CAVITATIONAL MODEL OF MACRODEFECTS FORMATION MECHANISM DURING ELECTROCHEMICAL MACHINING

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ABSTRACT

Experimental research results are presented which shows that under definite conditions of the electrochemical machining electrolyte flow oriented defects ("jet" defects) can be formed on the machined surface. Influence of machining parameters and electrolyte supply scheme on defects parameters was observed experimentally.

The phenomenological model of defects formation based on cavitation mechanism was presented. On the basis of model data the formal criterion was defined which makes possible to estimate principal possibility of jet defects appearance under various conditions of electrochemical machining.

To prevent this undesirable effect technological recommendations for machining parameters selection as well as equipment and electrode-tool requirements was formulated. For pulse electrochemical machining with vibrating electrode-tool the indirect information signal were defined allowing recognition of jet defects appearance situation. It can be used by the operator of electrochemical machine or by automatic control system immediately during the machining process.

1. INTRODUCTION

The impulse electrochemical machining (ECM) by a vibrating electrode-tool (ET) is now one of the most perspective flow diagram, providing the highest accuracy of copying and quality of the machined surface [1]. At the same time this scheme is not free of some shortcomings, which are characteristic for traditional schemes of dimensional ECM in a whole. In particular, under certain conditions, macro-defects as macro-protuberances directed as electrolyte flow in the interelectrode space (IES), can arise. In science-engineering literature this phenomenon is called «Streamness».

The problem of streamness arising at ECM has been considered by different authors [2, 3]. Different mechanisms of this undesirable phenomenon have been offered as well as relevant methods of eliminating it. It is noticed, that the streamness on the workpiece (anode) surface appears when the process in a whole is defined by diffusion kinetics. In particular, it was supposed, that arising of local pittings on the surface under machining causes turbulence of the electrolyte stream as micro-jets, favoring appearance of macro-defects in the form of streamness (figure 1). In this connection the authors made conclusion about main directions of eliminating the streamness: elimination of pitting formation (for example, by modification of electrolyte chemical composition), and elimination of diffusion limitations of the process (for example, by applying pulse current).

In [4] an assumption has been made on the base of experimental data that the macrodefects appearance (in particular, the streamness) and dimensions are defined by chemical composition and structure of the material under machining and depend on some parameters of the machining conditions as well. So for the ECM of a magnesium alloy it was ascertained, that streamness arising is favored by increasing of current density, and decreasing of IEG and electrolyte temperature, acidity and concentration. At this there was not defined any substantial influence of the electrolyte flow rate in the IES on streamness forming.

In [5] it was hypothesized that the streamness forming at ECM is substantially influenced by the flow hydrodynamics and especially by cavitations phenomena. It is noted that disturbance of the electrolyte flow hydrodynamics in IES causes arising of zones having bad electrical conductivity. Decreasing of the material removal velocity in these zones is the cause of macro-protrusions forming on the anode surface.

As follows, the above presented opinions and results concerning mechanism of the streamness arising are contradictory and have been obtained for different conditions of ECM (predominantly for direct current). As a whole it discourages effective application of conclusions and recommendations presented in these works for the conditions of impulse ECM with a vibrating electrode-tool.

In this work we made an attempt to create phenomenological model of streamness forming on the base of our experimental researches and apply them in order to elaborate recommendations for eliminating this unfavorable phenomena.
2. EXPERIMENTAL PROCEDURE AND DISCUSSION OF THE EXPERIMENTAL RESULTS

The experimental researches were carried out according to the scheme «the tube (ET-cathode) – the plane (anode-workpiece)» with the electrolyte being pumped through the central hole in the ET (Figure 1).

Figure 1. Technological scheme of the experiment

It was ascertained from our experimental researches that a character pattern of the macroprofile (figure 3) obtained by the same tool at equal machining modes and conditions remains unchanged for any quantity of the workpieces. Moreover, the pattern remains unchanged at the same ET even at changing the machining mode.

As an exception the IEG value decrease or the electrolyte IES pressure increase must be noted, in this case at the unchanged pattern the streamness decreases or even disappears at all. On the other hand even marginal varying of the macro- and microprofile of the ET inlet edge (figure 1) in the electrolyte feeding channel substantially changes the streamness pattern (figure 3). And at last, in the cross section every «stream» on the workpiece surface represents extended and widening along a streamline macroprotuberance. Decreasing or complete eliminating of the streamness can be also obtained by exact selection of current pulse phase and duration.

On our opinion the facts we presented best of all conform to ideas of streamness origin which are expounded in [5], where a supposition of cavitations as a fundamental cause of streamness arising was propounded. In this connection we have formulated a following hypothesis concerning the mechanism of streamness developing at the impulse ECM with a vibrating ET.

