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## **ADAPTIVE CONTROL OF ECM CURVILINEAR SURFACES**

Electrochemical machining (ECM) of curvilinear surfaces is one of the most basic and widely spread among electrochemical technology procedures for machine and tool parts. Constant parameters for preset machining time are hard to determine in this technology. This article presents a method of creating controlling code for ECM processing for which machining parameters changing over time are determined in a computer simulation of the process. An example of carrying out calculations, leading to determining process controlling code for preset electrode surfaces, is also presented, as well as the outcome of experimental verification.

### **1. INTRODUCTION**

Some of the most important issues which stimulate further development of technology are: learning and increasing its ability to achieve the desired geometry of machined surfaces, minimizing the distribution of workpiece (WP) shape deviations, and increasing the rate of machining performance indicators repeatability. Issues of surface machining using ECM process are directly linked to its researches field.

Machined surface development issues include [3]:

- shape change in time analysis,
- determining the final shape and its variation when changing machining conditions,
- determining geometry of the tool electrode (TE) to obtain a desired machined shape,
- process conditions optimization with respect to minimization of machined shape deviations,
- searching for new ways to increase machining accuracy.

Conventional methods of machining have reached the current stage of development thanks to the introduction of: numerical control, optimization of the process structure and

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machining parameters, control through microcontrollers or computers. The multidimensional, dynamic process of ECM requires a computer-based design system and sophisticated control of machining. The condition for the development of modern ECM technology is a good understanding of the nature of physical phenomena that occur during machining and inherent limitations of the process of electrochemical dissolution. Precise quantification of these constraints will allow to select optimal value of parameters at any given time of machining. This will ensure both high quality and economic rates, and at the same time will not lead ECM process to the so-called critical state, in which the machining is interrupted and electrodes are damaged [5].

## 2. MODELING OF SURFACE SHAPING USING ECM

Modeling ECM machining means designating the changes of the inter-electrode gap (IEG) width, evolution of the machined surface shape in time and distribution of the physicochemical conditions occurring in the machining area, such as: static pressure distribution, electrolyte flow speed, temperature and volume concentration of the gas phase. Determining these distributions for each time step during the simulation is essential for adaptive control of the process. This is particularly important when drilling the surface of a curved outline.

### 2.1. MATHEMATIC AND NUMERIC MODELING

A two-dimensional, two-phase vesicular electrolyte flow in an IEG is assumed; at the same time triggering a complex TE vibrating movement in mutually perpendicular directions is assumed as well, that is TE progressive and electrolyte flow. Detailed assumptions and a mathematical model of electrochemical machining with vibrating TE for curvilinear-outlined surfaces is presented in papers [1],[8],[9].

Determination of machined surface (anode) shape evolution in time is described by the equation of evolution [2],[3],[8],[9], showing the real shape change of the machined surface.

The initial shape of the machined surface and the TE was defined in the 3D modeler as free surfaces of the type NURBS (non-uniform rational basis spline). For numerical calculations discretization of WP and TE was performed by an approximation of a surface with curves. Detailed algorithms developed for the numeric model were shown in papers [9],[10].

### 2.2. ADAPTIVE CONTROL

Both theoretical and empirical studies have proved that in case of complex curvilinear surfaces for which the electrolyte flow route differs for different IEG

intersections, it is very hard to select constant machining parameters for a preset process time. This is a reason for the development of adaptive control of ECM at the level of mathematical and numeric model. Assumed machining parameters, for which ability to reach liminal values (critical state) will be examined, in practice would lead to an interruption of the process. Methods of system reaction were then designed, and so was their proper relation with examined process parameters. Fig. 1 shows a diagram of adaptive control.

