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Technological parameters of process of electroerosive piercing of microholes at different processing depths

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Abstract. In the paper, results of the research of dependence of a process productivity and wear of an electrode-tool on the depth of its penetration in the workpiece during electroerosive piercing of microholes are set out. It has been established that up to the depth equal to ten diameters, the wear of the electrode-tool increases insignificantly. Then, at depths from 15 to 17 diameters of the processed hole, there is a gradual increase of the wear ratio up to 90-100%. A sharp increase of the wear occurs at depths over 15-20 diameters of the processed hole. The process productivity during penetration of the electrode-tool reduces monotonically from 25-40 µm/s (at the beginning of the process) to 7-7,5 µs/s (at a depth of 15-17 diameters of the processed hole), which is explained by the wear increase of the electrode-tool and deterioration of conditions of erosion products evacuation from the interelectrode gap. It has been established that the greater wear and lower productivity correspond to the electrode-tool of less diameter, which is explained by the fact that electric modes of processing for all diameters were set as similar.

1. Introduction

Productivity (*Q*), as is well-known, is one of the key indicators of economic efficiency of some processing. In this case, dependence of linear productivity *Q* of piercing capillar holes and wear of the electrode-tool on diameter *d* of the electrode-tool and penetration depth H of the electrode-tool:

$$Q = f_1(d,H),\ \gamma = f_2(d,H)$$

since the diameter and the depth of the hole exert significant influence on productivity.

With a small square of processing, the number of areas, in which an effective discharge is possible, is considerably less than the number of pulses, coming from the generator, since a part of the square is overlapped with gas bubbles from previous discharges. And a discharge through gas possesses considerably low eroding influence on electrodes than the discharge in liquid. As far as the hole deepens, removal of processing products and entry of working fluid in the interelectrode gap become complicated. The presence of a large number of electroconductive products of erosion initiates pulses, the energy of which is spent on secondary melting of such particles, which causes a significant wear of the elctrode-tool and a productivity reduction [1-10].

2. Materials and methods

In case of processing 12 holes with the depth ranging from 100 µm to 1200 µm with the measurement of the electrode-tool movement by an indicator and measuring the wear of the electrode-tool and piercing time, it is possible to find an actual depth of each hole, H_i; an actual size of each area of the hole, HH_i; wear of the electrode-tool in different areas of hole processing, ZZ_i; and the time of piercing each area tt_i according to the following formulae:

$$H_i = I - Z_i\Big|_{i=1}^{n}, \quad (1)$$

$$HH_i = H_i - H_{i-1}\Big|_{i=1}^{n}, \quad (2)$$

$$ZZ_i = Z_i - Z_{i-1}\Big|_{i=1}^{n}, \quad (3)$$

$$tt_i = t_i - t_{i-1}\Big|_{i=1}^{n}, \quad (4)$$

where Z_i – wear of the electrode-tool of each hole, t_i – processing time of each hole, I – movement of the electrode-tool by the indicator.

In addition, it is possible to find linear wear ratio of the electrode-tool in each of the areas:

$$\gamma_i = \frac{ZZ_i}{HH_i} \cdot 100\ \%\Bigg|_{i=1}^{n}. \quad (5)$$

Productivity Q for each area can be calculated according to the following formula:

$$Q_i = \frac{HH_i}{tt_i}\Bigg|_{i=1}^{n}. \quad (6)$$

In case of accepting the size of each area of the hole as a small value and knowing the productivity function in each area, it is possible to find the piercing time of the hole, T, according to the following dependence:

$$T = \int \frac{dH}{Q_i}. \quad (7)$$

3. Research results

To study dependence $\gamma = f_1(d, H)$ и $Q = f_2(d, H)$, a number of experiments were conducted on the electroerosive machine 04EP10M. The experiments were carried out in the following modes: pulse generator frequency – 25 kHz; pulse energy – 9.25 mJ; vibration frequency of the electrode-tool – 330 Hz; vibration amplitude of the electrode-tool – 12 µm. The material of the electrode-workpiece is medical steel ZI-90, that of the electrode-tool – tungsten.

The experiment was carried out as follows. The hole piercing was conducted using three electrode-tools different in diameter – 20 µm, 30 µm and 50 µm. For each diameter of the electrode-tool, n =12 holes were pierced in the range from I_1 =100 µm to I_{12} = 1200 µm every 100 µm with reading I by the machine indicator. When piercing, piercing time t was measured and wear of electrode-tool Z was measured.

