electrochemical forming of holes in this size range. The less the diameter of the processed hole is, the more significant these limitations are.

Paper [12] describes the experimental installation for the erosive-electrochemical hole piercing by the immovable cathode. Investigations show that the implementation of electro-erosive discharges during the electrochemical dissolving increased the processing productivity by more than 10 times, when the immovable cathode for the hole piercing in copper was used.

The paper under consideration is devoted to assessing the perspectives of using erosive-electrochemical processing to form the holes of small diameter in stainless steel 12H18N10T by applying the linear motion of electrodes.

2 Methods of experimental investigations

Stainless steel 12H18N10T was used as a sample material for hole piercing. The scheme and physical configuration of the experimental installation for the erosive-electrochemical hole piercing are shown in Figure 1.

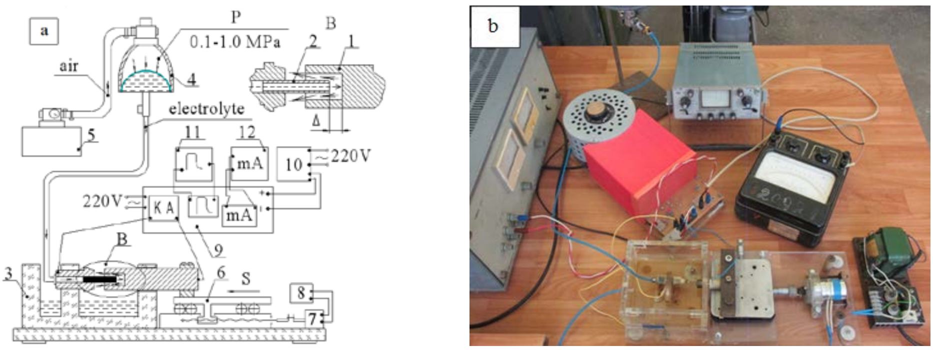

Fig. 1. Scheme (a) and physical configuration (b) of the experimental installation for the erosive-electrochemical piercing of holes

Forming the holes in the sample (anode 1) is accomplished by the tool (cathode 2) in the electrochemical unit (3). The tool is a hollow rod in which the ratio between the internal and external diameter is 0.26/0.46 mm. The delivery of the electrolyte in the processing zone is accomplished from spherical cylinders 4 under pressure produced by compressor 5. To pierce holes at the relative movement of electrodes, a system of sample displacements is provided as a feeding unit (6), an electric motor (7), a control unit (8). A special source of forming impulses 9 is designed. Its electrical scheme is described in detail in Paper [12]. To combine electro-erosive and electrochemical methods in one processing, a possibility of connecting the source of direct current 10 is provided. Registering the process parameters is done by such devices as an oscillograph 11 and an milliamperemeter 12.

The solution of sodium nitrate out of the electrolytes as water solutions of neutral salts traditionally applied during the electro-chemical processing was chosen for the investigation. The choice of the electrolyte concentration 5% $NaNO_3$ for the mode parameters such as the technological voltage – 10 V, the electrolyte pressure – 0.8 MPa was made according to the recommendations presented in Paper [14]. The recommendations were based on the theoretical analysis of hydrodynamic processes, imposing the restrictions on the mode parameters of the electrochemical piecing of holes with a small diameter. The parameters of high-voltage impulses with an amplitude of 300 V, duration of 4 μc, repetition cycle of 27.5 μc providing the electro-erosive component during the combined processing are adopted according to the investigation results of Paper [12].

3 Results and discussion

The value of feed (S) in the electrochemical piercing was based on the statement that the processing was accompanied by the self-adjustment of the current density in the inter-electrode gap when the speed of the anode dissolution of the processed material became equal to the feed of the relative electrode displacement. Figure 2 presents the graphical dependence of the ratio between the speed of the anode dissolution feed and the value of the inter-electrode gap for the chosen conditions of the electrochemical processing, which can be presented in the following way [15]:

$$V = \frac{k \times \chi \times U \times \eta}{\Delta \times \gamma \times 60}, \qquad \text{[cm/min]}$$

where

k - electrochemical element of the processed material g/A x h;

χ - electric conductivity of the electrolyte om^{-1} x cm^{-1};

U - voltage of the source of technological current, V;

η - emission of the processed metal depending on the current;

Δ - inter-electrode side gap, cm;

γ - specific weight of the processed material, g/cm^3.