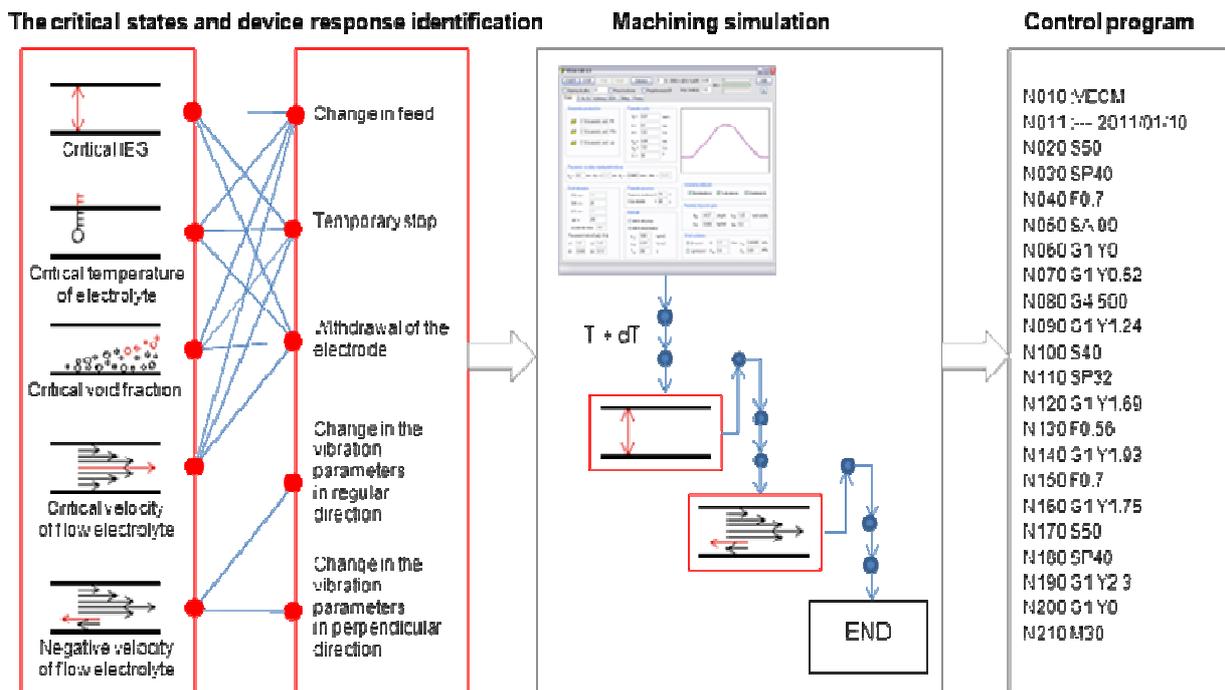


Fig. 1. Adaptive control diagram

On the diagram examined machining parameters were singled out, that is: IEG width, electrolyte temperature, gas phase volume concentration, electrolyte flow speed and system reaction manners. Above-mentioned parameters were connected with possible system reaction manners in a way which allowed to control the strength of its interaction. In case of occurrence of a critical state, machining simulation moves back in time to earlier established control points, where suitable parameter modification is performed. It should be stressed that modified machining parameters are brought back to initial values in case of no critical state occurrence. Consequences of such – adaptive – control are the changing in time machining parameters, which forces a necessity of generating a hollowing (research bench) controller code.

This assumption allowed new algorithms to be developed for numeric models in order to accomplish adaptive control (Fig. 2). Consequently, this allowed to expand the simulation program with another module.