Having processed the obtained data by formulae (1-4), dependences (5) and (6) can be presented in a graphic form.

Figure 1 presents a diagram of dependence of linear wear ratio of the electrode-tool (%) on penetration depth H of the electrode-tool.

The obtained diagrams can be described by the grapho-analytical method using mathematical functions in the form of:

$$\gamma(d, H) = 0{,}1 \cdot e^{\frac{H_i}{2.3 \cdot d}} + \frac{12.824}{d^{0.212} - 1.761}\Bigg|_{i=1}^{n}, \quad (8)$$

where H – actual depth of the hole (penetration depth of the electrode-tool), taking into account wear of the electrode-tool, µm; d – diameter of the electrode-tool, µm.

Figure 1 shows diagrams of dependence of the linear wear ratio for three diameters of electrode-tools. The maximum error when describing the data by mathematical functions in the points that are of interest does not exceed 20%.

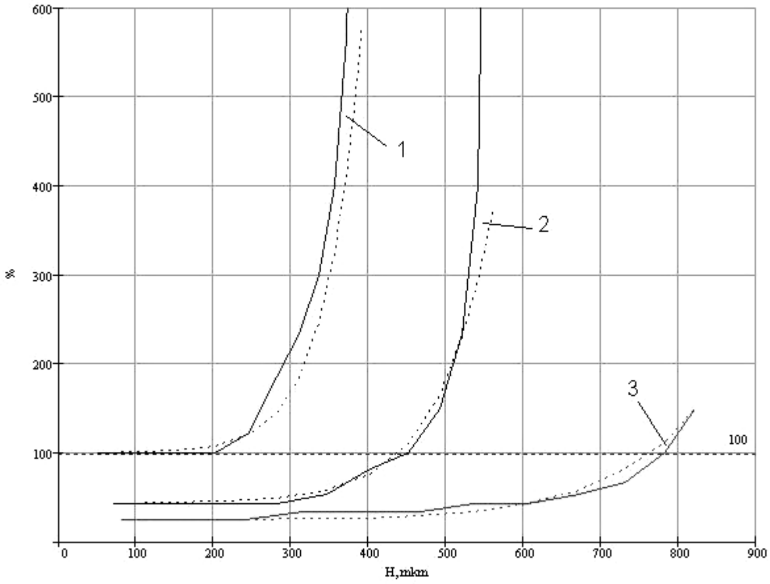

Figure 1. Diagrams of electrode-tool wear at different depths of the pierced hole: *1* – for the electrode-tool with a diameter of 20 µm; *2* – 30 µm; *3* –50 µm (solid lines – experimental, dotted lines – theoretical).

If from technological and economic considerations the maximum linear wear at the level of 100% is taken, then it is possible to establish that the ultimate depth of the hole for the electrode-tool with a diameter of 20 µm makes 200 µm; for the electrode-tool with a diameter of 30 µm – 440 µm, for the electrode-tool with a diameter of 50 µm – 760 µm.

When processing other materials with tungsten and molibdenum electrode-tools, the functional dependence of the wear ratio on diameter d and depth H of penetration of the electrode-tool can be approximated by the following generalised mathematical model [11]:

$$\gamma(d,H)=k_1\cdot e^{\frac{H}{2.3d}}+\frac{k_2}{d^{0.212}-1.761}.$$

Table 1 presents experimentally obtained values of coefficients k_1 and k_2 for different materials.

Table 1. Wear coefficients of the electrode-tool

Work material	Electrode-tool of tungsten		Electrode-tool of molybdenum	
	k_1	k_2	k_1	k_2
Brass L63	0.0033	0.43	0.012	1.496
Molybdenum	0.047	6	0.133	17.1
Steel U8	0.12	15.4	0.22	28.2
Kovar 29NK	0.11	14.1	0.433	55.6
Copper	0.016	2	0.067	8.55
Hardmetal VK6M	0.05	6.4	0.07	8.98
Nickel	0.053	6.8	0.21	26.9
Tungsten	0.025	3.2	0.06	7.7

Steel 12H18N10T	0.1	12.8	0.183	23.5
Chromium	0.13	17.1	– *	– *
Alloy 47ND	0.11	14.5	0.283	26.3
Tantalum	0.14	17.5	0.24	30.8
Constantan SNMts 40-1.5	0.21	27.4	– *	– *

* – is not processed in water

Figure 2 presents diagrams of productivity (µm/s) at different depths of the pierced hole for three diameters of electrode-tools.

