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ELECTRODE TOOL DESIGNING IN THE ECM MACHINING FOR CURVILINEAR SURFACES

Electrochemical machining with the use of a tool electrode (ECM.S) is one of the basic and most widely used electrochemical technological operations for machining tools and machine parts. This article presents a method of approximating the surfaces with electrode designing curves, with an assumed two dimensional electrolyte flow model in the inter-electrolyte gap. An example of calculations is also presented.

1. INTRODUCTION

Electrochemical machining (ECM) requires connecting the tool electrode to the negative pole of a direct current source and the work piece to the positive pole. The inter-electrode gap is supplied with electrolyte. During ECM process the electrolyte flows through the gap carrying away the products of the dissolution from the surfaces of the electrodes. These are mainly hydrogen and ions of the dissolved metal [2,4]. We can therefore assume that in the inter-electrode gap forms a mixture of the electrolyte, hydrogen particles and the products of the electrochemical dissolution. The physical phenomena of the flow are thus controlled by the processes of mass, momentum and energy exchange, which significantly influence the precision of the operation of electrochemical machining [2, 4, 5].

While designing the technological process of the machining we should point out the following tasks:

- selection of ECM process conditions (electrolyte composition, machining parameters, the gap power supply, technological requirements),
- determining the geometry of the tool - the tool electrode,
- machining process accuracy analysis.

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Solving these tasks is connected with determining the evolution of the PO machine surface shape in time and arrangement of physical conditions in the machining area corresponding to a given TE shape.

On this account a program for ECM process computer simulation is a fundamental subprogram in a computer system. To draw up a computer system ECM NURBS [3] digitization was defined, a modeling of ECM shaping was conducted and algorithms and numeric procedures were worked up, whose main elements are enlisted below.

Calculations were conducted basing on an example of analysis of electrochemical machining with the use of vibrating electrode with curvilinear surface which shape is shown on Fig. 1a. The curvilinear surface is curved also in the z axis direction that is the direction perpendicular to chosen direction of the electrolyte flow. It imposes searching for a different plane for the calculations than the plane parallel to the XY plane.

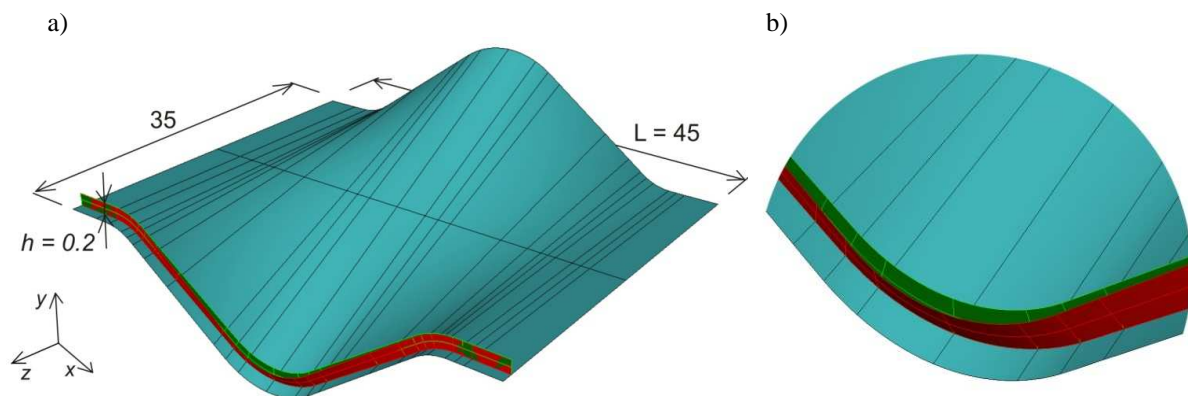A magnified fragment of such planes is presented in Fig. 1b.

Fig. 1. The shape of the plane assumed for calculations
a) geometrical characteristics, b) a section with a designed calculation plane

2. MODELING OF THE ELECTROCHEMICAL PROCESS SHAPING

Modeling ECM machining means designation the changes of the inter-electrode gap width, evolution of the machined surface shape in time and distribution of the physical-chemical conditions occurring in the machining area, like: static pressure distribution, the electrolyte flow speed, temperature and volume concentration of the gas phase.

2.1. MATHEMATIC MODELING

A two-dimensional, two-phase vesicular electrolyte flow in IEG is assumed. At the same time, triggering a complex TE vibrating movement in mutually perpendicular directions, that is TE progressive and electrolyte flow. Detailed assumptions and mathematical model of electrochemical machining with vibrating tool electrode is presented in works [1,8,9].

2.2. NUMERIC MODELING

Determination of the machined surface (anode) shape evolution in time is described by equation of evolution [2,4,8,9] showing the real shape change of the machined surface.