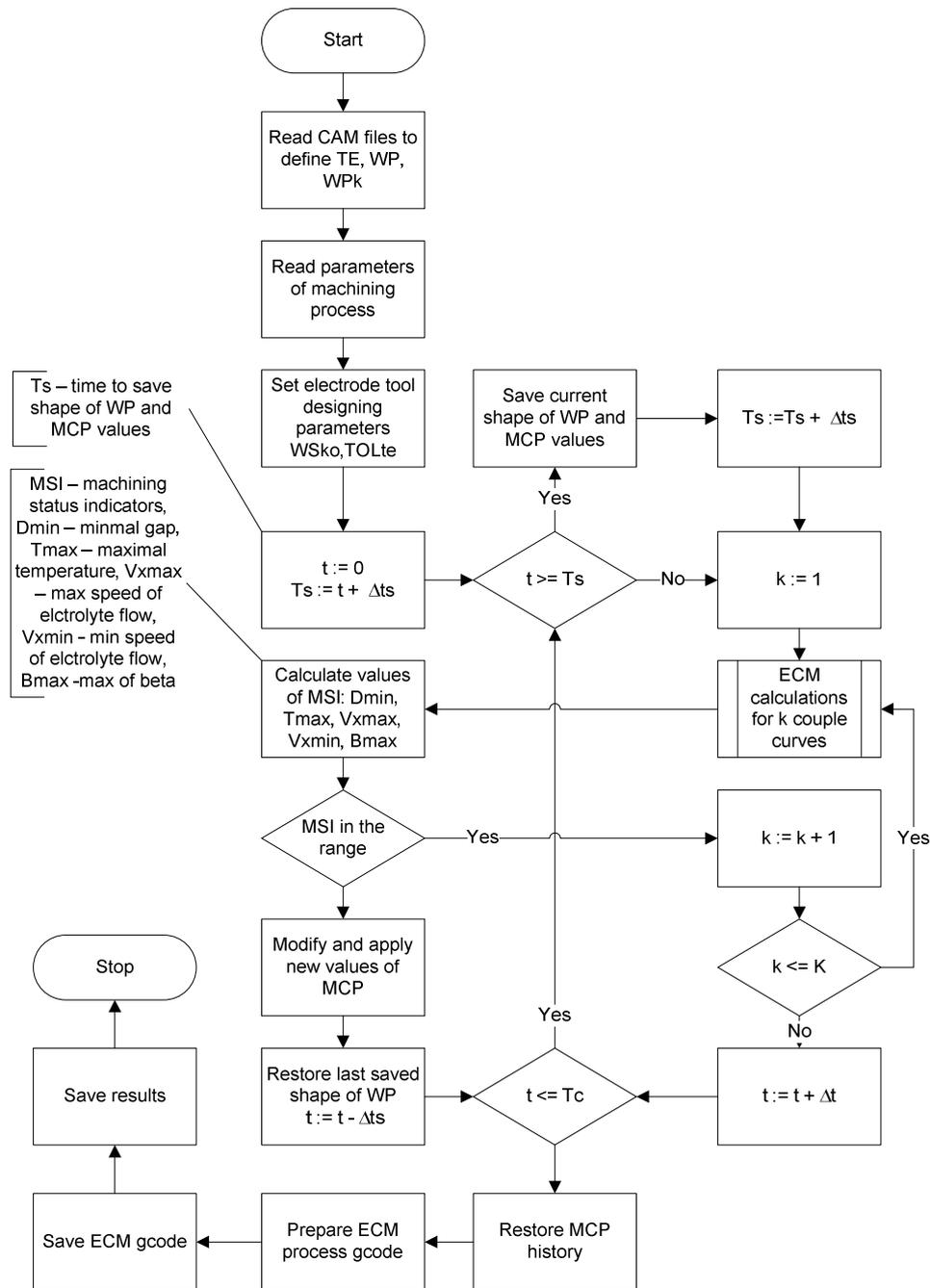


Fig. 2. Adaptive control diagram

Where:

MCP – machining control parameters,  $Dts$  – time between storing a state of simulation,  $t$  – current time,  $Tc$  – complete simulation time,  $Dts$  – step for the simulation time,  $K$  – number of curves on the WP and TE surface,

Fig. 3 shows a modified machining simulation program. In the first bookmark of this program initial process parameters are entered, which are at the same time reference parameters for adaptive control. In a new module of adaptive control we choose mutual interrelationships between parameters and system reaction for set values of interaction.

Additionally, the module allows to load and save selected settings, modify initial parameters for any machining moment (for example in the final part of the process, as optimal parameters for finishing machining), and generate a code which controls hallowing (research bench).

