Methodology for Calculating the Productivity of Electrochemical Machining in Stationary Electrolyte

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Abstract. The technologies that make it possible to manufacture parts with high quality surfaces and with high accuracy of dimensions and configuration of the part are especially actual now. The technological capabilities of electrochemical machining (ECM) (no tool wear, high quality of the machined surface, etc.) have ensured widespread use of this method in the manufacture of parts from difficult-to-machine materials of complex-profiled surfaces, for example, in the production of dies, press forms, and turbine blades. Some manufacturing requirements cannot be met without the use of electrochemical machining equipment. The method of machining metals and alloys is considered based on the principle of anodic dissolution of the machined workpiece in the electrolyte. It is very important to know the processes occurring during the machining on the electrodes in order to understand the basic regularity and fundamental capabilities of the ECM. The machining of a specific metal must be carried out in the correct electrolyte as this has a significant effect on productivity, surface roughness, machining accuracy, current efficiency and energy consumption of the ECM.

Keywords: Electrochemical machining · Electrolyte · ECM in stationary electrolyte · Productivity · Current density

1 Introduction

Electrochemical machining has demonstrated several undeniable advantages when working with difficult-to-machine materials [1], which are often used in the manufacture of aircraft parts.

During operation, various unforeseen situations may arise, which can cause defects on the surface of the part [2]. The chemical nature of the ECM makes it difficult to predict results. The researchers think that mathematical and computer simulations are characterized by limited accuracy due to random behavior during the process. That is,

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in the manufacture of a finished part, it is possible to obtain parameters that differ from the required ones.

Numerous physical and chemical phenomena occurring in the processing area can cause difficulties in the implementation of the process and give insufficiently accurate simulation results [3].

However, electrochemical processing is characterized by a variety of schemes. For example, the authors of work [4] made a comparative analysis of two types of the ECM: impulse and jet, successfully selected the conditions for the processing of samples. This made it possible to obtain good surface quality and high dimensional accuracy. The changes that took place in the samples were calculated by simulations and confirmed by various experiments. The deviation of the obtained geometric shapes from the required ones was several micrometers.

ECM processing method shows high accuracy of product parameters. That is why it is widely used in aircraft production. The scientific team describes a new strategy for the manufacture of a critical part [5], which is an important component of an aircraft engine. The study of electrochemical treatment of a turbine blade was carried out in the form of a full-scale experiment and using computer simulation. The high accuracy of the obtained product proves the correctness of the strategy, and the insignificant discrepancy between the research results is the verification of the simulation.

Scientists of this scientific team [6] also analyzed the relationship between the initial parameters of the ECM process and the roughness of the finished part. The authors believe that the most influential parameter is the frequency of the switching mode power supply.

By influencing various factors during the process, it is possible not only to reduce the roughness, but also to change the quality of the surface layer as a whole. For example, the feed of compressed air to the treatment area can reduce the phenomenon of accidental corrosion [7]. Or regulation of the electrolyte flow rate and vortex distribution can optimize the overall parameters of the ECM [8].

In general, the ECM processing method has many advantages, which have become the reasons for its widespread use in the space, aviation, automobile and electromechanical industries, as well as the activity of researchers in the development of new methods and strategies for this process [3].

Electrochemical machining (ECM) – a method of processing electrically conductive materials, consists in changing the shape, dimension and (or) roughness of the surface of the workpiece as a result of the anodic dissolution of its material in the electrolyte under the action of an electric current. The peculiarities of electrolysis are the spatial dissolution of the anode and the deposition of metal on the cathode surface [3, 9, 10].

Methods of electrochemical machining of metals in production are becoming more widespread due to the relatively low energy consumption, low noise, vibration, high accuracy and repeatability of the result with strict adherence to processing technology. Permissible processing of any conductive materials resistant to the chemical constituents of the solution [5].

Electrochemical machining of parts is sometimes the only possible method of shaping a metal product [6]. In some cases, such types of processing as thermal or mechanical can cause changes in the structure of the surface layer [11, 12]. The properties of the metal will change: fragility will increase, elasticity and resilience will be lost, and corrosion resistance will decrease. This will make it impossible for the further use of the part in the mechanism assembly, especially if it is a critical design [13].

