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COMPUTER AIDED ELECTROCHEMICAL SHAPING OF CURVILINEAR SURFACES

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Abstract

Machining involves removing a surface layer from an object with the use of mechanical energy. It often happens that this process is very difficult or even impossible due to technical and economic problems (big strength and tear resistance of the machined material). Therefore, new technological processes of removing the material from the machined object, have been developed. They involve, e.g. dissolution, melting or the material vaporization. These processes need energy of electric discharge, chemical reaction energy, and energy carried by a stream of particles. the material destruction which occurs, then, are called the material dissolution (erosion). There are different classifications of dissolution machining The most popular one is electro discharge machining (EDM), electrochemical machining (ECM), stream-dissolution machining (i.e. electron-machining (EBM) and ion- machining (IBM).

The purpose of this work is to present the problems connected with the computer aided electrochemical (ECM) as one of a few kinds of dissolution machining.

Keywords: *ECM, computer simulation*

1. Electrochemical shaping

Electrochemical machining with the use of a tool electrode is today one of the basic electrochemical technological operations for machining tools and machines. Electrochemical machining (ECM) has been developed as a machining method for alloys of high strength and heat resistant, whose shaping with the use of traditional methods was very complicated and extremely hard [7, 13].

During this constant process the tool electrode performs most frequently a progressive motion in the direction toward the machined surface. The inter-electrode gap is supplied with electrolyte with high speed, causing carrying away of the dissolution products from the machined surface. These are mainly hydrogen particles and ions of the dissolved metal. In such conditions we can talk about a multi-phase flow and generally, three-dimensional [1, 12].

The flow hydrodynamic parameters and the medium properties determine the processes of mass, energy, momentum and energy exchange in the inter-electrode gap. Properly chosen they prevent from formation of cavitation zones, critical flow, circulation, excessive increase of the electrolyte temperature and void fraction of the gas [3, 11, 14].

The above mentioned processes have a significant influence on the electrochemical dissolution velocity and usability of the dissolved surface.

The following tasks should be dealt with during the design of the technological machining process [2, 4, 5, 6]:

- choice of ECM process conditions (electrolyte composition, machining parameters, technological requirements),
- design of the tool-electrode,
- analysis of the machining process accuracy.

It should be noted that the listed tasks are closely related to each other, and their solution is connected with prediction in time of the machined surface shape evolution, i.e. anode.

The choice of ECM process conditions is concerned with:

- material and the kind of semi-product, (dimensions defining allowance, shape),
- requirements concerning accuracy,
- requirements concerning the top surface,
- technical-economic requirements (work consumptions, cost and energy consumption)
- requirements concerning the type of the cutting machine e,(type of driving machine, supplied current , the electrolyte flow pressure, range of electrical intensity control and voltage, efficiency control, range of the feed rate, the working size of the chamber, kind of control, temperature regulation, the tool machine stiffness, etc.),
- choice of electrolyte,
- choice of machining parameters,

Design of the tool electrode involves:

- determination of the working part profile,
- arrangement of the electrolyte inlets and outlets from the inter electrode area),
- construction of the electrode (e.g. folding, all in one piece),
- technical conditions (material, accuracy, smoothness).

It also significant to predict whether the final shape of the machined object can be obtained in the final or temporary state.

Looking for the proper shape of the electrode involves a necessity of determination of physical-chemical conditions occurring in the inter-electrode gap. These conditions depend on ECM machining parameters.

Therefore, designing tools (tool electrode) is connected with active control of the criteria restricting ECM conditions. If the accepted conditions do not yield the expected final effect, a correction of accepted quantities of ECM parameters is carried out (working voltage, the pressure of progressive motion etc.)

The process of tool designing is connected with an analysis of electrochemical shaping which covers:

- determination of the influence of the main factors on the shaping and dimensional inaccuracy,
- determination of permitted changes of parameters (ECM parameters allowance).

2. Modeling of the shaping electrochemical machining process

The process of ECM electrochemical machining treated as a series of simplifications is shown in Fig. 1. The real object is replaced with a physical model, in the first stage. This model is a certain simplification of the real object but with maintenance of its significant features. The model can have a different degree of simplification. Complications of the model can lead to complication of the equations which describe it. Choice of the right physical model providing sufficient computing accuracy requires long experience.