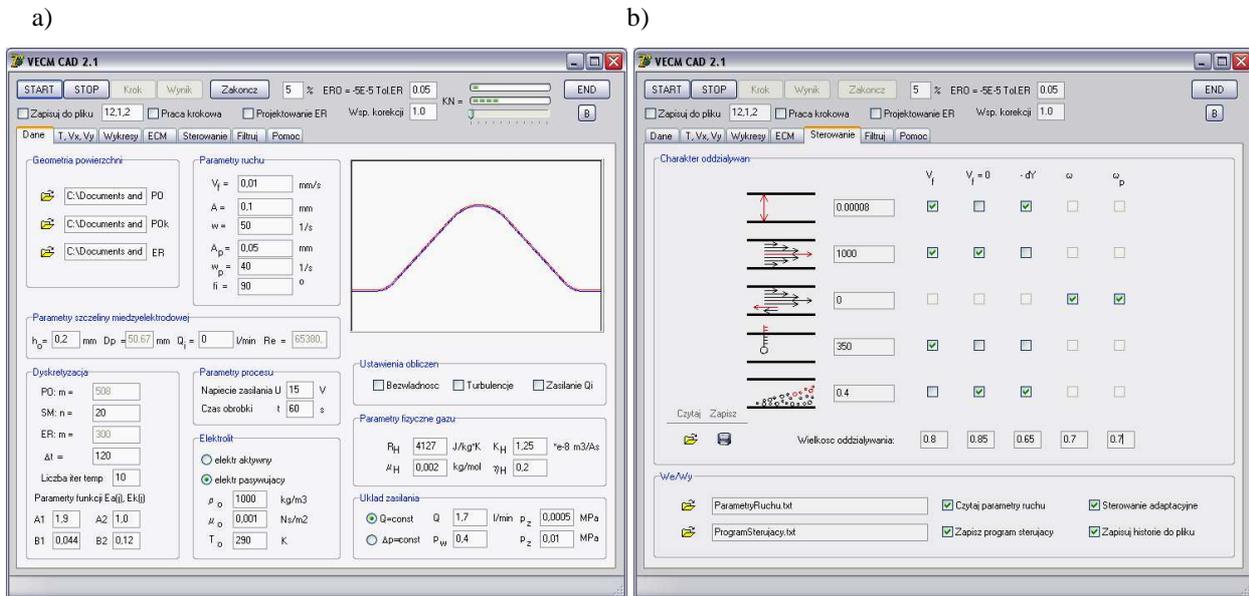


Fig. 3. Machining simulating program a) initial parameters of machining, b) adaptive control module

### 3. INVESTIGATION

In the ECM technology research on model experimental units is essential. It allows to determine electrochemical characteristics indispensable for conducting a computer simulation and measure deviations between results from computer systems and experimental studies.

A basic unit of a experimental setup is its body. It consists of two primary plates, 1 and 2, and two mobile plates, 4 and 5, (Fig. 4,) connected with four guiding bars. There is a number of electrodes connected to mobile plates. To the body of the unit drive units of 6 movement-inducing electrodes are fixed; sliding movement with velocity  $V_f$  and drive units inducing electrode vibrations in directions: regular 7 and perpendicular to feed motion plunge 8. In these systems servo-drives were employed, which allows to control it with the use of external programs. On the picture, drive units are marked with different colors. A machining chamber is a principle element of the experimental setup.

In a machining chamber, there are: the machined item (1) and TE (2) (Fig. 5.) Through the hole no.3 electrolyte is provided to the machining chamber, which is then removed through holes no.4. This method of supplying the IEG with electrolyte ensures a plane-parallel flow.