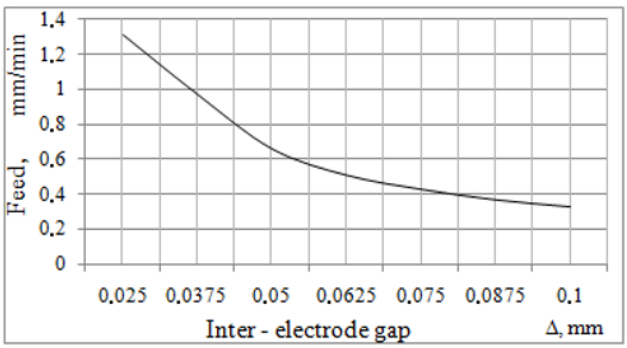

Fig. 2. Ratio between the feed and the inter-electrode gap in the electrochemical processing of stainless steel 12H18N10T in 5% $NaNO_3$ at U = 10 V

The choice of the feed (S), which is equal to 0.6 mm/min, provides a high level of the localization of the anode dissolution process. In this case, the estimated value of the inter-electrode gap will be equal to 0.053 mm due to the process of self-adjustment.

Figure 3 presents the photo of the hole cross section formed by the electrochemical piercing in stainless steel 12H18N10T at the continuous electrode feeding.

When the feed (S) was equal to 0.6 mm/min and the processing time (t) - 10 min, the depth of the hole piercing was 5.94 mm. The correlation of the parameters indicated allows stating that the localization of the electrochemical processing was provided in the inter-electrode gap equal to 0.06 mm.

Experimental results confirm the correctness of theoretical calculations to estimate the electrochemical processing parameters in setting the mode parameters, particularly the feed of the relative electrode displacement.

The formation of a certain taper (4.3°) during the electrochemical piercing should be noted. It is explained by the fact that the cathode with the electrically non-insulated side surface was used during the processing. It led to the additional electrochemical etching of the hole throughout the whole period of processing.

The decrease in the hole taper is possible by increasing the speed of the relative displacement of electrodes and reducing the time of the anode solution along the side gap. This is provided by the further localization of the process when the anode dissolution is accomplished in a smaller inter-electrode gap at a higher feed.

It is possible to increase the piercing accuracy by increasing the speed of the relative displacement of electrodes, implementing additional mechanisms of the removal of the processed material. It is provided by combining the electro-erosive and electrochemical processes in the inter-electrode gap.

Figure 4 represents the photo of the hole cross section formed in stainless steel 12H18N10T by using the erosive-electrochemical piercing.

In addition to increasing the process productivity by 3.7 times during the combined processing compared to the electrochemical piercing, the reduction in the hole taper up to 2.5° is achieved. If the hole etching up to 1.13 mm at the entrance took place during the electrochemical piercing by the cathode with an external diameter of 0.46 mm, the combination of the electro-erosive processes of the anode dissolution provided the formation of the hole with a diameter at the entrance equal to 0.8 mm. The increase in the accuracy of reproducing the diameter of the cathode in the hole is explained by restricting the etching time of the material along the hole side surface at a greater value of the feed.

The further increase in the processing accuracy, the decrease in the taper and the maximum approach of the hole diameter to the cathode diameter is possible by applying an electrically isolated thin coating on the side surface of the tool.

Fig. 3. Photo of the hole cross section formed by the electrochemical piercing in stainless steel 12H18N10T by a hollow cathode in 5% $NaNO_3$ at U = 10 V; S = 0.6 mm/min; P = 0.8 MPa

Fig. 4. Photo of the hole cross section formed during the erosive-electrochemical piercing in stainless steel 12X18H10T by a hollow cathode in 5% $NaNO_3$ at U = 10 V; S = 2.2 mm/min; P = 0.8 MPa; U = 300 V; τ = 4 μc; T = 27.5 μc

4 Conclusions

It is shown experimentally that the implementation of electro-erosive discharges in the inter-electrode gap during the electrochemical hole piercing in stainless steel 12H18N10T increases the processing speed by 3.7 times. In this case the taper reduces from 4.3° to 2.5° during the electrochemical hole forming. The possibility of implementing the erosive-electrochemical processing at increased piercing rates provides the reduction in the etching of the processed material along the side surface. As a result, the accuracy of reproducing the cathode geometry in the processed hole increases.