Mathematical model as a system, most often of integral differential equations, describes the real model resulting from the physical one, always, in some approximation.

On the basis of the mathematical model and data resulting from the physical model there emerges a given computational algorithm, whose result is computer program in a given programming language.

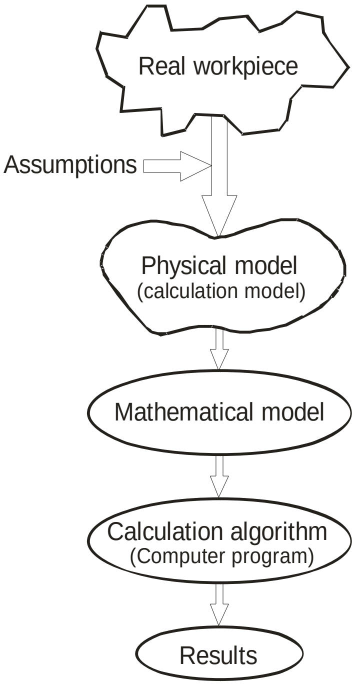

Fig. 1. Mathematical modeling algorithm

In order to carry out the algorithm (Fig. 1) it is necessary to define conditions of the electrochemical machining.

The electrochemical machining conditions are described by means of the following data [7, 13]:

- kind of electrolyte (chemical composition) and its properties:

κ_0 - electrolyte conductivity,
α - temperature coefficient of the electrolyte electrical conductivity,
ρ_e , ρ_H - electrolyte density, hydrogen,
c_p - electrolyte specific heat,
μ_e, μ_H - dynamic viscosity coefficient of the electrolyte and hydrogen,
η_H - electrochemical equivalent of hydrogen,
k_H - current dissolution efficiency,
β - void fraction,
p_H - pressure of hydrogen,
v_x, v_y - velocity,
T_i - temperature of the electrolyte on the inlet,

- the machined material (chemical composition),

- the machining parameters:

v_f - feed rate of the tool electrode,
U - working voltage between the electrodes,
p_w - the electrolyte pressure on the inlet to the inter-electrode gap,
p_z - the electrolyte pressure on the outlet to the inter-electrode gap,
Q_v - volume stream,

- characteristics of the electrochemical system: cathode-electrolyte-anode:

kv - coefficient of electrochemical machinability,
E_a-E_k - fall of the potential in near electrode layers,
x_i - coordinate of the inter-electrode gap beginning,
x_o - coordinate of the inter-electrode gap,
T_0 - the temperature of electrodes,

Modeling of ECM machining involves predicting the machined surface shape evolution in time, changes of the inter-electrode gap thickness and distributions of physical-chemical conditions in the machining area, such as: distribution of static pressure, the electrolyte flow velocity, temperature, and void structure.

General differential equation describing evolution of the machined surface shape, in result of anode dissolution, according to the ECM dissolution theory, has the form [5, 11].

$$\frac{\partial F}{\partial t} + k_v \vec{j}_A \nabla F = 0 \qquad (1)$$

with the initial condition $F(x, y, 0) = F_0$

where:

$j_A = j(X_A, Y_A, t)$ - current density distribution on the machined surface
k_v - is equal to volume of the material removed by anode dissolution during flow of a unit electrical load
$F_0(x, y) = 0$ - equation describing the machined output surface
$F(x, y, t) = 0$ - equation describing the anode surface in time t

Current density on the anode is expressed in the following way [4, 5]:

$$j_A = \kappa_0 \Phi_{TG}^{-1} \frac{U - E}{h} \qquad (2)$$

Function Φ_{TG} describes the influence of conductivity change inside the inter-electrode gap and is determined from the balance of voltage fall along the way.

$$\Phi_{TG} = \frac{1}{h}\left[\int_0^h \frac{dy}{(1+\alpha(T-T_0))(1-\beta)^{3/2}}\right] \qquad (3)$$

In order to finish the equations system describing electrochemical shaping it is necessary to determine temperature distributions and void fraction. It is connected with solution of an integral differential equations system describing the electrolyte flow through the inter-electrode gap. Equations governing the flow movement through the inter-electrode gap result from basic principles of conservation, i.e. principles of mass, current, momentum and energy conservation. In literature we can find approaches to the subject in one dimensional terms, [2, 4, 5], two-dimensional terms [6], [8]. Differences between solutions result from simplification assumptions and mathematical methods used for solution of the above problem.