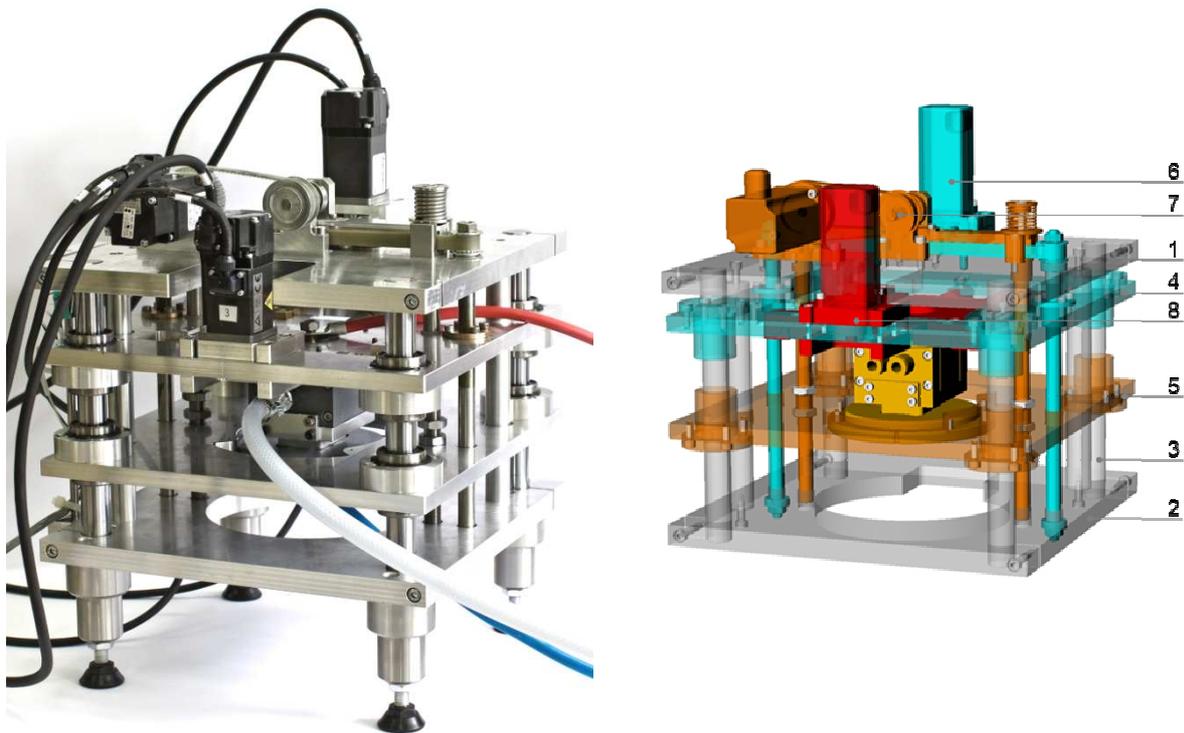


Fig. 4. Experimental setup

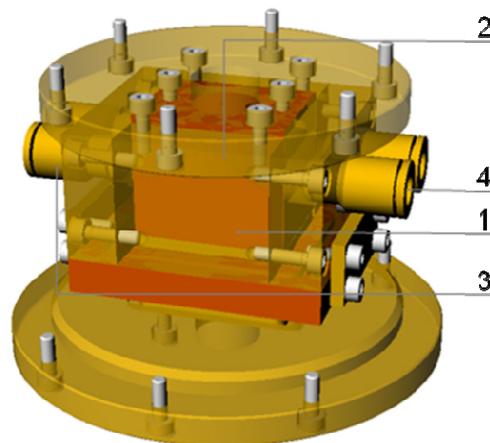


Fig. 5. Machining chamber

#### 4. VERIFYING TESTS

Tests verifying the mathematical ECM process were conducted for two methods of machining simulation:

- simulation of machining with a shaped TE vibrating simultaneously in two planes, with activated machining adaptive system – tests run for preset initial parameters modified during the machining process,

- simulation of machining with a TE vibrating simultaneously in two planes, without activation of the machining adaptive system – tests run for preset initial parameters. Tests conducted for geometrical samples and dimension configuration as shown on Fig. 6.