The initial shape of the machined surface and the tool electrode was defined in the modeler 3D as free surfaces of the type NURBS. For numerical calculations digitization PO and TE was performed by an approximation of the surface with curves. In this way there was received a set of curve pairs TEk, WPk, later described by points with a fixed, global accuracy in a coordinate system (Fig.2):

$$x_i = \sum_{i=1}^{I} \Delta x_i \qquad (1)$$

where: $i = 0, 1, 2... I$

After having performed digitization of the TE and WP surfaces, equation of WP machined object's shape evolution was solved using the method of subsequent approximations, through the method of time steps. (Fig. 2b).
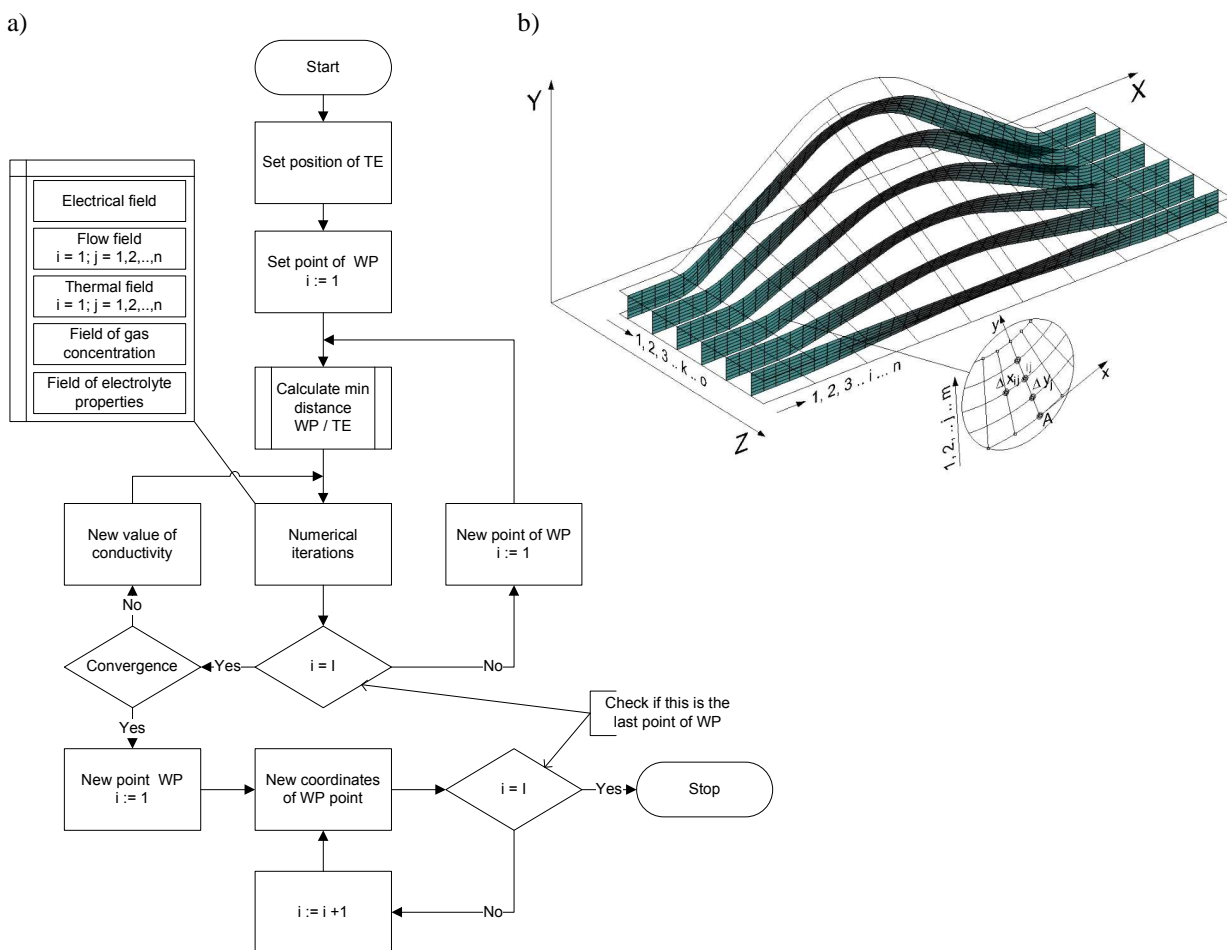

Fig. 2. ECM numerical model: a) algorithm for solving equations describing the process (l, i - current and last points of WP describing curve), b) IEG digitization

The sequence of calculations is realized with a "frozen" distribution of the gap's width for a given time step. Fig. 3. presents time steps schedule for compounding two movements of a vibrating tool electrode:

- longitudinal (main) vibrations - with vibration frequency f_w and amplitude A_w, realized in the direction of main progressive
- transverse vibration - with vibration frequency f_p and amplitude A_p, realized along X axis on a plain perpendicular to the main movement.

Vibration amplitudes were moved relatively to each other by 90° with the same vibration frequencies.

Such amplitude movement gives a symmetric resultant TE movement in relation to main vibrations on extreme deflections. It's a very beneficial cause due to ECM machining accuracy.