There are several ECM schemes [1, 3, 14]:

- Machining with a stationary electrode-tool (ET). Using this scheme, holes are made in sheet metals, information is engraved, burrs are removed, sharp edges are rounded, and the tool is sharpened.
- Drilling of recesses, cavities, holes. According to this scheme, processing cavities of forging dies are made, holes, grooves, and turbine blade feathers are drilled.
- Broaching outside and inside surfaces in workpieces that have pre-machined surfaces on which the ET can be based. According to this scheme, finishing machining of cylindrical holes, splines, screw grooves is performed.
- Cutting workpieces. The ET is a rotating disc. According to this scheme, grooves, slots are made, springs are cut.
- Grinding or polishing. A cylindrical ET is used that rotates and moves progressively along the workpiece. This scheme is used as the final operation in the manufacture of thin plates, as well as parts from tough and strong alloys.

The main technological properties of the ECM processes are productivity, dimensional and shape accuracy and roughness of the treated surfaces.

Various metals are actively dissolved only in electrolytes of a certain composition and concentration. However, the technological properties of the processes are influenced not only by the composition of the electrolyte and concentration, but also by the temperature, hydrogen pH, which characterizes the concentration of hydrogen ions in the ECM or acidity, and the rate of its pumping in the inter-electrode gap (IEG) [15].

The concentration of components in the electrolyte is an indicator of their quantitative content in the solvent (water). It is expressed in relative, weight, or volumetric values. In the technological documentation, to control the concentration of the electrolyte, the required density is additionally indicated, which makes it possible to perform a more accurate dosing of the components. The composition of the electrolyte is determined based on the required productivity and the purpose of this ECM process, the accuracy and quality of processing. For example, in the electrochemical polishing of steel parts, aqueous solutions of phosphoric or sulfuric acids are used with the addition of chromic anhydride CrO_3, since this will provide a low roughness of the polished surface with a relatively minimum productivity of the process. And in the electrochemical shaping of products from the same steel, when it is necessary to maintain the dimension and shape with a given accuracy, aqueous solutions of sodium nitrate $NaNO_3$ are used. Because it is necessary to achieve high productivity with a relatively low roughness of the processed surface.

The ECM varieties are combined into two groups, depending on the physicochemical characteristics of the removal of the workpiece material. The first group includes all types of the ECM, during which the allowance from the workpiece is removed due to electrochemical dissolution, and the second group includes processing methods in which, together with the electrochemical dissolution of the removed allowance, mechanical or electrothermal action is carried out.

The electrochemical polishing process can be performed in a flowing or stationary electrolyte. The best results are obtained when electropolishing homogeneous metals and alloys [16].

Most often, surface cleaning and degreasing, marking, stock removal, edge rounding, blade sharpening, making engravings, changing the physical and technical properties of the surface (removing surface stresses after machining, increasing corrosion resistance), polishing gear teeth are performed in a stationary electrolyte.

The ECM at a low current density (from 0.02 to 0.03 A/mm^2) is carried out in a stationary electrolyte. For example, a diagram of the most typical operation is shown – electrolytic grinding or polishing (Fig. 1).

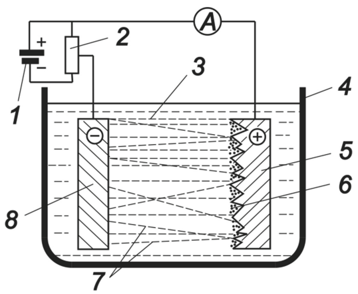

Fig. 1. Schematic diagram of the ECM in a stationary electrolyte: power supply (1), resistor (2), electrolyte (3), bath (4), electrode-workpiece/anode (5), film of dissolved metal products (6), power lines (7), electrode-tool / cathode (8)

When processing the ECM in a stationary electrolyte with fixed electrodes, the average rate of metal dissolution is determined by the formula (1):

$$V_{avg} = {}^{Z}/_{\tau} \tag{1}$$

where $\boldsymbol{Z}$ is machining allowance; $\boldsymbol{\tau}$ is process time.