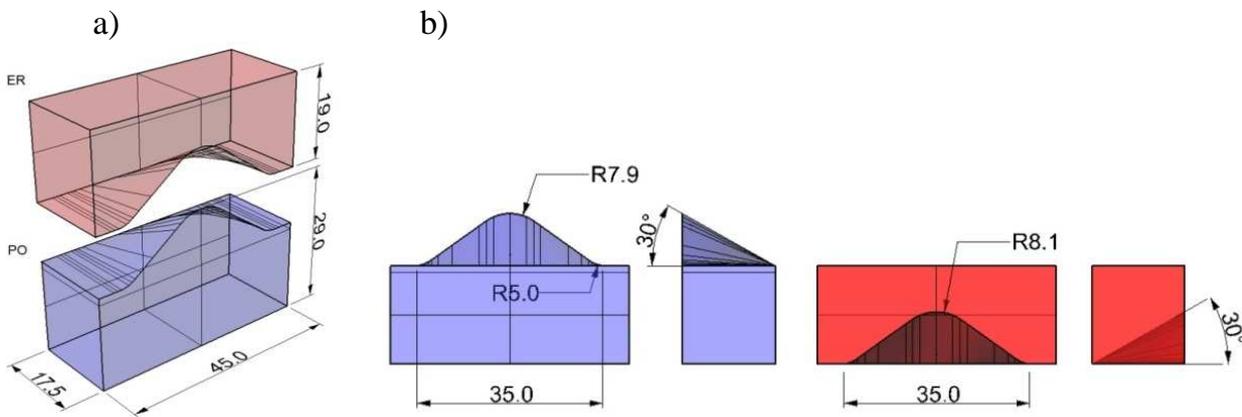


Fig. 6. Geometric form and dimensional system of ER and WP: a) isometric projection, b) face views

Table 1 presents values of constant parameters assumed for the examination. In the examination WP surface received from computer simulation was compared with the surface which was a result of the machining.

Table 1. Constant parameters assumed for the examination

Factor	Value
Inter-electrode voltage	15 V
Electrolyte type	NaNO <sub>3</sub> 15%
Electrolyte temperature	293 K
Electrolyte supply	$Q = 2$ l/min, $p_z = 0.01$ MPa
Initial ME gap width	0.2 mm
Sliding movement velocity	$V_f = 1$ mm/min
Machining time	60 s
Longitudinal vibration	$f = 30$ Hz, $A = 0,1$ mm
Transverse vibration	$f = 30$ Hz, $A = 0,05$ mm

Diagrams (Figs 7, 8) show distribution of  $\delta$  shape deviation (red line) along L section and TE section shape (blue line), described with L and H values; as well as accuracy indexes that were estimated,  $S$  – standard shape deviation and  $\delta_{max}$  maximum deviation, for selected samples.

