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RESEARCHING OF INFLUENCE OF ROTATION ANGLE OF TOOL ELECTRODE FOR ELECTROCHEMICAL MACHINING OF MATERIAL

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Abstract. A non-stationary problem of electrochemical machining with a rotating plate tool electrode of finite thickness is considered. A mathematical model has been constructed, which makes it possible to modify the process of formation by performing the rotation manoeuvre of the tool electrode. A computational experiment is conducted. Estimation of the error and refinement of the numerical results are carried out by the method of numerical filtering. With the help of the obtained numerical values, the phenomenon of the formation of a wave-like shape of the lateral part of the treated surface is explained and a number of other conclusions are made. Restrictions have been found on the values of the parameters within which this manoeuvre will be safe, i.e. will not initiate a short circuit.

Keywords: electrochemical machining; tool electrode; formation; groove cutting process; computational experiment; numerical filtering.

INTRODUCTION

Nowadays, many electrochemical machining processes are developed [1–8]. They are used in the manufacture of details of complex configurations (dies, molds, etc.), for engraving, smoothing edges, deburring, etc. All these processes occur due to the phenomenon of anodic dissolution during electrolysis.

The author of the idea and technical implementation of many varieties of electrochemical processing is the soviet engineer V. N. Gusev (1904–1956). The first industrial machine for electrochemical machining process was created in 1943.

The workpiece and the tool electrode are connected to a direct current power source. An electrolyte is supplied under pressure into the space between the anode and the cathode, which ensures that the electrical circuit is closed. As a result, the anode surface is dissolved, i.e. the workpiece machining process is carried out.

Dimensional electrochemical machining occurs when the electrolyte is continuously and intensively renewed, pumped under pressure through the inter-electrode gap. Forced removal of the electrolyte from the working area makes it possible to form the treated surfaces with smaller inter-electrode gaps than during electrochemical etching and polishing.

In order to achieve high performance, technical and economic characteristics, it is necessary to develop new technological methods of processing [9, 10]. And it is necessary for this to develop new numerical and analytical methods that simulate the process [11–13].

THE MATHEMATICAL MODELING OF THE PROCESS

The problem statement and formulation

Let us consider a nonstationary problem of electrochemical machining using a finite-thickness plate tool electrode. The center of the tool electrode moves inside the workpiece at a velocity V_C downward along the ordinate axis. The diagram of the inter-electrode space is shown in Fig. 1. At the same time, the tool electrode rotates relative to its center with angular velocity ω. The initial hole in the workpiece has some shape (usually circular), the potential difference between the electrodes is equal to U. The rotation of the tool electrode creates conditions for a more intensive moving of electrolyte in the working area and avoids problems associated with sludge [14]. The model of the electrochemical machining process according to this scheme is described in detail in [15].

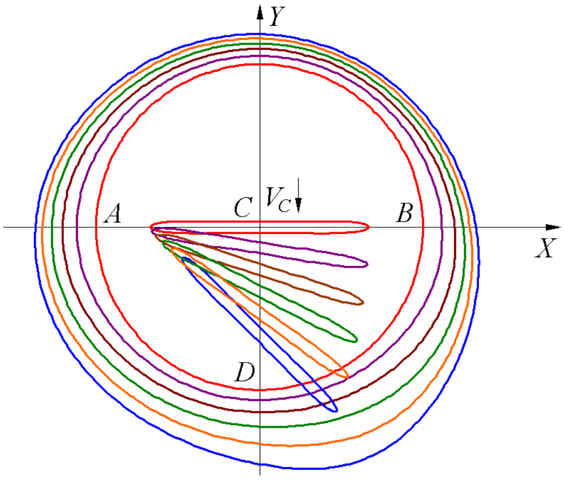


Fig. 1 Cross-section diagram of the interelectrode space:
ADB is the treated surface (anode); *C* is the tool electrode (cathode)

Dimensionless quantities x, y, τ and φ are defined as follows:

$$x = X/l,\ y = Y/l,\ \tau = t\,V_C/l = t\,kU/l^2,\ \varphi = \Phi/U, \tag{1}$$

where $l = kU/V_C$ is steady-state gap value in the problem of processing with plane horizontal tool electrode. Here $v_C = -dy_C/d\tau = 1$.