In every time step minimum distance between anode points and tool electrode is calculated.
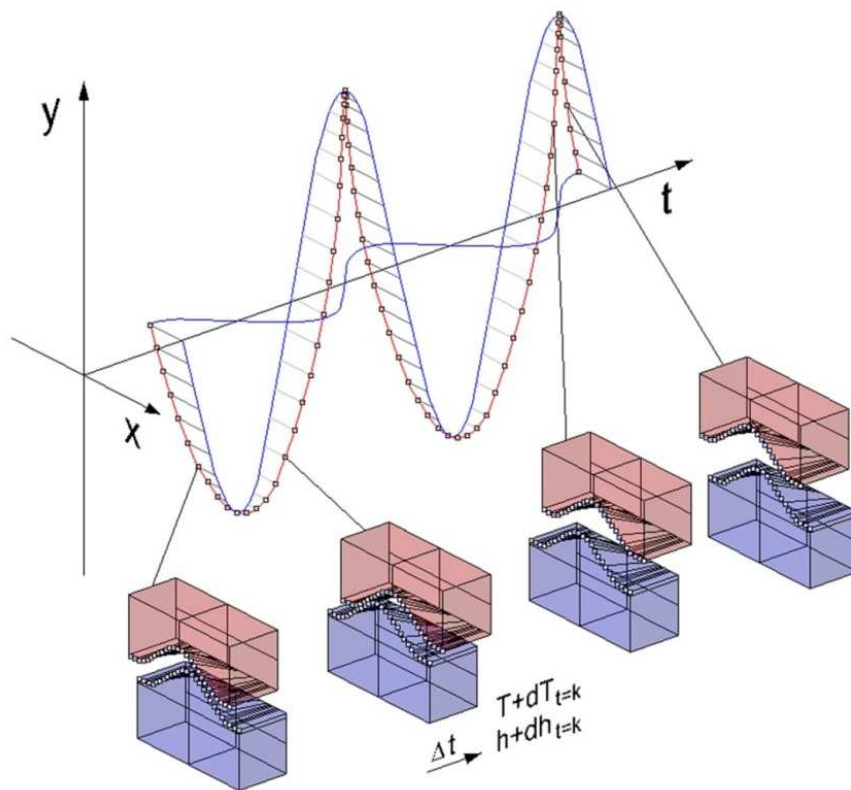

Fig. 3. Vibrating movements compound time steps diagram

In case of shape surfaces calculating the minimal WP and TE distances is a complex process. It's caused by the fact that analysis of a given WP point should be conducted accordingly with the TE points that are in the vicinity with the considered point, in all possible directions of 3D plane. To optimize the calculations a matrix of all points laying on TE over the considered WP point is created Fig. 4.

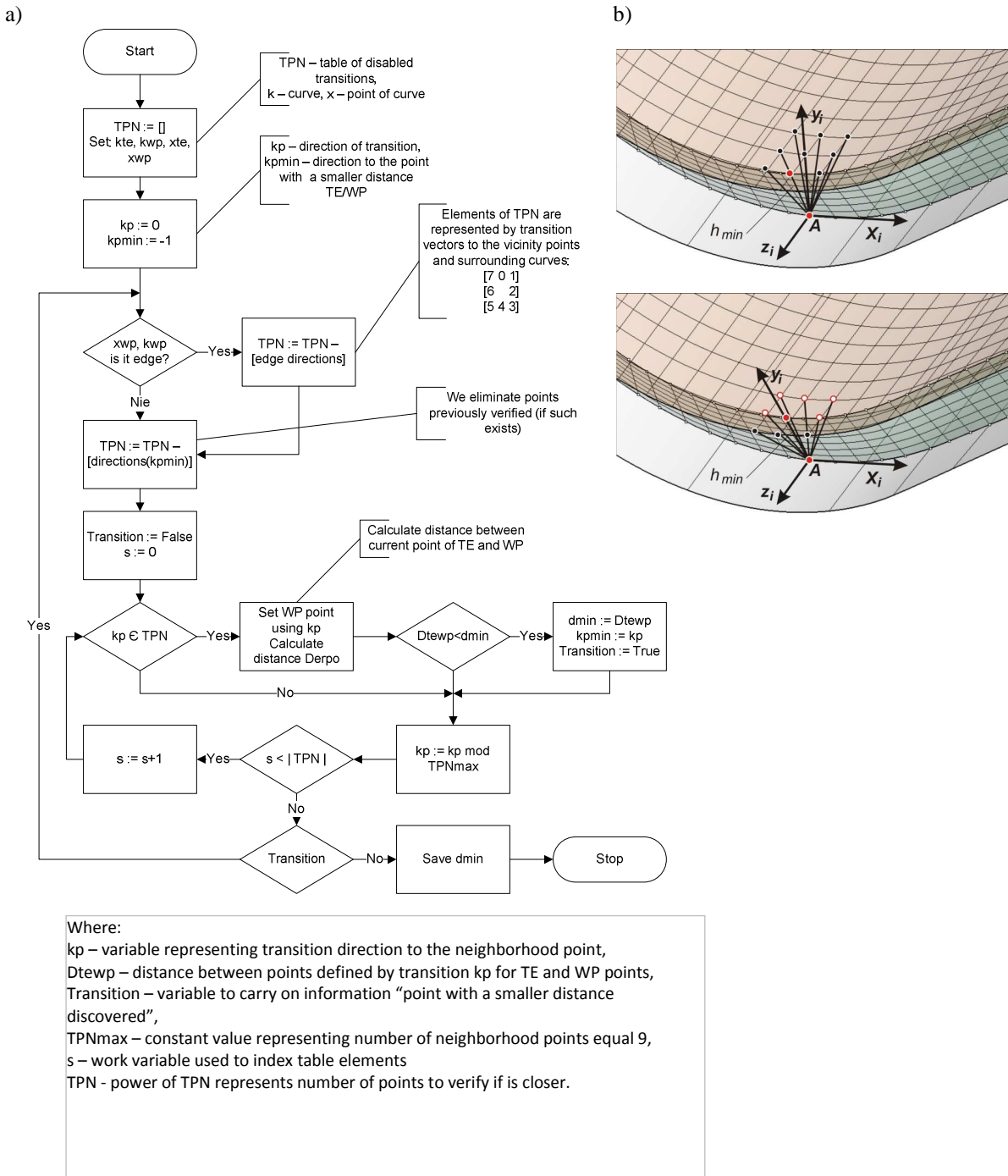A sequence of these actions is shown on a diagram Fig. 4.