The productivity of the ECM in a stationary electrolyte can be determined by the process time, which ranges from 5 to 10 min for polishing carbon steels and from 2 to 3 min for aluminum. The productivity of dimensional electrochemical shaping is characterized by the rate of anodic dissolution of the metal, which is expressed in linear (mm/min) or volume (mm^3/min) units.

The study of the influence of the current density on the productivity of the ECM process in a stationary electrolyte has been carried out. The influence of the current density on the roughness of the processed samples was not included in the objectives of this study.

2 Methodology for Calculating the Productivity of the ECM

Samples with dimensions of 25 × 40 × 1 mm made of 1X18H9T stainless steel sheet were used for the experiment. (Fig. 2). They were immersed in the solution to a depth of 25 mm. The immersion time was 5 min.

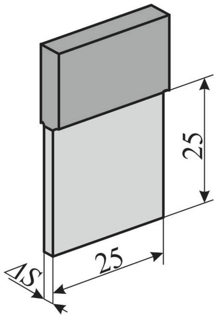

Fig. 2. The workpiece-sample (anode) for the ECM in a stationary electrolyte.

The prepared electrolyte has the following composition: phosphoric acid – 73–74%; chromic anhydride – 9–10%; water – 15–16%.

The study was carried out on a serial machine ЭЗИ–2M for electrolytic sharpening of a tool, the main structural elements of which are shown in Fig. 3.

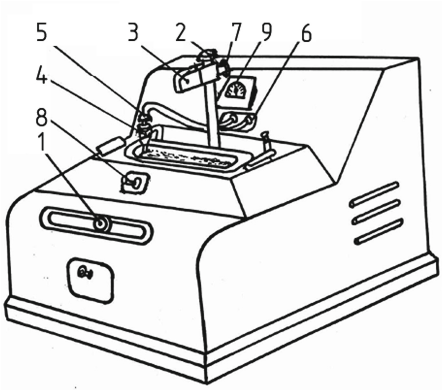

Fig. 3. Machine for the ECM in stationary electrolyte: movable contact of the rheostat (1), rack (2), anode clamp (3), bracket (4), thermal contactor (5), panel (6), screw (7), toggle switch (8), ammeter (9)

Contact occurs on both sides; the end face machining has been neglected. Then the contact area of the metal with the electrolyte can be calculated in advance (2):

$$F = 2a^2 = 2 \cdot 25 \cdot 25 = 1250\,\text{mm}^2 = 0.125\,\text{dm}^2; \tag{2}$$

where ***F*** is the contact surface area; ***a*** is the workpiece-sample side.

The known relationship between density and current (3):

$$i = {}^{I}/_{F}; \tag{3}$$

where ***F*** is the area of the processed surface; ***I*** is the current.

The current density in the ECM process in a stationary electrolyte is set according to the technological recommendations for stainless steel: $\boldsymbol{i} = 15, 20, 25, 30, 35$ A/dm^2. The dimension of the current density, which differs from the designations in the SI system, is generally accepted in mechanical engineering technology for the ECM processes.

The current $\boldsymbol{I}$ [A] can be determined by the formula (4), knowing the contact surface area $\boldsymbol{F}$ and the density formula $\boldsymbol{i}$:

$$I = i \cdot F = 0.125 \cdot i. \tag{4}$$

It is possible to determine the volume $\boldsymbol{V}$ [mm^3] using the formula (5):

$$V = F \cdot \Delta S = 25 \cdot 25 \cdot \Delta S = 625\Delta S; \tag{5}$$

where $\boldsymbol{F}$ is the area of the processed surface; $\boldsymbol{\Delta S}$ is the difference in sample thickness.

The productivity of the ECM process in a stationary electrolyte $\boldsymbol{Q}$ [mm^3/min] can be defined as the volume of dissolved metal lost over a certain time (6):

$$Q = {}^{V}\!/_{\tau}; \tag{6}$$

where $\boldsymbol{V}$ is the volume of dissolved metal; $\boldsymbol{\tau}$ is time of the process.

2.1 Procedure for the Experiment

1. Preparing the machine for work:

   – the movable contact 1 of the rheostat was set in the middle position, otherwise, when the current is turned on, the ammeter may break down;
   – the anode clamp 3 was fixed on the rack 2;
   – the thermal contactor 5 was inserted into the bracket 4 and connected to the machine circuit using two pins inserted into the sockets of the panel 6;
   – the thermal contactor 5 was lowered into the electrolyte to a depth of 15 mm;
   – the machine was connected to an alternating voltage of 220 V.