In dimensionless form, the normal velocity of motion of the detail boundary is given by the equation

$$\frac{dx_a}{d\tau} = \frac{\partial\phi}{\partial n}\cos n\,,\ \frac{dy_a}{d\tau} = \frac{\partial\phi}{\partial n}\sin n. \tag{2}$$

Here $x_a(\tau)$, $\mathrm{y_a}(\tau)$ are coordinates of points on the treated surface; n is unit vector of the outer normal to the treated surface.

Moving of the points on the surface of tool electrode during machining is the following

$$\begin{gathered} x_c(\tau) = Re\big[(x_c^0 + iy_c^0)e^{i\alpha(\tau)}\big], \\ y_c(\tau) = -\tau + Im\big[(x_c^0 + iy_c^0)e^{i\alpha(\tau)}\big], \end{gathered} \tag{3}$$

where x_c^0, $\mathrm{y_c^0}$ are the coordinates of points on the initial surface of the tool electrode (for $\tau = 0$); and $\alpha(\tau) = -\omega\tau$ is the rotation angle of the tool electrode around its axis relative to the initial position (in figure 1 the value α varies from 0 to $-\pi/2$).

The dimensionless time is discretized in the numerical solution, and at each step the boundary problem for the Laplace equation with conditions $\varphi_\alpha = 0$, $\varphi_c = -1$. The normal derivatives $\partial\varphi/\partial n$ are defined. Then, according to (2) and (3), a time step is performed by the Euler method and the process is repeated.

The solution of the boundary problem for the Laplace equation with boundary conditions of the first order on the base of the Green integral is reduced to the boundary integral equation. To solve the integral equation, we will use the method of constant boundary elements, in which the electric field strength has constant values. The boundary Γ is divided into n rectilinear elements Γ_m. The discrete form of the boundary equation is of the form

$$\frac{1}{2}\varphi_k = \textstyle\sum_{m=1}^{n} F_{km}\varphi_m + \sum_{m=1}^{n} G_{km}\varphi'_m, \tag{4}$$

φ_m, φ'_m are the values of the potential and the normal derivative at the nodal points.

Herewith

$$G_{km} = \pm\frac{1}{2\pi}\begin{cases} r^e_{km}\sin\theta^e_{km}\,(\ln r^e_{km}-1) - r^b_{km}\sin\theta^b_{km}\,(\ln r^b_{km}-1) + d_{km}(\theta^e_{km}-\theta^b_{km}), m \neq k, \\ \pm l_m(\ln\frac{l_m}{2}-1), \quad m = k, \end{cases}$$

$$F_{km} = \frac{1}{2\pi}\begin{cases} \theta^e_{km}-\theta^b_{km}, & m \neq k, \\ 0, & m = k. \end{cases}$$

The sign "+" is selected for passing along the anode (counterclockwise), the sign "–" is selected for passing along the cathode (clockwise).

Using the boundary conditions of potential constancy at the cathode and anode, we obtain a system of linear algebraic equations (SLAE) for the calculation of normal derivatives on the elements, which for these conditions has the form

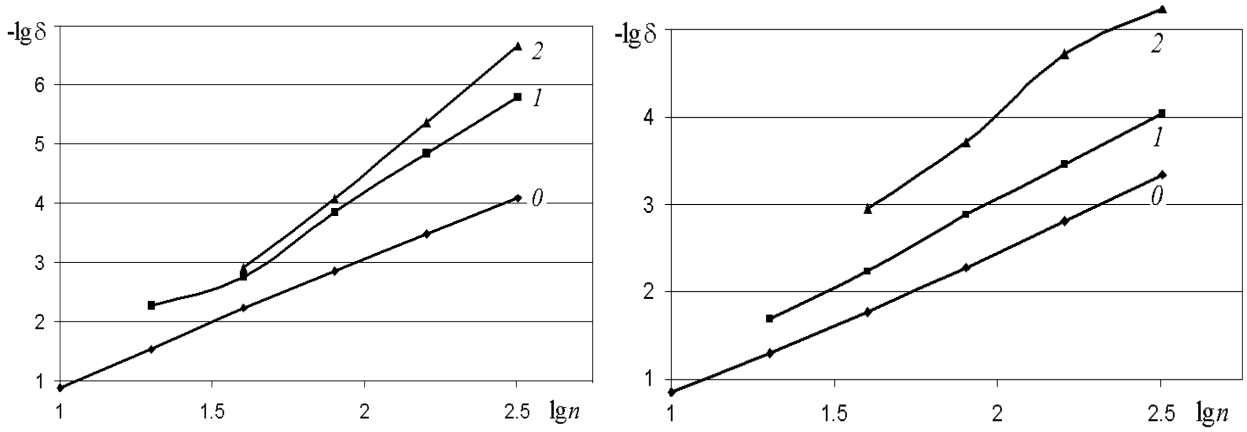
$$\sum_{m=1}^{n_1+n_2} G_{km}\varphi'_m = 0 + \sum_{m=n_1+1}^{n_1+n_2} F_{km} = 0, \qquad k = \overline{1, n_1},$$