a)

b)

Start

TPN := []
Set: kte, kwp, xte, xwp

TPN – table of disabled transitions,
k – curve, x – point of curve

kp := 0
kpmin := -1

kp – direction of transition,
kpmin – direction to the point with a smaller distance TE/WP

Elements of TPN are represented by transition vectors to the vicinity points and surrounding curves:
[7 0 1]
[6   2]
[5 4 3]

xwp, kwp is it edge? —Yes→ TPN := TPN – [edge directions]

Nie

TPN := TPN – [directions(kpmin)]

We eliminate points previously verified (if such exists)

Transition := False
s := 0

Calculate distance between current point of TE and WP

kp ∈ TPN —Yes→ Set WP point using kp Calculate distance Derpo —→ Dtewp<dmin —Yes→ dmin := Dtewp kpmin := kp Transition := True

No

s := s+1 ←Yes— s < | TPN | ←— kp := kp mod TPNmax

No

Transition —No→ Save dmin —→ Stop

Where:
kp – variable representing transition direction to the neighborhood point,
Dtewp – distance between points defined by transition kp for TE and WP points,
Transition – variable to carry on information "point with a smaller distance discovered",
TPNmax – constant value representing number of neighborhood points equal 9,
s – work variable used to index table elements
TPN - power of TPN represents number of points to verify if is closer.

Fig. 4. Designing a minimal distance of the electrodes: a) h_{min} designing algorithm, b) momentary point matrixes

3. DESIGNING GEOMETRY OF THE TOOL ELECTRODE

Numeric model of the ECM process shown above enables also designing the shape of the tool electrode with given initial shapes TEp and WPp and final WP. Characteristic feature of this task is ambiguity of the result and a need to use the method of subsequent

approximations. Attaining the final TE shape is possible through comparing the outcomes of the machined item shape evolution simulation for i- WPpi iteration with final shape WP. In result of conducted simulation the distribution of deviation from the desired shape $\tilde{F}$ is calculated [2]:

$$\Delta \tilde{F} = \tilde{F}_i - F \tag{3}$$

TEi tool electrode shape is modified then by moving points of its outline in a proper direction (Fig. 5):

$$\Delta h = \alpha \Delta \tilde{F} \tag{4}$$

where: α – factor determining the iteration process convergence speed.
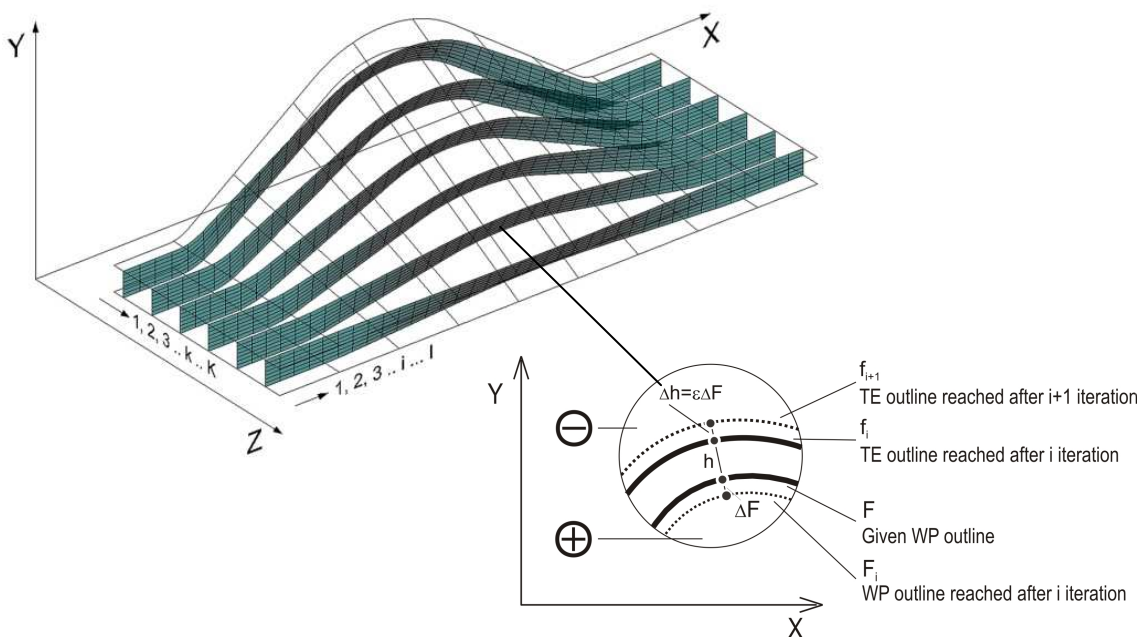
Fig. 5. TE correction diagram

Fig. 6 shows a general ECM machining process modeling algorithm with the TE procedure of shape designing.

Algorithms and procedures presented here were used for writing a computer program simulating the electrochemical machining process and enabling the designing of a tool electrode.