References

1. T. Masuzawa, *Micro – EDM*, Proc. Intern. Symp., Electrical Mach, Bilbao, Spain, (2001)

2. O. Koch, W. Ehrfel, F. Michel, *Recent progress in micro-electro discharge machining* Part 1: Technology, Proc. Intern. Symp., Electrical machining, Bilbao, Spain, PP. 117 – 127 (2001)
3. B.N. Zolotykh, *Modern physical Theory of Metals Electric Erosion as the Basis for the Deve-lopment of New Trends in EDM*, Proc. Intern. Symp. Electromach, (ISEM-XI) Switzerland, Lausanne, PP. 114 – 116 (1995)
4. Kh.M. Rakhimyanov, B.A. Krasilnikov, V.V. Yanpolskii, D.B. Krasil'nikov, *Elektrokhimicheskaya obrabotka bezvol'framovykh tverdykh splavov [Electrochemical processing of tungsten carbide],* Obrabotka metallov (tekhnologiya, oborudovanie, instrumenty) – Metal Working and Material Science, no. **3 (48)**, PP. 3–7 (2010), (In Russian)
5. A.G. Grigor'iants, A.A. Sokolov, *Lazernaia rezka* metallov *[Laser cutting of metals],* Moscow, Vysshaia shkola Publ, 127 (1988)
6. Kh.M. Rakhimyanov, A.A. Loktionov, *Tochnost' formoobrazovaniya pri tonkostruinoi plazmennoi rezke metallicheskikh materialov i puti ee povysheniya [Shaping accuracy at high-precision plasma arc cutting metal and the way of its increase]*, Obrabotka metallov (tekhnologiya, oborudovanie, instrumenty) – Metal Working and Material Science, no. **4 (45)**, PP. 31–32 (2009), (In Russian)
7. Kh.M. Rakhimyanov, A.I. Zhuravlev, N.P. Gaar, *Ustanovka dlja issledovanija jelektrohimicheskih processov v uslovijah lazernoj aktivacii processa jelektrohimicheskoj razmernoj obrabotki [Installation for electrochemical processes investigation when laser activation of electrochemical dimensional processing occurs],* Nauchnyj vestnik Novosibirskogo gosudarstvennogo tehnicheskogo universiteta – Science bulletin of NSTU, no. **2**, PP. 135 – 144 (2010), (In Russian)
8. B.R. Lazarenko, N.I. Lazarenko, *Prohozhdenie jelektricheskogo toka cherez jelektrolity [The passage of electric current through the electrolyte],* Jelektronnaja obrabotka materialov – elektronnaya obrabotka materialov, no. **1**, PP. 5 – 9 (1978)
9. K.V.Takuntsev, A.N. Zaitsev, *Jelektrojerozionno – jelektrohimicheskaja obrabotka: sovremennoe sostojanie, problemy, perspektivy [Electroerosion-electrochemical treatment: current state, problems, prospects],* Perspektivnye tehnologii fiziko – himicheskoj razmernoj obrabotki i formirovanija jekspluatacionnyh svojstv metallov i splavov [Perspektivnye tehnologii fiziko – himicheskoj razmernoj jekspluatacionnyh formirovanija i obrabotki metallov i splavov svojstv], Ufa, PP. 9 – 13 (2001)
10. B.P. Saushkin, *Electrical discharg in liquid and gas medium is the base of a new generation of methods and technologies in machine – building production***,** Jelektronnaja obrabotka materialov – elektronnaya obrabotka materialov, no. **1**, PP. 4 – 17 (2004)
11. Kh.M Rakhimyanov, S.I. Vasilevskaya, *Ocenka gidrodinamicheskih processov pri jelektrohimicheskoj proshivke otverstij malogo diametra [Evaluation of hydrodynamic processes in electrochemical stitching of small-diameter holes],* Trudy Vserossijskoj nauchno - tehnicheskoj konferencii [High, critical electro-and nanotechnologies: Proceedings of the all-Russian scientific-technical conference], Tula, December 19, PP. 62 – 74 (2017), (In Russian)
12. Kh.M. Rakhimyanov, I.A. Leontyev, S.I. Vasilevskaya, *Tehnologicheskie perspektivy kombinirovanija jelektrojerozionnyh i jelektrohimicheskih processov v obrabotke otverstij malogo diametra [Technological prospects of the combined electroerosion and electrochemical processes in the machining of small-diameter holes],* Naukoemkie tehnologii v mashinostroenii – Science intensive technologies in mechanical engineering, no. **10 (64)**, PP. 7–13 (2016), (In Russian)

13. Kh.M. Rakhimyanov, S.I. Vasilevskaya, *Vybor jelektrolitov dlja jelektrohimicheskoj obrabotki otverstij malogo diametra v medi [The choice of electrolytes for electrochemical machining of small diameter holes in copper],* Naukoemkie tehnologii v mashinostroenii – Science intensive technologies in mechanical engineering, no. **4 (70)**, PP. 17–24 (2017), (In Russian)
14. Kh.M. Rakhimyanov, S.I. Vasilevskaya. Zhuravleva A.V, *Podbor anionnogo sostava jelektrolita dlja proshivki malyh otverstij v medi [The choice of the anionic composition of electrolyte for firmware of small holes in copper]*, Sbornik trudov VIII Mezhdunarodnoj nauchno – prakticheskoj konferencii [Innovations in mechanical engineering proceedings of VIII international scientific-practical conference], Novosibirsk, PP. 126 – 131 (2017), (In Russian)
15. I.I. Moroz, *Elektrokhimicheskaya razmernaya obrabotka metallov [Electrochemical machining of metals]*, Moscow, Mashinostroenie, 279 (2009)