For the purpose of predicting the tool electrode shape, an analysis is performed which is called a reverse issue.

The reverse issue, in electrochemical machining, whose aim is to obtain the proper shape of the tool electrode ER consists in comparing the results of simulation of the machined object shape evolution with the i-th iteration of the final shape [4, 5].

After performing simulation computing the distribution of ΔF shape deflections from the expected shape is defined [2, 4, 5]:

$$\Delta\tilde{F} = \tilde{F}_i - F \tag{5}$$

then, the shape of tool-electrode is corrected by moving its profile points in the proper direction(Fig.2):

$$\Delta h = \alpha\,\Delta\tilde{F} \tag{5}$$

here: α – is a coefficient conditioning velocity of the iteration process convergence.

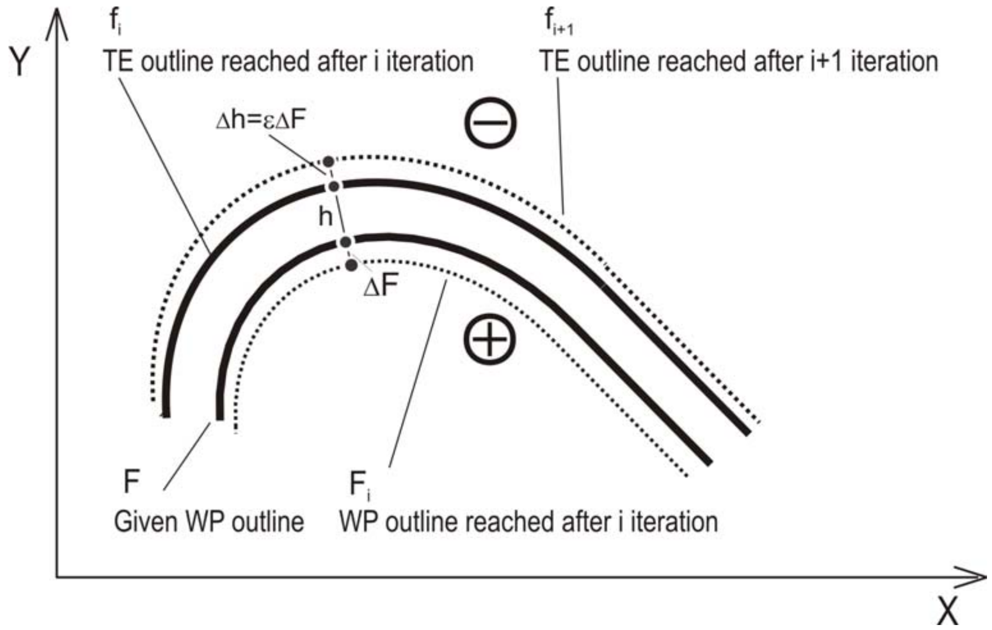

Fig.2. Scheme of the tool electrode correction

3. Algorithm of the shaping machining process computer simulation

Computer simulation is carried out with the use of successive approximation method [6, 14] regardless of the methods used for the solution of equation system which describe the flow hydrodynamics and they result from the principles of mass, momentum energy conservation.

Simulation of the machined object shape evolution is based on a method of, the so called, time steps. This means that equation (1) is approximated by differential quotient. The end of the simulation process takes place with practical stabilization of the ECM process In the stable state there follows stabilization of the inter-electrode gap thickness distribution and the physical flow field, as well as the medium properties in the gap.

The course of computer simulation of the shaping machining have been presented in the form of an algorithm [8, 9, 10] (Fig3).