2. The order of the experiment:

   – each of the samples was installed in the anode clamp 3, lowered into the bath to the line of the immersion mark, then the anode clamp was fixed with the screw 7;
   – the current was switched on by toggle switch 8;
   – the required current was created using the movable contact of the rheostat 1 by the ammeter 9 for a given current density;
   – each sample was processed within 5 min;
   – the current was switched off by the toggle switch 8;
   – the movable contact of the rheostat 1 was set to the middle position;
   – the sample was taken out of the bath, was removed from the anode clamp 3 using tweezers;
   – the samples were washed with running water.

The processing of samples on the ЭЗИ-2M machine was carried out in the following sequence:

After washing the sample and wiping it with dry napkins, the thickness of the plates was measured with a device (lever bracket).

Each sample was processed under specific conditions (Fig. 4).

(a) (b)

Fig. 4. Samples for studying the ECM process in a stationary electrolyte: (A) untreated part of the sample, (B) sample after ECM processing

Measurements of the difference in the thickness of the material of the initial and processed samples $\boldsymbol{\Delta S}$ were performed using the lever bracket CP 0–25 (0002) ГОСТ 11098–64 with an absolute measurement error of 2 µm (Fig. 5).

Fig. 5. Measuring the thickness of the sample-plate

The results of measurements of samples and calculations are presented in tabular form (Table 1):

Table 1. Parameters of the ECM process in a stationary electrolyte.

No. of sample plate	Current density ***i***, A/dm^2	Current ***I***, A	Difference in sample thickness ***ΔS***, mm	Volume of dissolved metal ***V***, mm^3	Productivity ***Q***, mm^3/min
1	14	1.75	0.033	20.625	4.125
2	15	1.87	0.040	25.00	5.0
3	16	2	0.045	28.125	5.625
4	18	2.25	0.053	33.125	6.625
5	20	2,5	0.060	37,50	7,5
6	22	2.75	0.061	38.125	7.625
7	24	3	0.065	40.625	8.125
8	26	3.25	0.066	41.25	8.25
9	28	3.5	0.069	43.125	8.625
10	30	3.75	0,070	43.75	8.75
11	32	4	0.069	43.125	8.625
12	34	4.25	0.070	43.75	8.75
13	35	4.37	0.070	43.75	8,75
14	36	4.5	0.069	43.125	8.625

The figure graphically shows the dependence of productivity on current density (Fig. 6).

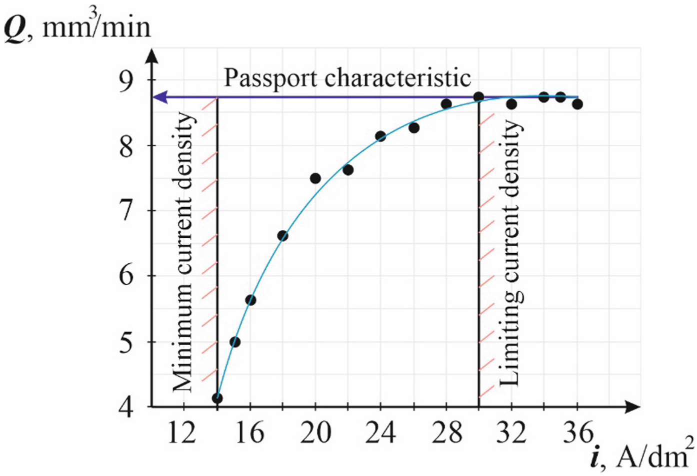

Fig. 6. Productivity of the ECM process in a stationary electrolyte

3 Conclusions

The proposed methodology for calculating the productivity of the ECM in a stationary electrolyte is illustrative and can be used for production and educational purposes.

The productivity of the ECM in a stationary electrolyte, depending on the current density, has a non-linear character.

There is a limiting current density, which is the passport characteristic of a specific machine model for the ECM in a stationary electrolyte.

Applying a current density in excess of the limit shown in the graph does not improve the surface quality of the sample. Only overheating of the electrolyte occurs.

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