Activation of Electrochemical Piercing of Small Diameter Holes by Implementing High-Voltage Pulses in the Inter-Electrode Gap

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Abstract. The results of intensifying the process of electrochemical piercing of small diameter holes in the range of 0.3 mm to 1 mm by implementing the high-voltage pulses in the inter-electrode gap are presented. It is shown that the implementation of electro-erosive discharges in the inter-electrode gap during the electrochemical processing with immovable electrodes intensifies the process, increasing the speed of forming by more than 10 times. It is explained by increasing the current density from 5 – 15 A/sm² to 50 – 100 A/sm² at the initial moment of processing and from 2 – 3 A/sm² to 10 – 15 A/sm² after obtaining a processing depth of 0.5 – 1.2 mm. It is established that the geometry distortion at the hole entrance is caused by instability of inter-electrode gap value. Increasing the accuracy of forming requires the implementation of the inter-electrode gap in the scheme of processing the stabilization system. Thus, it is necessary to conduct further investigations on forming the small diameter holes during relative displacement of electrodes.

1 Introduction

The modern development of technology in different spheres of activity determines the appearance of new technical solutions and requires constant improvement of technological methods. The success achieved in creating the samples of new devices both of the global level in cosmic and military engineering and of micro-objects for microelectronics, medicine, machine building, aviation engineering should be noted. So, it is not occasional that new terms such as "micro-object", "micro-technology" appeared in the technology of processing the details. Due to this fact, the technological provision for realizing the design tasks in creating the samples of new devices in different branches of industry requires a search for new solutions.

The geometrical dimensions of the processed part surfaces often constitute fractions of millimeter [1]. They are made of corrosion-resistant, heat-resistant, high-strength metals and alloys. It imposes certain limitations for their forming. It is connected mainly with the impossibility of using traditional mechanical methods of processing. Similar limitations appear in producing deep holes of small diameter in the range of 0.3 mm to 1 mm.

The holes of the dimension range mentioned are used as the channels of lubrication, cooling (turbine blades), feed and dispersion of fuel (injectors), construction elements in medicine, filieres and others.

At present, forming holes of such a kind is rather a time-consuming operation and represents certain difficulties. For instance, in piercing deep holes of small diameter by the axial tool such as a drilling tool, there appear a number of problems caused both by small toughness and by the insignificant strength of the cutting tool. The methods of plastic deformation by a punchon are not also applied to piercing deep holes of small diameter because such a processing of holes requires using quite long tools of small diameter, which are unstable under considerable efforts of forming. As a result, it leads to their breakdown.

The use of electro-physical methods, namely electro-erosive, laser and electron beam based on the heat destruction of the processed material causes the necessity of further development of the hole produced to provide the required characteristics of accuracy and quality of the surface. However, in spite of disadvantages mentioned, electro-physical methods used for the hole forming in the diameter range mentioned is of indisputable interest [2 – 7].

Paper [5] shows that nowadays electrochemical [8, 9], electro-erosive [5] methods and their combination [10, 11] are more and more used in technological processes for piercing deep holes of small diameter.

In practice, considerable results in realizing erosive – electrochemical piercing of holes are achieved [12]. However, despite such a fact, the perspective of using the combined process for forming small diameter holes in the range of 0.3 mm to 1 mm is not studied yet.

The paper under consideration suggests conducting the intensification of the electrochemical piercing small diameter holes by implementing high voltage pulses in the inter-electrode gap.

2 Experimental Methods

Paper [13] shows that there are limitations in the mode parameters in realizing the process during the electrochemical forming small dimension holes. The less the diameter of the processed hole is, the more significant these limitations are. At the first stage the assessment of the results of forming small diameter holes in imposing electro-erosive discharges on the process of the anode dissolving of the processed material was made in hole piercing with immovable electrodes [14]. Technological experiments on the hole forming were done on a specially designed and manufactured installation, the description of which is presented in Paper [15]. Copper M1 as a model material, on the one hand, and as a construction material, on the other hand, was chosen as a material of samples for hole piercing. The forming in the sample was accomplished by the electrode in the form of a hollow cylinder with the ratio between outside and inside diameters of 0.46/0.26 mm. 5% NaCl solution for hole piercing was used in the present investigation. The research was conducted at three levels of the electrolyte excessive pressure $P = 0.3$ MPa; $P = 0.55$ MPa and $P = 0.8$ MPa, at minimum ($U = 5$ V) and maximum ($U = 20$ V) values of technological voltage. The values of the pulse voltage (U_{imp}) were equal to 300 V and 350 V for the pulse duration $\tau_{imp} = 4$ μ s. The processing time was 30 seconds, 60 seconds and 90 seconds. The technological voltage on the electrodes (U), the pulse voltage on the electrodes (U_{imp}), the pulse duration (τ_{imp}), the electrolyte pressure (P) were taken as varied parameters in the present paper. In this case the pulse repetition period was constant and equal to $T = 27.5$ μ s. The measuring microscope Nikon MM – 400 was used to assess the results of the combined processing.