The program starts with a first tab "Data" (Fig. 7a). This is where modification of chosen calculation parameters is possible:

- tool electrode movement: the speed of electrode progressive movement, vibration amplitude, vibration frequency - for longitudinal and transverse vibrations and in case of axially symmetric electrodes the rotational speed of the electrode,
- ECM process: inter electrode voltage, overall calculations time,
- electrolyte properties: density, viscosity, temperature at the inlet to the gap and electrolyte type - passive or active,

- digitization parameters: IEG thickness and machining time,
- parameters of phase gas concentration in an electrolyte: hydrogen gas constant, hydrogen molar mass, current efficiency, hydrogen emission in normal conditions,
- electrolyte flow parameters.

In the "surface geometry" field of the same tab we input a path to the files defining electrode surface shapes and the shape of final surface for machined object in case of designing a tool electrode.
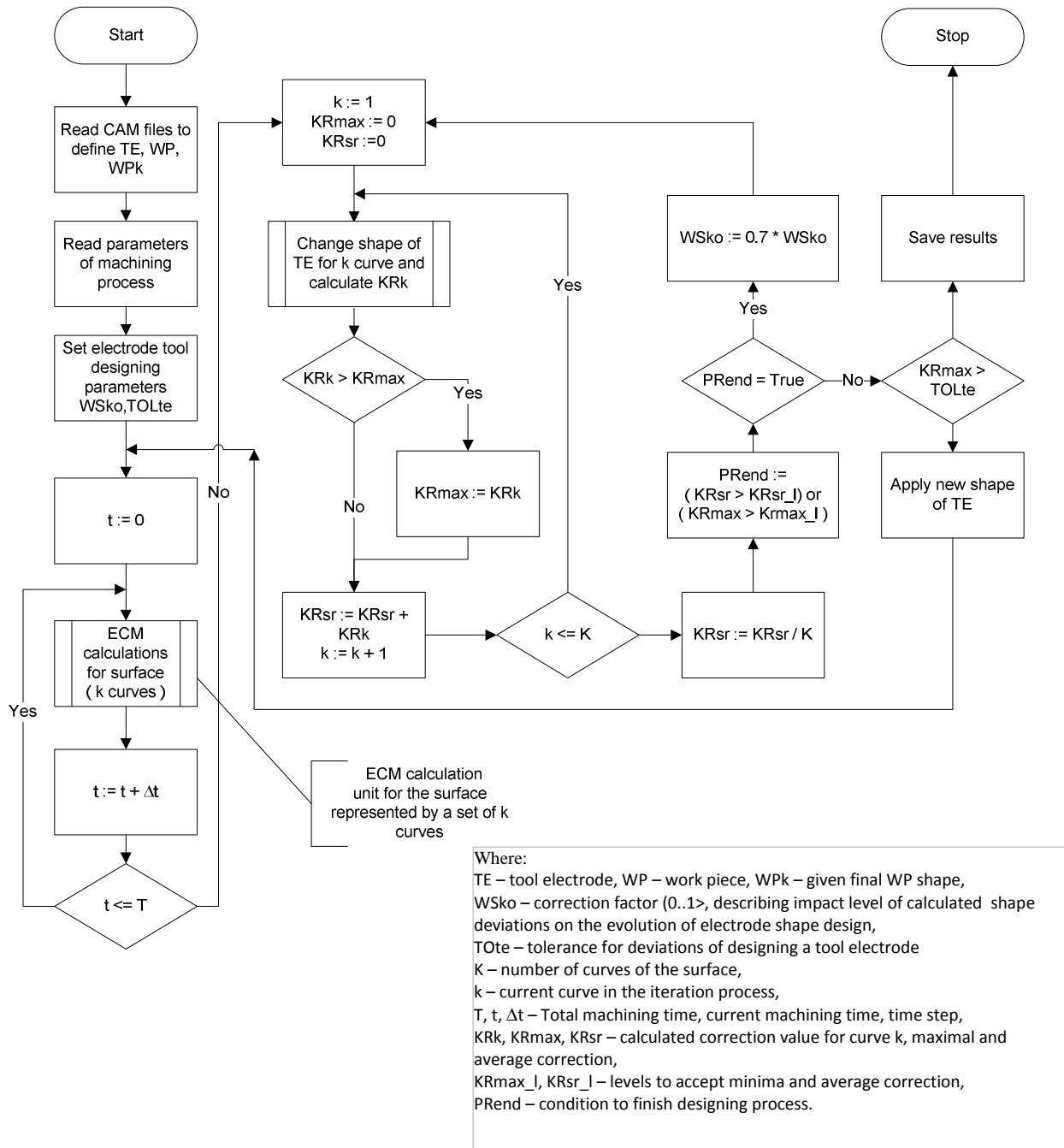
Where:
TE – tool electrode, WP – work piece, WPk – given final WP shape,
WSko – correction factor (0..1>, describing impact level of calculated shape deviations on the evolution of electrode shape design,
TOte – tolerance for deviations of designing a tool electrode
K – number of curves of the surface,
k – current curve in the iteration process,
T, t, Δt – Total machining time, current machining time, time step,
KRk, KRmax, KRsr – calculated correction value for curve k, maximal and average correction,
KRmax_l, KRsr_l – levels to accept minima and average correction,
PRend – condition to finish designing process.