$$\sum_{m=1}^{n_1+n_2} G_{km}\varphi'_m = -\frac{1}{2} + \sum_{m=n_1+1}^{n_1+n_2} F_{km} = -1, \quad k = \overline{n_1+1, n_1+n_2},$$

where n_1, n_2 are number of boundary elements on the anode and cathode.

Numerical experiment

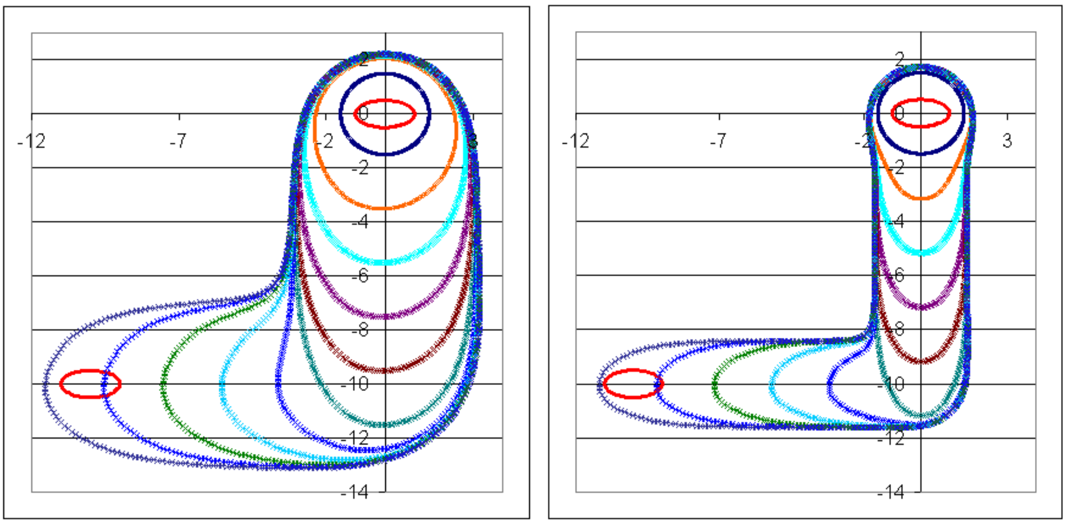
The results of calculations at the initial stage of the process for ellipsoidal tool electrode with the ratio of the cathode half-axes $k_1 = 0.1$ are shown in Fig. 2. Here for error estimate the method of numerical filtration is applied [16–19]. The error estimate shows four correct digits on the anode and three correct digits on the cathode for n=320, which is quite acceptable for calculations. The order of precision with respect to n is the second.



a *b*

Fig. 2 The results of the tension calculation:
a — on the anode; *b* — on the cathode

The anode boundary was uniformly divided along its length $l(s)$. This made it possible to study long-term (up to 100 units of dimensionless time) processes without increasing of the number of nodes with an error not exceeding 1% (relative to the half-width of the groove). In order to reduce the width of the groove, it is possible to use voltage switching only for a part of the rotation period of the tool electrode. Let us consider the effect of the angle between the tool electrode axis and the vertical Δθ, at which the voltage at the ends of the tool electrode is switched on.