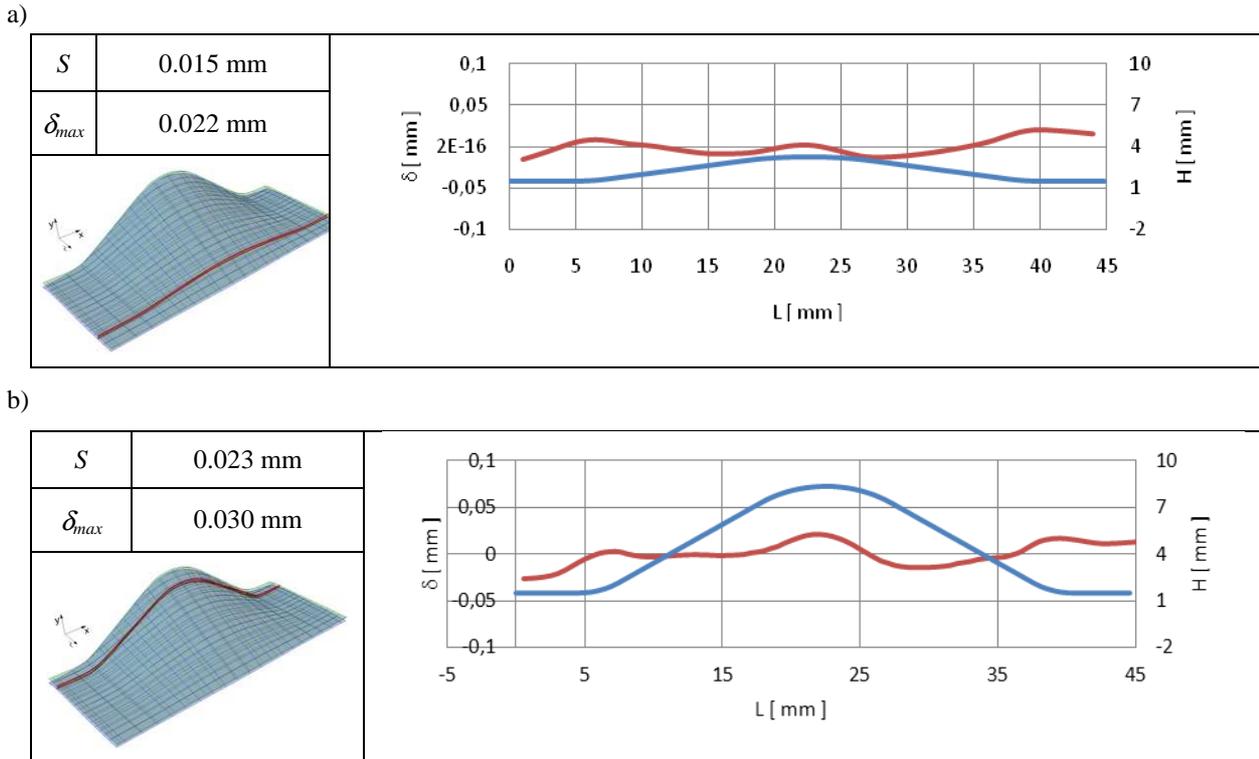


Fig. 7. Shape deviation distribution  $\delta$  for systems with active adaptive control for a) first TE section shape b) second TE section shape