Fig. 6. General ECM process simulation algorithm with the TE shape designing procedure

Visualization of electrode kinematics is presented in tab "Data". We can observe here the dynamics of electrode movement, including vibrating movement, and machined object shape evolution.

In the next tab (Fig. 7b) changes in electrolyte flow velocity v_x, v_y and T temperature along the inter electrode gap width are shown dynamically. The visualization can be conducted for any gap section, chosen with a slider. Current values for visualized rates are entered in the table.
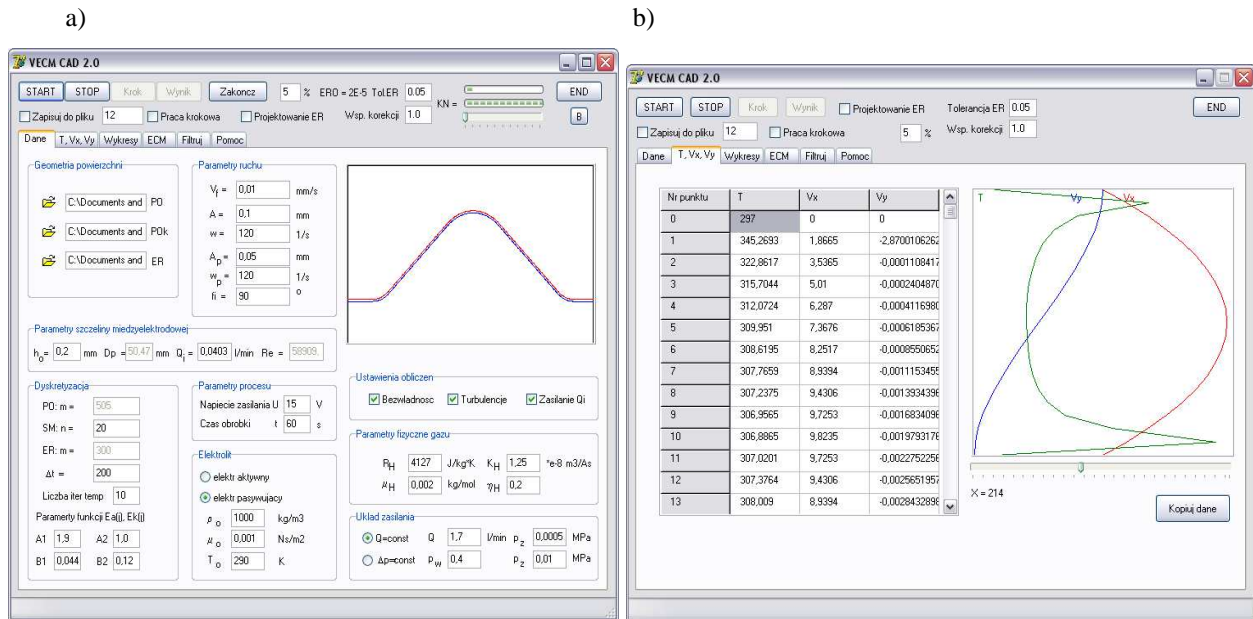
a)   b)

Fig. 7. V_ECM program: a) active tab „*Data*", b) active tab „*T, Vx, Vy*"

During calculations, after choosing tab "Charts", schedules on the charts can be attained for:

- along interelectrode gap width for its different sections, course changeability: velocity v_x, v_y, temperature T, conductivity κ, kinematic viscosity μ,
- along interelectrode gap: gas saturation β, pressure p, average velocity $v_{śr}$, average temperature $T_{śr}$, gap width h, current density j, average kinematic viscosity $\mu_{śr}$.

Example charts are shown in Fig. 8 - 10.

To copy data form the table to clipboard "Copy data" button is used. It makes statistic analysis of the results in other programs, for example Excel or Statistica possible. Saving to file data from a few time steps makes creating 3D charts possible.