At the early stage of electrode approaching at relatively great values of interelectrode gaps, in the IES inlet, there is a local increase of the electrolyte flow velocity and decrease of the pressure due to a bend (non-smoothness) of the flow bounds. Conditions for cavitations developing are created, i.e. caverns filled with saturated vapor of the liquid at the pressure \( P_c \) appear. The shape of the cavern and conditions of their arising are defined basically by a cavitations number

According to [6], the first signs of cavitations appear when the value \( Q \) becomes less than a value \( Q' (0.35<Q'<1) \). In this case in the low pressure zone small caverns appear which are filled with vapors moving with the flow. As further decreasing of \( Q \) the bubbles becomes greater and then coalesce into a common cavity (called a cavern), i.e. the flow breaks away. In the end of the cavern there is a substantial non-stationary of the flow [18], a part of the liquid falls inside of a cavern and, with some quantity of vapor and gas, is periodically released into the main flow, forming a twophase liquid zone beyond the cavern. Then the liquid expands along the flow. The quantity and distribution of the caverns depend both on macro- and microprofile of the flow bounds, i.e. on the shape of the cavitator. In our case – on the shape of the ET inlet edge.

Extending along the electrolyte flow lines, the twophase cavern tracks derivate nonconducting areas in the interelectrode environment. On the segments of the anode surface located under them, the current density decreases and, accordingly, the anode dissolution is decelerated. The latter also promotes formation of "stream" ledges on the anode surface. At the further approaching of the electrodes the pressure in the IES begin to increase fast, that can promote termination of the cavitations. This time period is the most favorable for the current pass. But after the phase (the closest approach of the electrodes) has finished the cavitations can appear again.

Resuming the above presented we can suppose that for conditions of the impulse ECM a locating character and a shape of cavitations cavities practically does not depends on machining mode, chemical analysis of the electrolyte and a material being machined. These cavities appear even at absence of the electrolyze current. The main cause of stream macroprotuberances at the current pass are distortings in

![Figure 3. Cavities with a different pattern of streamness traces, obtaining by the tools of an equal macroprofile at equal regimes, but with different radii of the outlet edge rounding off](image-url)
distribution of electrical conductivity of interelectrode environment due to the cavitations.

The main recommendations for elimination of the streamness follow from this explanation. Firstly, cavitators in the pumping channel must be removed. In the considered experimental example a radius of the ET inlet edge must be increased and polished. Secondly, the electrolyte pressure must be increased, for example, by decreasing the interelectrode gap or creating back pressure at the IES outlet. According to this, for conditions of the impulse ECM with a vibrating ET it is expedient to move the current pulse into an area which is directly adjacent to the phase of vibrator low position on the branch of electrode approaching. Here there are an increased pressure, which can multiply excess the IES inlet pressure, created by the standard pump unit of the machine.

It must be noted, that changing of electrolyte physical parameters (temperature, density and viscosity) in the studied parameter range gave no results, but their more substantial changing has a negative effect for the output technological parameters (accuracy and surface quality).

3. THEORETICAL ANALYSIS OF THE STREAMNESS ARISING CONDITIONS AND DISCUSSION OF THE EXPERIMENTAL RESULTS

In this work we attempt to carry out a theoretical analysis of the streamness arising conditions according to the phenomenological model propounded above. At impulse modes, at relatively small electrolyte temperature and gas-filling variations a location and a shape of the caverns will be defined mainly by hydrodynamic parameters and a shape of electrolyte flow bounds.

Possibility of the cavitations arising was estimated for the considered scheme by the cavitations value $Q_c$

$$ Q = \frac{2 P_c - P_1}{\rho_{el} V_\infty^2}, $$

where $P_c, P_1$ – pressures in a cavern and in the liquid at a sufficient distance, $\rho_{el}$ – density of the liquid, $V_\infty$ - velocity of the liquid at a sufficient distance from the cavern.

In order to define the electrolyte inlet velocity $V_\infty$ in IES we formalize conditions of the task. Let us assume that the ET and the blank have plane parallel to each other work ends, the liquid (electrolyte) is viscous and incompressible, and its flow – plane and laminar. The work surface of the blank is immobile, and the ET surface moves reciprocally in direction of $z$- axis according to harmonic law.

We use the equations of motion for viscous non-compressible liquid.

Calculations of the cavitations value as a whole corroborate the experimental results which are presented above. So, as the end IEG and the electrolyte pressure (figure 4) increase, an oscillation period relative time fraction corresponding to a minimal cavitations coefficient grows, i.e. probability of cavitations increases. In [6] it is noted, that there is a critical value of the cavitations coefficient $Q'$, that, when exceeded, the cavitations’ arising is improbable (has very low probability). In this connection, on the base of obtained computational relations one can define acceptable values of the feed phase and current pulse duration, which make streamness on the machined surface impossible.

CONCLUSIONS

In conditions of the impulse ECM with a vibrating ET the streamness, as rule, reveals in the form of macroprotuberances, which start at the end IES inlet and widen in direction of the electrolyte flow up to the ET outlet edge.

On the base of the experimental results, theoretical analysis and available information in science-engineering literature a phenomenological model of streamness developing is propounded, which offers the base directions of its elimination.

On the base of mathematical modeling calculated relations for the electrolyte velocity and pressure distribution in IES at the impulse ECM with a vibrating ET were obtained. They can be utilized for estimating the cavitations value and election of optimal current pulse feed duration and phase, which prevent the streamness arising.

REFERENCES

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