3 Results and Discussion

The kinetics of forming a hole of small diameter with immovable electrodes during the electrochemical dimension processing of copper M1 in NaCl solution was considered in Paper [8]. The experimental results on assessing the productivity of the hole forming which depends on the processing time are presented in Figure 1 for technological voltage values $U = 5$ V and $U = 20$ V. Figure 2 presents the dependence of the depth change of the formed hole in copper M1 on the processing time at minimal values of the technological voltage ($U = 5$ V) and the pulse voltage ($U_{imp} = 300$ V) at different levels of the excessive voltage.

Implementing the electro-erosive discharges in the inter-electrode gap under the minimum values of the mode parameters of the electrochemical process ($U = 5$ V; $P = 0.3$ MPa) accelerates the process of hole forming, providing the piercing to the depth of 0.5 mm after 30 seconds of processing (Fig. 2, a). But without imposing the electro-erosive process on the anode dissolution the hole with a depth of 0.45 mm is formed after 10 minutes of processing (Fig. 1, curve 1).

Fig. 1. Dependence of the hole depth on the processing time of copper M1 in 5% NaCl for $P = 0.3$ MPa (1– 5 V, 2 – 20 V)

Thus, the combination of the processes provided the increase in the productivity of the hole forming with immovable electrodes by more than 20 times. Continuing the processing to 60 seconds and 90 seconds leads to increasing the hole depth till 0.69 mm and 0.95 mm, respectively. Increasing the excessive pressure to $P = 0.55$ MPa (Fig. 2, b) results in accelerating the processing at all the stages. The further increase in pressure to $P = 0.8$ MPa (Fig. 2, c) does not influence the processing speed. It is connected with the fact that the speed of the electrolyte flow through the working zone of the inter-electrode gap at a small pressure value $P = 0.3$ MPa is not sufficient for a full removal of the processing products. Judging by the experimental results, the flow hydrodynamics at $P = 0.55$ MPa is close to optimal because the further pressure increase does not lead to a considerable change in the processing speed. Increasing the amplitude value of the pulse voltage up to $U_{imp} = 350$ V at the same values of the other parameters of the electrochemical component leads to the further intensification of the processing (Fig. 3). On the whole, the character of the process remained the same, although the change in the power of the electro-erosive component was expressed in the piercing productivity.

The similar influence is caused by increasing the power of the electrochemical component when the technological voltage is maximum and equal to $U = 20$ V, which can be seen in the results presented in Figure 4.

The results of the processing maximum activation are presented in Figure 5, when electro-erosive and electrochemical components are realized at the maximum power. Thus, varying the parameters of both processes in the investigated ranges considerably influences the processing speed. The processing depth at 60 increased by 24 % under the maximum values of the technological and pulse voltage.

Fig. 2. Dependence of the hole depth on the time of the combined processing of copper M1 in 5% NaCl at $U = 5$ V; $U_{imp} = 300$ V; $\tau_{imp} = 4$ μs; $T = 27.5$ μs and at different values of the excessive pressure

Fig. 3. Dependence of the hole depth on the time of the combined processing of copper M1 in 5% NaCl at $U = 5$ V; $U_{imp} = 350$ V; $\tau_{imp} = 4$ μs; $T = 27.5$ μs and at different values of the excessive pressure

Fig. 4. Dependence of the hole depth on the time of the combined processing of copper M1 in 5% NaCl at $U = 20$ V; $U_{\text{imp}} = 300$ V; $\tau_{\text{imp}} = 4$ μs ; $T = 27.5$ μs and at different values of the excessive pressure

Fig. 5. Dependence of the hole depth on the time of the combined processing of copper M1 in 5% NaCl at $U = 20$ V; $U_{\text{imp}} = 350$ V; $\tau_{\text{imp}} = 4$ μs ; $T = 27.5$ μs and at different values of the excessive pressure

Figure 6 presents the photos of the entrance holes obtained for different energy parameters of the combines processing [10]. The experimental results showed that the appearance of the cone in the hole and its widening at the entrance with increasing the depth can be observed as during the electrochemical hole piercing in copper M1 presented in Paper [14]. It is typical of processing by immovable electrode-tool.