Example charts for a selected IEG cross-section are shown (Fig. 11). These are the distribution of Vx velocity and T temperature along gap width for laminar flow and turbulent electrolyte.
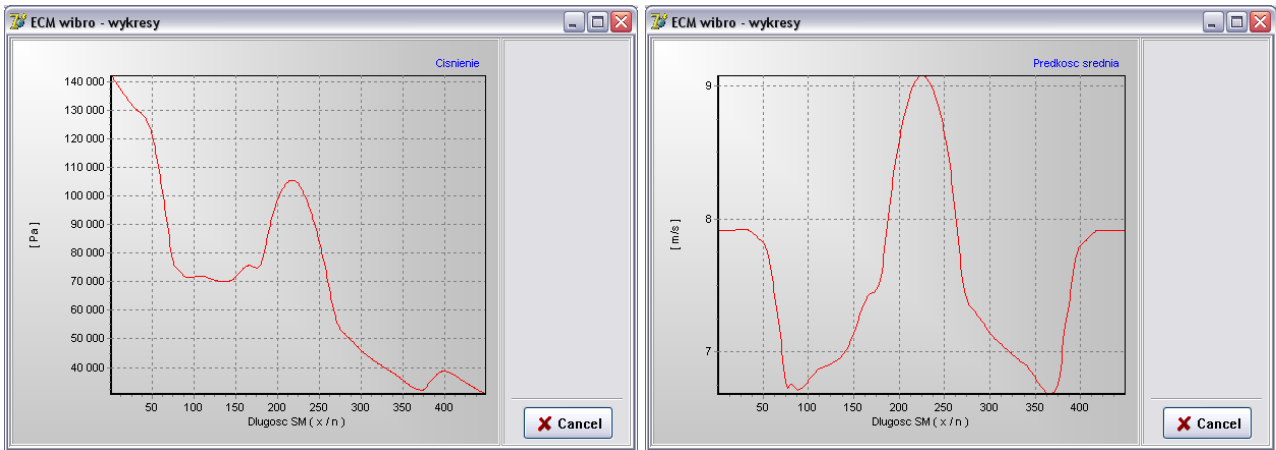
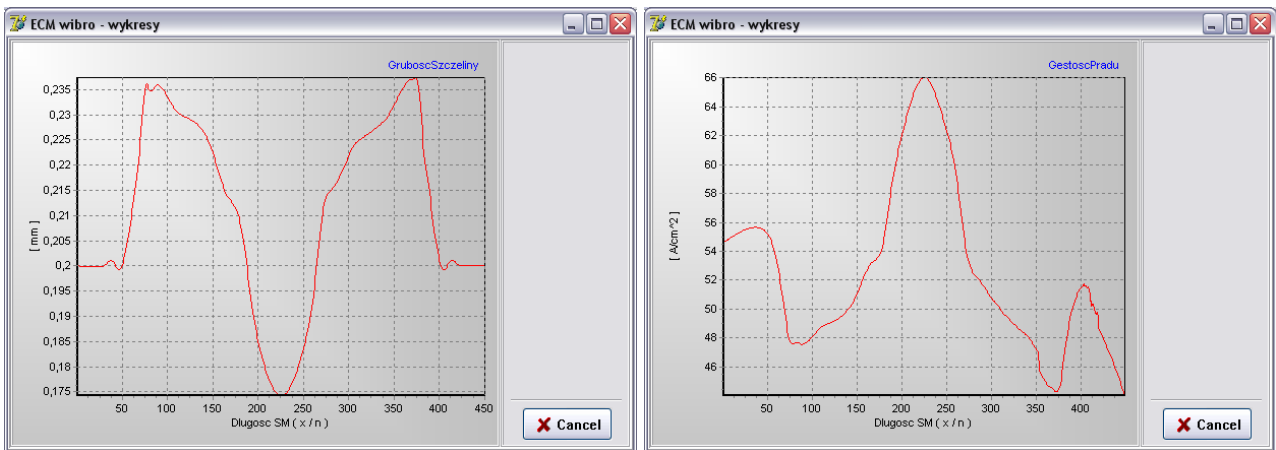Fig. 8. Distribution of pressure and electrolyte flow velocity along IEG

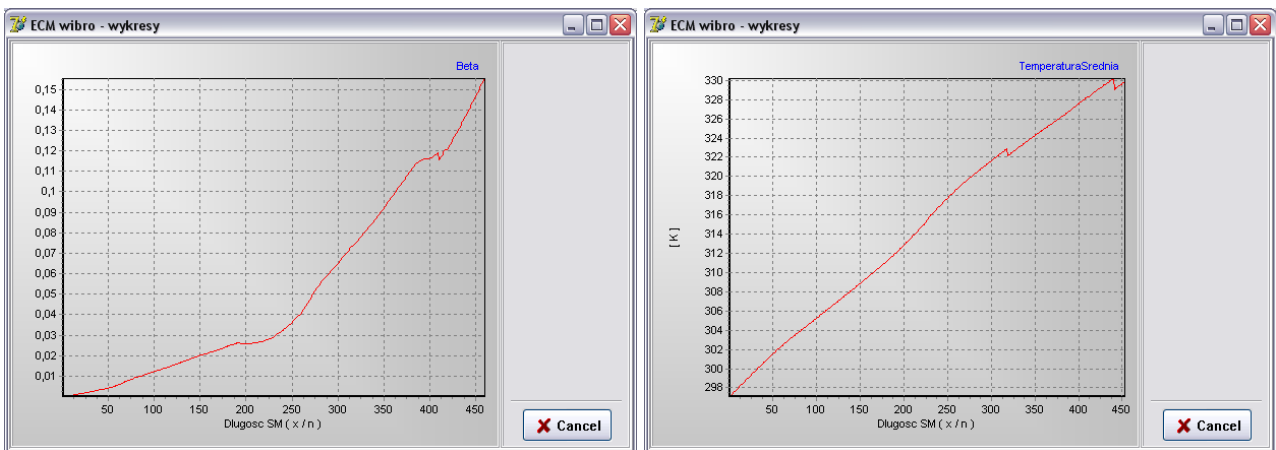Fig. 9. IEG thickness and current density distribution

Fig. 10. Gas phase concentration and electrolyte temperature along IEG distribution

Below are presented some of the most important machining parameters that were applied in the calculations:
- initial gap - 0.2 mm,

- TE progressive movement speed TE – 0.0125 mm/s,
- interelectrode voltage – 15 V,
- longitudinal vibrations parameters $A_w=0.1$ mm, $f_w=30$ Hz,
- transverse vibrations parameters $A_p=0.05$, $f_p=30$ Hz,
- phase shift for vibration amplitudes - $90\,°$