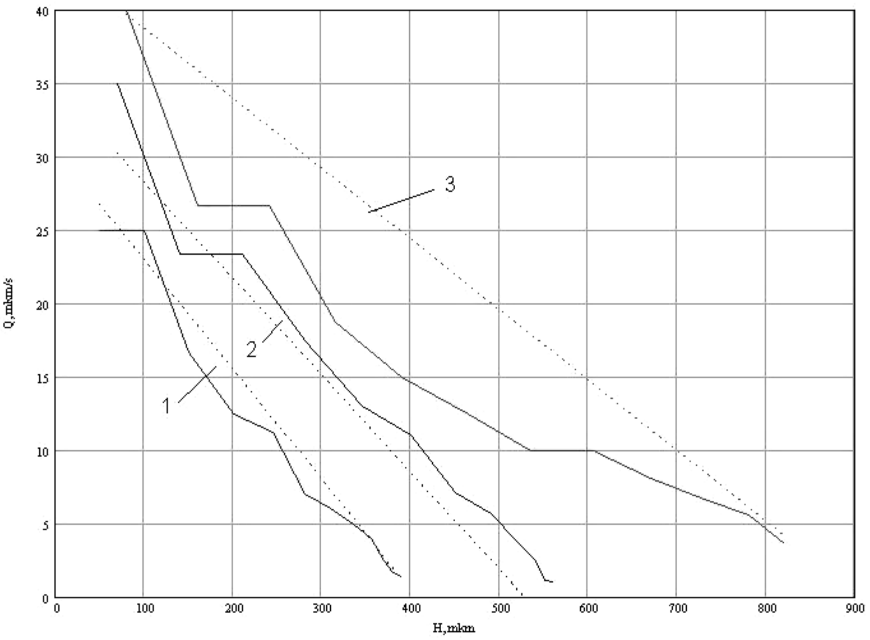

Figure 2. Diagrams of dependence of productivity at different depths of the pierced hole, *1* – for the electrode-tool with a diameter of 20 µm; *2* – 30 µm; *3* – 50 µm (solid lines – experimental, dotted lines – theoretical)

A series of these diagrams for different diameters of electrode-tools can be described mathematically by the grapho-analytical method in the form of the linear function:

$$Q(d, H) = (0.0009 \cdot d - 0.093) \cdot H_i + 0.435 \cdot d + 21.8, \quad (9)$$

where H – actual depth of the hole, taking into account the wear of the electrode-tool, µm; d – diameter of the electrode-tool, µm.

The maximum error when describing the data by the mathematical functions at the points of interest does not exceed 25%.

If the size of each area of the hole is accepted as a small value, and knowing the productivity function in each area, it is possible to calculate the time of piercing the hole, T, according to dependence (7):

$$T = \int \frac{dH}{Q_i} = \int \frac{dH}{(0.0009 \cdot d - 0.093) \cdot H + 0.435 \cdot d + 21.8} = \frac{\ln\left((0.0009 \cdot d - 0.093) \cdot H + 0.435 \cdot d + 21.8\right)}{(0.0009 \cdot d - 0.093)} + C,$$

where C – some constant depending on the diameter of the electrode-tool.

Having discovered boundary conditions, one can calculate the piercing time. The maximum error when claculating the piercing time according to this dependence does not exceed 15%.

For the above-mentioned mode of processing:

$$C = \frac{\ln(0.435 \cdot d + 21.8)}{0.093 - 0.0009 \cdot d}.$$

Thus, piercing time can be expressed as:

$$T = \frac{\ln((0.0009 \cdot d - 0.093) \cdot H + 0.435 \cdot d + 21.8)}{(0.0009 \cdot d - 0.093)} + \frac{\ln(0.435 \cdot d + 21.8)}{0.093 - 0.0009 \cdot d}.$$

Figure 3 presents a three-dimensional diagram of dependence of processing time on the diameter of the electrode-tool and the depth of the pierced hole.