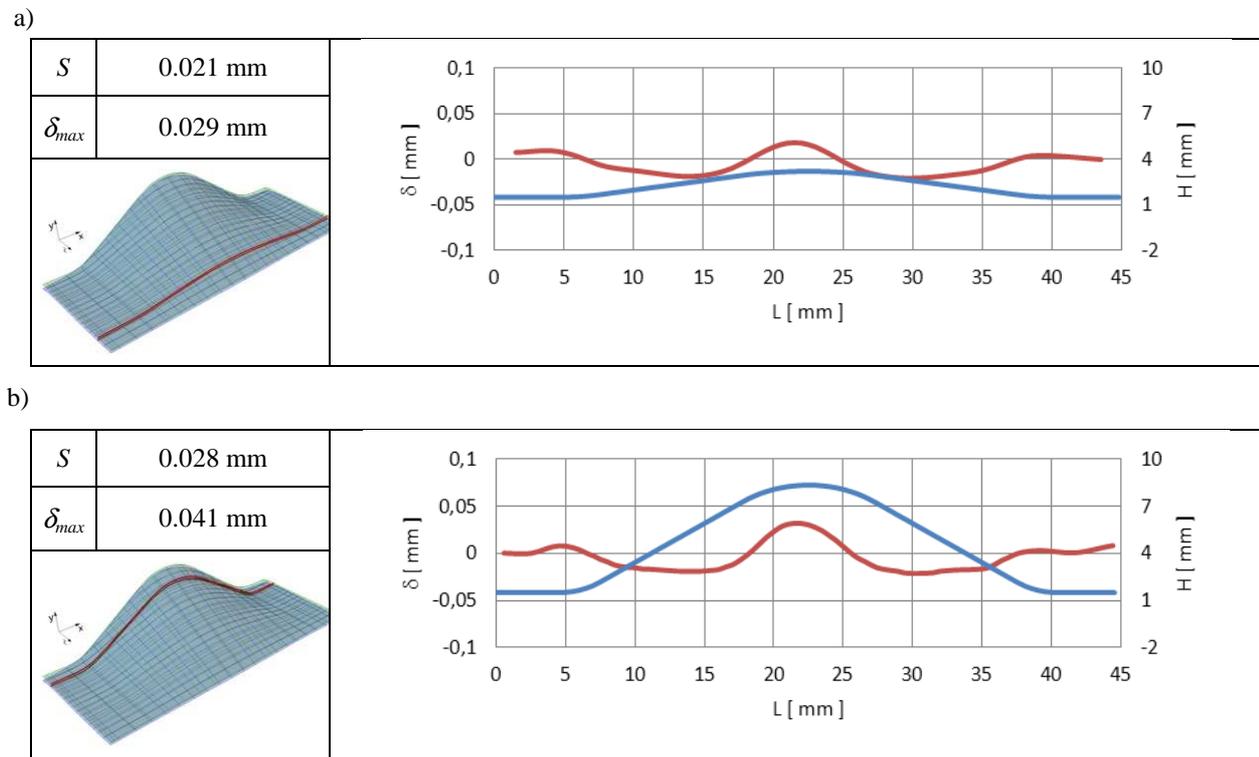


Fig. 8. Shape deviation distribution  $\delta$  for systems with inactive adaptive control for a) first TE section shape b) second TE section shape

Figure 9a presents a photo showing the surface of a sample obtained from examination with machining traces characteristic for ECM, and occurring critical states. These phenomena are explained by wave structure development on the anode surface, resulting from hydrodynamic field connexion, with diffusion processes and electrochemical solvation. They are a result of wrongly selected machining parameters, which is particularly difficult in the case of curvilinear surfaces. A method for increasing process reliability is using machining parameters changing in time. It allows to produce machined surfaces which are geometrically proper and obtained in a repetitive way (Fig. 9b). The same sample indicates that so called surface traces still remain a problem of ECM. Research on boundary layers proved that in proper conditions areas of low fluid flow velocity become unstable, which then leads to local swirls in the electrolyte flow. In the areas where the swirls occurred, local erosion of passive layer takes place which, to some extent, influences ECM process. These phenomena are highly complex and in practice impossible to model mathematically.

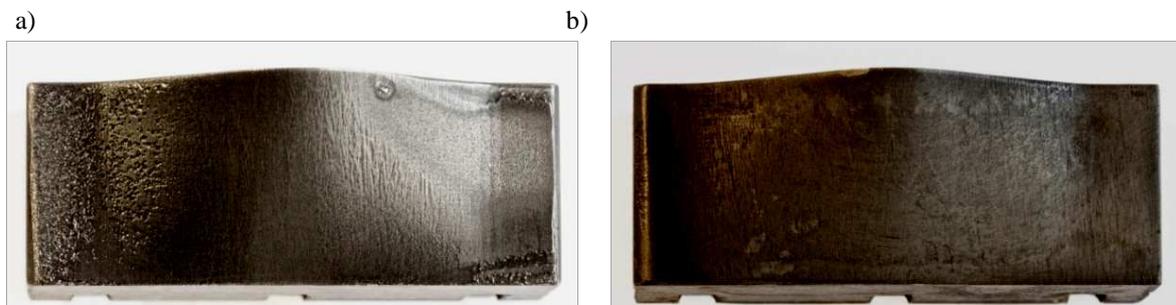


Fig. 9. Sample surfaces obtained in the examination: a) for constant machining parameters, b) for machining parameters changing in time

## 5. SUMMARY

In this work we presented a method of ECM machining adaptive control on the level of mathematical model for complex electrode surfaces, as a result of which control code changing machining parameters in time was acquired.

Presented methods of modeling and controlling ECM process made possible an increase of machining stability and accuracy, especially for electrodes with complex shapes. Electrochemical drilling is a very complex process, therefore computer modeling of ECM machining process allows machining parameters to be chosen properly, and thus saving time and expenses. It needs stressing that results were obtained through analytic and numerical integration of complex simultaneous partial differential equations. It allowed developing of complex numerical algorithms simulating and at the same time analyzing and modifying ECM process for any curvilinear surface. IEG distribution, temperature, gas phase concentration and electrolyte flow velocity are subject to analysis when concerning critical states.

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