The described software, aside of physical conditions in the electrode gap distribution, is mainly used for designing the surface shape of the machined item or tool electrode. Essential tools adjusting format of the data to CAD-CAM program format are located in the "Filter" tab. They make drawing of the calculated surface possible.
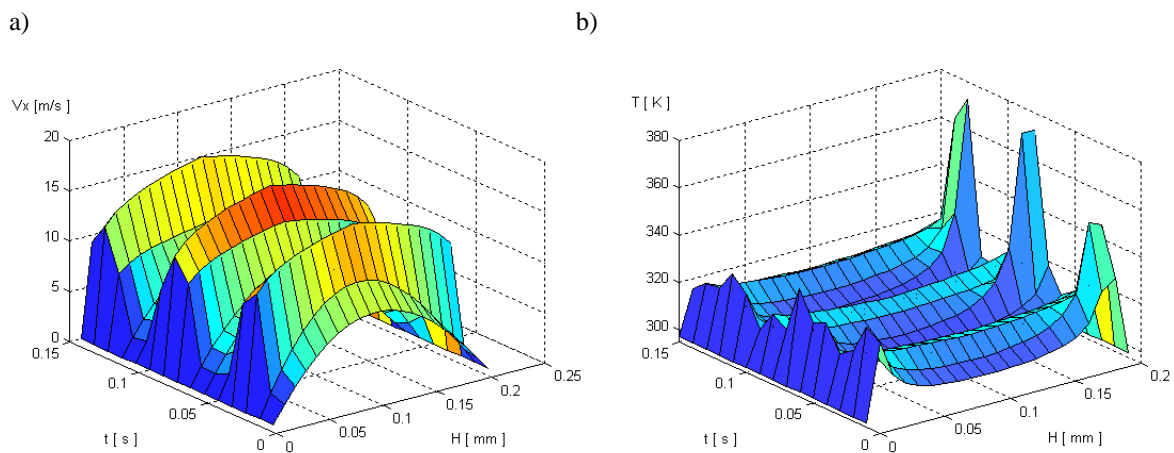
a)   b)

Fig. 11. Distribution along IEG width: a) for electrolyte flow velocity V_x, b) for electrolyte temperature T

In Fig. 7 is shown shape of a surface obtained in result of ECM calculations (red color) with the initial surface in the background.
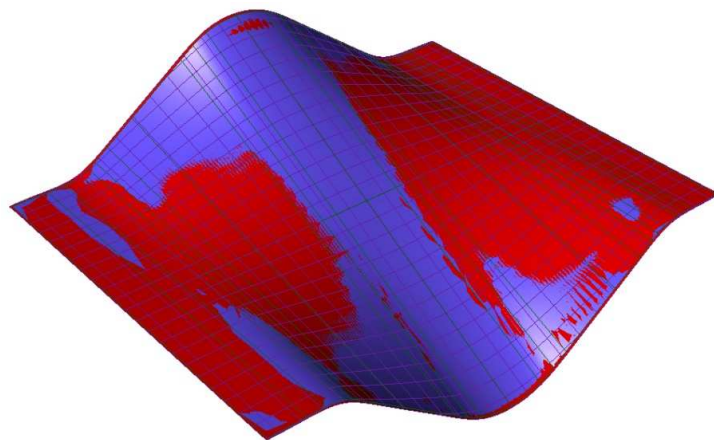

Fig. 12. Shape of the surface designed in result of ECM calculations with the initial surface in the background

4. SUMMARY

NURBS digitization method and superposition of the obtained results for respective calculation sections made designing the evolution of the machined object shape in the z axis possible as well.

Electrode tool designing is possible thanks to comparing the results of i WP_{pi} iteration machined item shape evolution simulation, with the final WP shape. As a result of performed simulation deviation distribution of the resulting shape and desired shape is calculated. Then TE_i tool electrode shape is modified by moving in right direction the points of its outline. The calculations are continued in iterative system until the desired calculation accuracy is reached.

It should be stressed that the resulting outcome is achieved through analytic and numeric integration of compound systems of partial differential equations [6,9].

Attained calculations results confirm predicted quality change tendencies of selected parameters:

- triggering the vibrations of a tool electrode results in a distortion of electrolyte flow velocity profile along IEG width, which results in temperature rise in vicinity of the vibrating partition (Fig.11a),
- distortion of the velocity profile of the electrolyte flow along IEG width deepens in accordance to the electrode vibration frequency rise. Therefore some borderline values exist for vibration frequency and amplitude, for which the phenomenon of electrolyte withdrawal in IEG will occur,
- turbulent electrolyte flow in ME gap causes flattening of electrolyte flow velocity profile, what has a direct influence on temperature distribution along IEG width (Fig.11b),
- local interelectrode gap widths (Fig. 9) are changing. It is influenced by electrochemical dissolution velocity changeability, and tool electrode profile inclination angle in relation to the direction of machining,
- uneven distribution of interelectrode gap width significantly influences pressure and electrolyte flow velocity distribution (Fig. 8),
- changeability of physical conditions is influenced by rise of volumetric gas phase concentration and electrolyte temperature (Fig.10). These factors influence the change in such physical values as: viscosity, density, electrolyte conductivity, and as a result the velocity of electrochemical dissolution and machining precision.

Electrochemical machining is a very complex process, in which mutual connections of physical in time and space occur. Therefore ECM process modeling seems to be essential in order to enhance the precision of electrode designing, machining parameters selection, and also reducing the time and costs of the process.

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