The productivity of the process of the electroerosive piercing of microholes also depends significantly on the materials of the electrode-workpiece and the electrode-tool. After processing the results of numerous experiments, a generalised mathematical model of dependence of productivity on diameter d and depth H of the electrode-tool penetration has been obtained, in which the difference of influence of electrode materials has been taken into account:

$$Q(d, H) = k_3 \cdot d \cdot H - k_4 \cdot H + k_5 \cdot d + k_6.$$

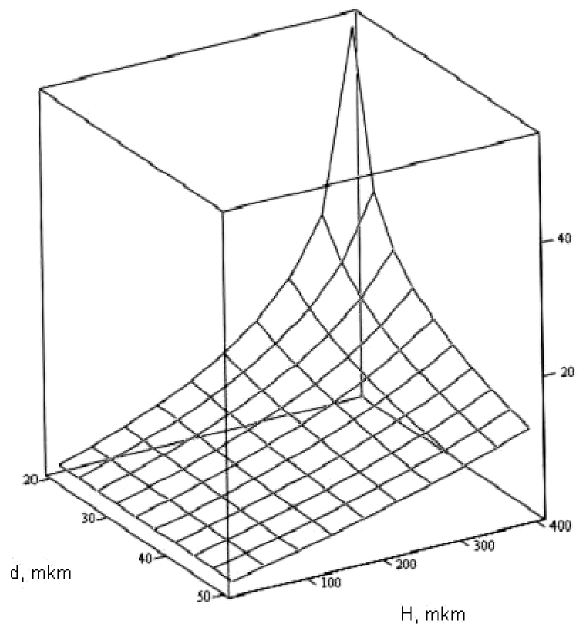

Figure 3. A diagram of dependence of the processing time on the diameter of the electrode-tool and the depth of the pierced hole

Table 2 presents experimentally obtained values of coeffficients k_3, k_4, k_5, k_6.

Table 2. Coefficients of process productivity

Processed material	Electrode-tool of tungsten				Electrode-tool of molybdenum			
	k_3	k_4	k_5	k_6	k_3	k_4	k_5	k_6
Brass L63	0.004	0.417	1.953	97.86	0.0055	0.572	2.678	134.2
Molybdenum	0.003	0.308	1.44	72.18	0.0034	0.351	1.643	82.36
Steel U8	0.002	0.207	0.967	48.44	0.0026	0.271	1.266	63.46

Kovar 29NK	0.0017	0.178	0.831	41.66	0.0005	0.056	0.261	13.08
Copper	0.0014	0.145	0.677	33.91	0.0042	0.435	2.03	101.73
Hardmetal VK6M	0.0014	0.143	0.667	33.43	0.003	0.314	1.469	73.64
Nickel	0.0012	0.128	0.599	30.04	0.003	0.31	1.45	72.67
Tungsten	0.0012	0.124	0.58	29.07	0.0044	0.455	2.127	10.66
Steel 12H18N10T	0.0009	0.093	0.435	21.8	0.0025	0.26	1.218	61.04
Chromium	0.0007	0.074	0.348	17.44	– *	– *	– *	– *
Alloy 47ND	0.0006	0.06	0.28	14.05	0.0012	0.126	0.59	29.55
Tantalum	0.0005	0.052	0.242	12.11	0.0011	0.112	0.522	26.16
Constantan SNMts 40-1.5	0.0004	0.041	0.193	9.69	– *	– *	– *	– *

* – is not process in water

The conducted scientific studies have demonstrated a considerable correlation between technological parameters of the process (process productivity and wear of the electrode-tool) and the depth of microhole processing. The obtained mathematical models of this dependence allow determining with high accuracy the technological paramaters of processing and predicting the results of processing with high accuracy for different worked stocks.

4. Conclusion

1. With penetration of the electrode-tool into the workpiece, its wear increases insignificantly up to the depth equal to ≈10 · *d*. Further, a gradual increase of the wear ratio up to 90-100% at depths (15 – 17)·*d* is observed. A sharp increase of wear takes place at depths over (15 – 20)·*d* and reaches hundreds of percent (see Figure 1).

2. The process productivity of the electroerosive piercing of microholes during deepening of the electrode-tool decreases monotonically almost linearly (see Figure 2). At the beginning of the piercing, the productivity reaches 25-40 µm/s (depending on the diameter of the electrode-tool); at a depth of (15 – 17)·*d*, the productivity decreases up to 7-7.5 µm/s, which is explained evidently by the wear increase of the electrode-tool (see Figure 1), as well as deterioration of conditions of evacuation of erosion products from the interelectrode gap.

3. Greater wear and less productivity correspond to the electrode-tool of less diameter. Evidently, this is explained by the fact that electric modes of processing for all dimaeters were set as equal, which is not an optimal technology solution. In future, this assumption will find a well-grounded scientific confirmation.

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