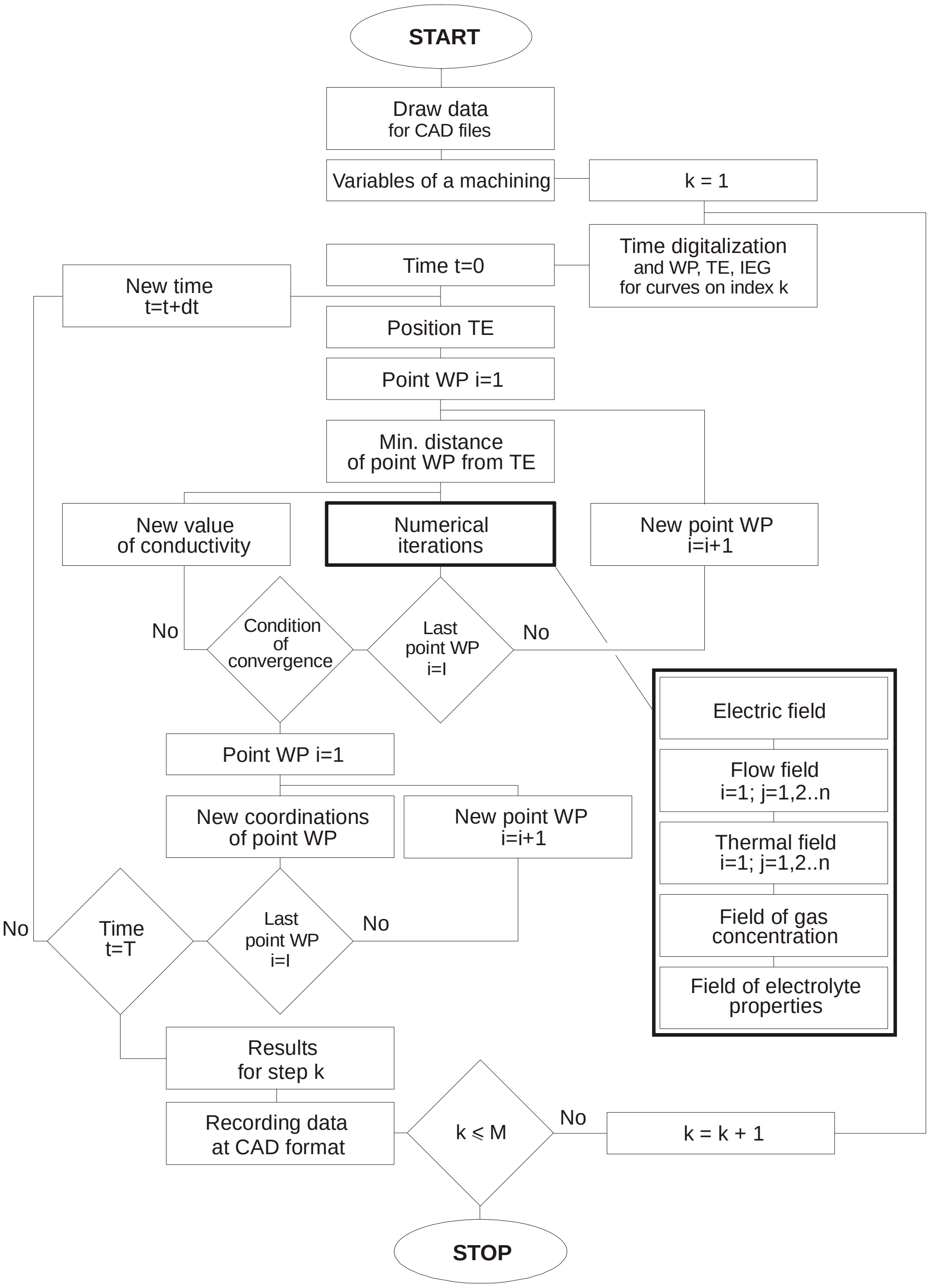

Fig.3. Algorithm of computer iteration

4. Conclusions

Modern design of tools for electrochemical machining, especially, tools for the shaping machining, involves the necessity of making the right choice of ECM process conditions (electrolyte composition, machining parameters, technological requirements), as well as of determination of the tool geometry, best, by performing computer simulation, respecting all the factors which determine accuracy of the machining process.

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