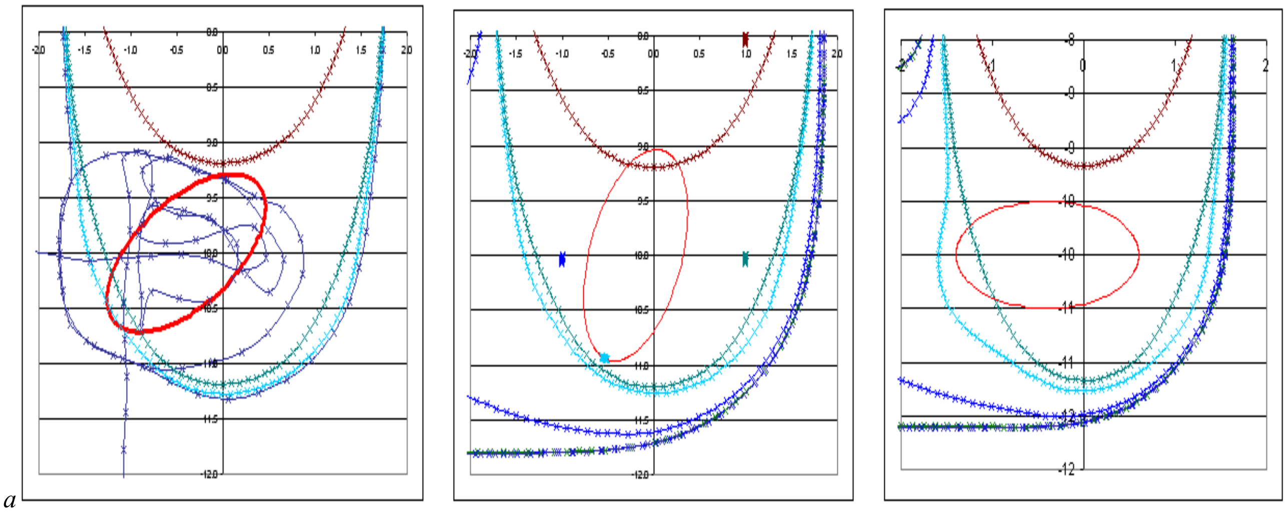


a *b*

Fig. 3 Shapes of treated surface for a/*b*=0.5 (*a*, *b* are the parameters of the ellipse):
a — ω=2π without switching; *b* — ω=2π, Δθ=45°

The configurations for tool electrode with an elliptical half-axis ratio $a/b = 0.5$ for $n_1 = n_2 = n = 320$ are presented in Fig. 3. It can be seen that partial voltage switching has a significant effect on the width of the groove.

The initial configurations with *a/b* = 0.5 with different values ω and Δθ are shown in Fig. 4. It can be seen that at Δθ = 60° a short circuit occurs (Fig. 4, *a*) or self-crossing of the boundaries. The problem is solved by increasing the rotational velocity of the tool electrode (Fig. 4, *b*, *c*).



a *b* *c*

Fig. 4 Shapes of treated surface for a/*b*=0.5 with rotation of the tool electrode:
a — ω = 2π, Δθ = 60°; *b* — ω = 3π; *c* — ω = 5π, Δθ = 45°.

CONCLUSIONS

Thus, the computational experiment has been carried out with different values of the angular velocity of the tool electrode rotation in a clockwise direction. The values of the parameters at which the self-crossing of the electrode boundaries occurs, as well as other phenomena, have been investigated.

The calculations have been carried out using various methods of specifying the nodal points of the grid on the anode surface, which undergoes large stretches in a non-stationary process. A uniform grid was chosen at each step. After each step, splines were drawn on the modified grid (separately for x and y), and a uniform grid has been restored along the splines.

Thus, investigation has been carried out for ellipsoidal electrode tools with different semi-axis ratios and different process durations $\tau_{\max}$. The results were obtained for $\tau_{\max} = 20, \tau_{\max} = 100$ and $\tau_{\max} = 200_{\max}$.

The error is estimated using numerical data obtained for grids with different numbers of nodes and different time step values.

A computational experiment is carried out for the voltage switching on only for a part of the period of rotation of the tool electrode. Restrictions on the size of this part are found to avoid self-crossing of boundaries.

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МЕТАДАННЫЕ / METADATA

Название: Исследование влияния угла поворота вращающегося электрод-инструмента при электрохимической обработке материала.

Аннотация: Рассматривается нестационарная задача об электрохимической обработке вращающимся пластинчатым электрод-инструментом конечной толщины. Построена математическая модель, позволяющая модифицировать процесс формообразования за счет исполнения маневра поворота электрод-инструмента. Проведен вычислительный эксперимент. Оценка погрешности и уточнение численных результатов осуществлены методом численной фильтрации. С помощью полученных численных значений объяснено явление образования волнообразной формы боковой части обрабатываемой поверхности и сделан ряд других выводов. Найдены ограничения на значения параметров, в рамках которых данный маневр будет являться безопасным, т.е. не будет инициировать короткое замыкание.

Ключевые слова: электрохимическая обработка; электрод-инструмент; формообразование; процесс прорезания паза; вычислительный эксперимент; численная фильтрация

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