Fig. 6. a, b – Photos of the sample entrance hole; a – $U_{\text{tech}} = 5 \text{ V}$; $U_{\text{imp}} = 300 \text{ V}$; $t = 1 \text{ min}$; b – $U_{\text{tech}} = 20 \text{ V}$; $U_{\text{imp}} = 350 \text{ V}$; $t = 0.5 \text{ min}$

The comparison of the obtained results of the combined processing with the data on the electrochemical processing presented in Paper [14] at the same conditions (the processed material, the electrolyte composition, the electrolyte pressure, the dimensions of the electrode-tool, the value of the inter-electrode gap, technological modes of the electrochemical process) testifies that the combination of electrochemical and electro-erosive processes in one processing provides the increase in productivity by more than an order.

If it is necessary to spend 10 minutes on the electrochemical hole piercing at a depth of 0.4 mm under the pressure $U_{\text{tech}} = 5 \text{ V}$, implementing the electro-erosive component in the processing provided the hole piercing at a depth of 0.6 mm to 0.76 mm for 30 sec. The speed of any electro-physical processing of materials is mainly determined by the value of power density realized in the processing zone. The initial value of the current density was equal to 5 – 15 A/sm² during the electrochemical piercing by the immovable cathode-tool in the inter-electrode gap. This value reduced to 2 – 3 A/sm² in increasing the processing depth. The combination of the electrochemical dissolving with the electro-erosive destruction of the processed material allowed increasing the process parameters to 50 – 100 A/sm² at the initial stage and to 10 – 15 A/sm² in reaching the processing depth of 0.5 – 1.2 mm [10].

4 Conclusions

Thus, implementing the electro-erosive discharges with an amplitude of 300 – 350V, the duration to 4 μs and the period of their repetition to 27.5 μs during the electrochemical dissolving of copper allowed realizing the combination of the electrochemical and electro-erosive processes in the inter-electrode gap. The creation of the discharge channels on the vapor-gas shell in the inter-electrode gap allowed realizing the current density of 50 – 100 A/sm² at the initial moment and to 10 – 15 A/sm² at the end of the processing. It led to increasing the speed of the hole piercing process by 10 times and more. Decreasing the current density and slowing down the processing speed with increasing the piercing depth is connected with the increase in the inter-electrode gap value in processing with the immovable cathode-tool. The geometry distortion at the hole entrance is also caused by instability of the inter-electrode gap value. Increasing the accuracy of the forming requires implementing the stabilization system of the inter-electrode gap in the processing scheme.

It follows that further investigations on piercing small dimension holes should be made under conditions of the relative displacement of electrodes, i.e. with the feed of one of the electrodes.

References

1. V.V. Lyubimov, V.K. Sundukov, Modern high technologies, **1**, 77 (2004)
2. A.B. Zhogolev, *Electrochemical microformation of micro details such as rotation bodies, diss. ... kand. tekhn. nauk*, Tula, 140 (2005)
3. Z.Y. Yu, T. Masuzawa, M.Fujino, Proc. Intern. Symp. Electrical Mach. Bilbao, Spain, 169 (2001)
4. O. Koch., W. Ehrfeld, F. Michel, Proc. Intern. Symp. Electrical machining, Part 1, Technology, Bilbao, Spain, 117 (2001)
5. B.N. Zolotikh., Proc. Intern. Symp. Electromach. (ISEM-XI) Switzerland, Lausanne, 114 (1995)
6. J. Narasimhan, Z. Yu, K.P. Rajurkar, J Manuf Process., **7**, 75 (2005)
7. K.P. Rajurkar, M.M. Sundaram, A.P. Malshe, The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM), **6**, 13 (2013)
8. Kh.M. Rakhimyanov, S.I. Vasilevskaya, Metal Working and Material Science, **2 (75)**, 6 (2017)
9. Kh.M. Rakhimyanov, S.I. Vasilevskaya. K.Kh. Rakhimyanov, Bulletin of the Kuzbass state technical university, **4**, 5 (2018)
10. Kh.M. Rakhimyanov, I.A. Leontyev, S.I. Vasilevskaya, Science intensive technologies in mechanical engineering, **10:64**, 7 (2016)
11. B.P. Saushkin, Metalloobrabotka, **1:13**, 8 (2003)
12. K.V. Takuntsev, A.N. Zaitsev, *Perspective technologies of physical and chemical dimensional processing and formation of operational properties of metals and alloys*, 9 (2001)
13. Kh.M. Rakhimyanov, S.I. Vasilevskaya, High, critical electro-and nanotechnologies: Proceedings of the all-Russian scientific-technical conference, 62 (2017)
14. Kh.M. Rakhimyanov, S.I. Vasilevskaya, Metal Working and Material Science, **2:71**, 12 (2016)
15. Kh.M. Rakhimyanov, S.I. Vasilevskaya, MATEC Web of Conferences, **224**, 01013 (2018)